Optimum Shelterbelts Project

OSBs

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Summary

The importance of trees on farms is now acknowledged with a focus on improvements in the delivery of ecosystems services. However, there are many questions still about how to go about planting 'right tree, right place' thus balancing the functionality and productivity of farmed land with these recognised wider benefits. Shelterbelts are an established linear pattern of planting trees for a specific goal, i.e., slowing down wind, but currently the only funded option is a 10-metre shelter wood. By halving the width to five metres, with careful design and management, a range of benefits, beyond shelter, can be built into the landscape whilst reducing land taken out of food production. In all, 18 different tree species are included in the OSB design with six species each of shrubs, intermediates and tall trees selected for their leaf distribution and density considered likely to create the desired sloping profile and levels of porosity as well as food and habitat for wildlife.

Across the Optimum Shelterbelt (OSB) consortium, there is a commitment to understanding how to optimise landscape management and care alongside responsible food production. Successful and responsible food production includes optimising growing conditions for crops, good animal welfare, managing emissions and optimising biodiversity, whilst being productively and economically resilient. The research element is key to identifying best practice within and between the research themes to support farmers in making informed management decisions.

The Organic Research Centre has developed a range of protocols to determine how the presence of the OSB influences the themes overtime. The themes are shelterbelt properties; biomass carbon; microclimate; crops; animals and biodiversity. Protocols for various measures under each theme have now been developed and the OSB consortium gathered at a workshop to discuss each theme, and all related protocols. Consortium members and farmers, in particular, were asked for their feedback. The response was positive where the overall approach was considered to be '*pretty comprehensive and balanced*' between included themes.

Introduction

The historic separation of trees from farming systems, into agriculture and forestry, has reduced many of the inherent benefits trees bring to a landscape including shade and shelter, nutrient recycling, capturing emissions, and providing food and habitat for wildlife. The recent recognition of the need to reinstate trees into the farmed landscape for the delivery of 'public goods' or ecosystem services raises many questions about how to do so, balancing functionality and productivity of farmed land with these recognised wider benefits.

There are several recognised designs for incorporating trees into fields including evenly spaced (e.g., orchards), alley planting, clustered planting and random placement (e.g., wood pasture) along with hedgerows, shelterbelts and shelter woods for field boundaries. All designs have benefits and limitations with symmetrical designs being easier to navigate with machinery but more clustered/random designs potentially offering higher environmental enrichment.

Shelterbelts are an established linear pattern of planting trees for a specific goal, i.e., slowing down wind across otherwise exposed landscapes. Historically, they were typically composed of a single and sometimes questionable species such as Leylandii which are shallow-rooted, have little tolerance for either very dry or very wet soils and are short lived. Whilst these single-species shelterbelts may be successful in their primary role, their provision of wider benefits is limited.

Shelterbelts are not currently a funded option in UK. Until recently, farmers were only able to access financial support for planting 1-metre wide hedgerows or 20-metre wide shelter woods as boundary options though the latter option has now been reduced to ten metres by the Forestry Commission. By halving the width again to five metres, with careful design and management, a range of benefits, beyond shelter, can be built into the landscape whilst reducing land taken out of food production.

Shelterbelt design is key to optimising available shelter and three components considered to be important are: a sloping profile to elevate wind smoothly over to minimise turbulence; a good height which holds the elevated wind higher for longer thus optimising shelter across the landscape; and porosity. Along with the sloping profile, porosity is considered important for reducing turbulence. The sloping profile can be achieved by planting several parallel rows with shrub-tree and intermediate tree species in the outer rows, against the prevailing wind, and taller trees, for height, behind them.

Optimal porosity is more difficult to manage particularly with deciduous trees changing both over seasons and time, as the plants grow. A further challenge is whether to plant trees closer together to achieve the desired shelter earlier on, which then requires higher levels of ongoing management, or to plant with wider spacings and delay the benefits as trees mature to fill the space. A fourth component to consider is length since unwanted turbulence is also created at each end. Length also plays an important function in connectivity where maintained, linear, woody structures act as corridors for wildlife to move around the landscape.

The Optimum Shelterbelt Project

Some benefits of hedgerows are well-established and whilst a well-designed shelterbelt may be considered as an enhanced hedgerow (with an increased width, varying heights and potentially more tree species), there is minimal research carried out in UK conditions on shelterbelt design, on the outcomes of the range of intended benefits or on how to manage them for optimal performance across the different themes of agro-ecological resilience. The Optimum Shelterbelt Project Consortium consists of the Farm and Wildlife Advisory Group – South West (FWAG-SW), the Tree Shop, a Forestry Consultant, the Organic Research Centre (ORC) and 12 participating farmers in the Cotswold region. There is diversity among the farms with arable, mixed and livestock farms represented alongside one horticultural enterprise on one of the farms. A uniting focus across the consortium, is a commitment to understanding how to optimise landscape management and care alongside responsible food production and the research element is key to identifying best practice within and between the included themes to support farmers in making informed management decisions.

Optimum shelterbelt design

The optimum shelterbelt (OSB) design consists of a five-metre wide linear planting with four rows of trees and a total of 3.25 trees within each linear metre (Fig. 1). The smaller trees are planted slightly closer together compared to the taller trees to promote the consistent elevation of wind, provide shelter at ground level and cover for wildlife.

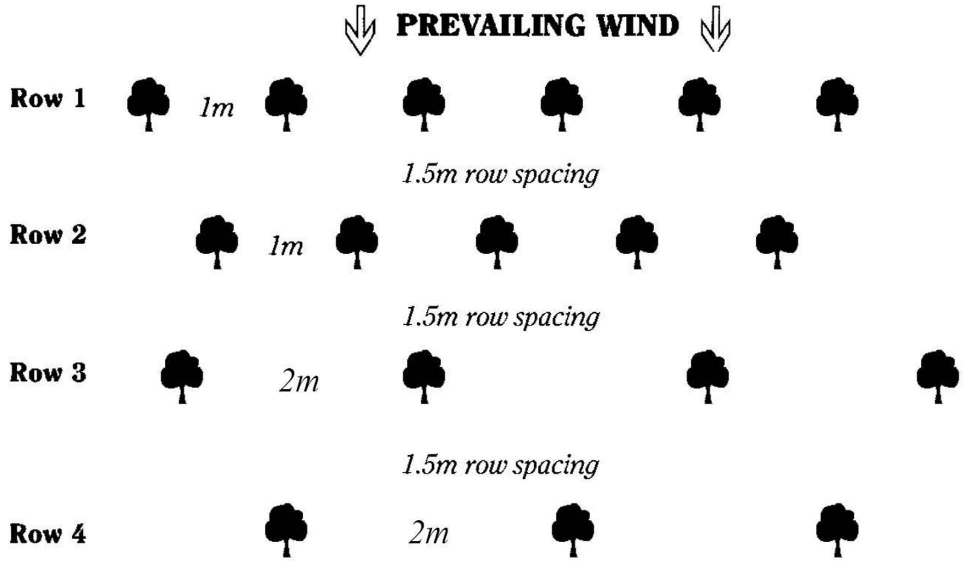

Figure 1: Planting design for optimum shelterbelts with the sloping profile rising away from the prevailing wind.

Tree species in OSB

In all, eighteen different tree species are included in the OSB with six species each of shrubs, intermediates and tall trees selected for their leaf distribution and density considered likely to create the desired levels of porosity. To help mimic the clustering of species in naturally occurring mosaics, each species is planted in repeat groups of five for smaller trees, in the first two rows, and groups of three for taller trees in the second two rows.

The six species selected as shrubs are hawthorn, buckthorn, alder buckthorn, hazel, spindle and guelder rose. The six selected as intermediate trees are field maple, silver birch, bird cherry, goat willow, rowan and crab apple and the six species of taller trees are hornbeam, black poplar, aspen, common alder, grey alder and Scots pine.

The mix of species used to achieve height and a sloping profile has been tailored to offer wider agricultural and ecological benefits including browse, medicine and parasite control for farmed animals alongside blossom, berries, nuts and habitat for wild animals. The selected species are appropriate for the Cotswold conditions and were agreed in consultation with the Cotswold AONB regulator.

OSB establishment

The first OSBs were planted in the 2020/21 planting season and, alongside the Dulverton Trust funding for research protocol development, the funding for trees, tree planting and protection has been gained from various private, charitable and publicly-funded agencies including Protect Earth, Woodland Trust, Trees in Protected Landscapes, Local Authority Tree Planting, and the Environment Agency (see Mid-term short report, Nov. 2022, Appendix 1, for description of establishment practices and tree protection). The 2023-24 replacement and management (beating up) round is now completed and the overall replacement rate this year was 8.9 percent.

The cumulative cost of OSB establishment to date is £234,176 and there are now 22 OSBs planted on the 12 farms including 20,744 planted trees, totalling 6.68 km in length. All but one of the OSBs is growing well with the different protection options trialled. This OSB has been heavily predated by deer and, subject to funding, will be replaced and more heavily protected leaving 21 OSBs currently at a level of establishment where the second phase of research can begin, namely the testing of protocols in the field to establish long-term data collection for each theme. Monitoring outcomes overtime is critical to understanding both short-term and long-term impacts and this is increasingly relevant now that weather patterns are changing and becoming more changeable.

For information, the OSB design is gaining interest from farmers with a further total length of 1.72 km of OSBs having been planted in the Wye Valley, in Monmouthshire and in Somerset but these are outside the scope of the current research focus.

Research themes and protocols

Successful and responsible food production includes optimising growing conditions for crops, good animal welfare, managing emissions and optimising biodiversity, whilst being productively and economically resilient. ORC has developed a range of protocols to determine how the presence of the OSB influences these different themes overtime. The protocols cover shelterbelt properties and influences on biomass carbon; microclimate; crops; animals and biodiversity. In addition, project partners will be assessing soil carbon (FWAG-SW) and economic impacts (Forestry Consultant).

There are challenges inherent in carrying out field trial research in each of these themes which include data collection equipment (technical know how and cost), time and in-field conditions. The latter challenges may be mitigated by, where possible, tailoring each protocol to local, on-farm conditions, including normal farm practice. One such challenge is identifying a control, for example, for the microclimate measures where a windward position is not accessible or available (e.g., land under different ownership), is not appropriate (e.g., road) or is sown with a different crop to the test field. To mitigate this challenge, a distant position in each test field has been selected where the shelterbelt has no impact on the local microclimate.

Data collection equipment can present a challenge in terms of cost and accuracy. Accurate and reliable data collection is essential for the integrity of the research and the reliability of any guidance and best practice recommendations developed from the result. However, costly equipment can be a limiting factor for ongoing management at the farm level. For this project, where existing equipment is affordable and easy to use, and the methodology is standard practice, data collection can be carried out by farmers and/or volunteers (Tier 1) and the data can be downloaded to a shared folder for analysis. Where equipment is costly and the method is complicated, overly time-consuming or novel, it is proposed that data collection will be carried out by researchers or other trained persons (Tier 2).

A benefit of investigating multiple themes simultaneously is the ability to use data from any theme to support and inform our understanding of the outcomes in other themes. The microclimate data will play a central role in interpreting data across all research activity. To further support this approach, the protocols (where possible) have been designed around a central 'T' shape design of data collection points (see Fig. 2) to consider both boundary and in-field changes overtime.

It is important to state that a further intention of research activities in this project is to devise methods which will not only deliver an increase in understanding of how the presence of OSBs impact the farmed and natural landscape across a range of themes, but to also support farmers in their daily, on-farm management practices, minimising researcher activity (where possible) and optimising farmer autonomy in the long term. There is an intention, where appropriate, to develop guidance material from the data collected. For example, the research on shelterbelt properties can be developed into best practice management guidelines for farmers to maintain optimal porosity and shelter as the OSBs grow and mature.

Figure 2: Data collection points for protocols in the OSB trial.

Protocol 1: Shelterbelt properties

For the shelterbelt properties protocol, there are four main aims which are:

To identify the relationship between porosity, windspeed reduction and area of effect,

To test the validity and value of ‘s’ in field conditions,

To capture seasonal variation in shelterbelt porosity,

To explore the impact of shelterbelt management on seasonal porosity and shelterbelt characteristics in the long term.

The key measures here are porosity, wind speed and shelterbelt profile, depth and height.

Measuring porosity

The measuring of porosity will focus on optical porosity where images are taken of the shelterbelt using a camera, phone or drone. Most people now have at least a smart phone with camera promoting on-farm data collection. The Tier 2 approach would be to use a drone which would better enable the capture of images at 90 degrees to the shelterbelt which both increases the accuracy of porosity calculations and allows for images to be taken where human access may be difficult or restricted (for example, where there is a mature field of maize growing). Images from both protocol tiers can be uploaded to free, online software which converts images to black and white, counts pixels as a proportion of total image that can then be converted to percentages.

$$\frac{No.of\ white\ pixels}{No.of\ black + No.of\ white\ pixels}$$

Images will be captured in partial and full leaf cover as well as no leaf cover to understand the changes in porosity over seasons. A mid-season data collection would result in fours sets of data for each OSB each year.

Measuring windspeed - testing ‘s’

Windspeed is the primary indicator of the effect of shelter and will be included in the microclimate measures using six of the nine purchased anemometers (following the ‘T’ design of data collection points). The remaining three anemometers will be used to test ‘s’ in field conditions. In 1999, Nelmes (PhD thesis, unpublished data) developed a simplified method for measuring windspeed that has yet to be tested in field.

$$s = \sqrt{\frac{Mean\ velocity\ downsteam^2 + RMS\ velocity\ downstream^2}{Mean\ velocity\ upsteam^2 + RMS\ velocity\ upstream^2}}$$

The model does not consider porosity and reduces the number of required in-field readings (the position of which changes over time according to tree height) and it makes several assumptions to achieve the simplified score ‘s’. The data captured from the ’s’ method and the ‘T’ design will be compared and used to evaluate the relationship between windspeed and optical porosity.

Measuring shelterbelt height, width and profile

The profile, height and width of the OSB are key measures to maintain OSB design and intended outcomes. OSB width is also required to calculate height which is needed for calculating ‘s’. The standard method for calculating height is to use a clinometer and a tape measure.

$$Height\ of\ shelterbelt = \ Distance\ from\ shelterbelt * \left(\frac{Percentage}{100}\right) + Height\ of\ eye\ level$$

Equipment: A clinometer (Fig. 3), which is also used to calculate profile, is a costly piece of equipment for individual OSB adopters given the low number of total measures required to record OSB height over time. Since height is required to determine ‘s’, it may inhibit the practical value and thus adoption of this method in field. Therefore, two alternative methods will be included and compared with the clinometer method. These use either a ruler or spirit level app on a smart phone) or a piece of cardboard/folded sheet of paper to create a right-angled triangle. If these methods provide reliable and comparable results, they may be recommended for use alongside ‘s’.

Figure 3: Suunto PM-5 Clinometer for measuring tree height and profile.

For more detailed background information and methodologies for OSB properties, please see Appendix 2

Protocol 2: Microclimate

For microclimate data, the four key levels of research interest are:

Annual, including seasonal, variation in microclimate

Daily (day and night) variation

Key points in crop development and animal management and welfare.

Flash weather events

Microclimate measures have a central role to play in the OSB project monitoring the changes in local climate from the presence of the shelterbelt and informing how these changes influence other focal themes included in the project. They will also be used to test the value of 's'. It is therefore of major importance to the interpretation of findings across themes that the data collected here are complementary, accurate and reliable.

Climate measures

Ten measures (Table 1) will be included in the microclimate data collection investigating elements of wind (speed and direction), ambient temperature and effective temperature (wind chill and relative humidity) and moisture content (humidity, dew point and wet bulb).

Recording time, frequency and duration.

With the simultaneous use of all nine anemometers at one site, there are challenges with data collection across 22 OSBs. Further challenges include the proximity of some OSBs to public access areas where vandalism has already been experienced and use of field where, for example, livestock are present. In order to optimise data collection, researcher efficiency and protection and safety of equipment, the following data collection protocols may be used in combination.

1) Monthly (12 datasets) x hourly x 24 hours – to measure annual and daily patterns of microclimate changes. Hourly data capture can be set to a single moment or a set length of time (e.g., 15 secs. and the mean is used (may be useful in very changeable, windy weather).

2) Seasonal (4 datasets) x hourly x 24 hours – still recording annual and daily patterns of microclimate changes. A simpler, less sensitive set of data but may be sufficient to gain basic knowledge overtime of shelterbelt influence on microclimate. Risk of theft or vandalism still present at some OSB sites.

Options 1 or 2 can be carried out on subset of shelterbelts (e.g. 1 OSB per farm) and/or hours (e.g., daytime hours) so that equipment is not left in the field unguarded. The welfare of humans is also important to consider.

Table 1: climate measures recorded by the Kestrel 5200 Professional Environmental Meter

Direction	Compass heading in true or magnetic North.
Wind speed	Wind Speed is the measurement of the wind passing through the impeller. For greatest accuracy, point the back of the Kestrel directly into the wind.
Crosswind	Crosswind uses the internal compass and a user selected heading to calculate the crosswind component of the full wind.
Headwind	Headwind uses the internal compass and a user selected heading or target direction to calculate the headwind component of the full wind.
Temperature	Ambient Temperature is the temperature measured at the thermistor. For best results, ensure the thermistor is not exposed to direct sunlight and is exposed to good airflow.
Wind chill	Wind Chill is a calculated value of the perceived temperature based on temperature and wind speed.
Humidity	Relative Humidity is the amount of moisture currently held by the air as a percentage of the total possible moisture that the air could hold.
Heat index (THI)	Heat Index is a calculated value of the perceived temperature based on temperature and relative humidity
Dew point	Dew Point is the temperature at which water vapour will begin to condense out of the air.
Wet bulb	Wet Bulb is the lowest temperature that can be reached in the existing environment by cooling through evaporation. Wet Bulb is always equal to or lower than ambient temperature.
Moisture/ humidity ratio	Moisture Content or Humidity Ratio is the ratio between the mass of water vapour measured in the air to the mass of dry air with no water vapour.

3) Seasonally important times determined by ‘crop’ E.g., sowing/ harvesting/ lambing/ outwintering or biodiversity surveys.

Options 1 or 2 and 3 are not mutually exclusive and the basic protocol will need to be tailored to suit different crops or animal system on each of the farms.

4) Flash weather events, though important, are difficult to measure since they require a response with minimal notice and may put people at risk when setting up equipment in field. They may also occur when the equipment is being used to collect data elsewhere and are therefore unavailable. The next phase of project activity, i.e., trialling protocols in the field, will determine whether this focus area can reasonably be addressed and at what level within the OSB project.

Soil temperature

With the purchase of soil thermometers, soil temperatures will be added to the list of microclimate measures since this is key for some aspects of crop germination and growth as well as animal thermal comfort and energy utilisation. The soil temperature will be measured at the same time as the microclimate data collection and following the ‘T’ design.

Equipment: nine, Kestrel 5200 Professional Environmental Meter weather stations (anemometers with a tripod and weather vane, Fig. 4) have been purchased for the trial. Whilst it was originally intended to give each farmer one anemometer for on-farm data collection, alongside the importance of these data for all themes, a review of methodologies indicated the value of collecting data simultaneously at different points both parallel and perpendicular to the shelterbelt. Therefore, following the ‘T’ design, the microclimate protocol will be implemented by researchers. Data from the anemometers can be uploaded electronically via Bluetooth alongside inbuilt storage capabilities with an average battery life of 400 hours. These anemometers also support the use of rechargeable batteries. Tatter flags may also be used as a visual aid of weather impacts overtime.

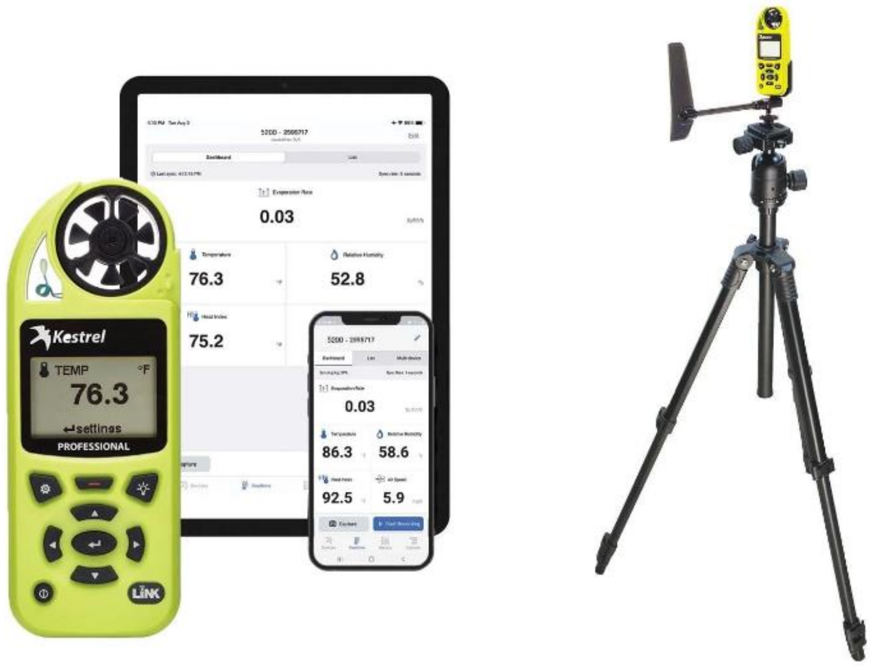

Figure 4: Kestrel 5200 Professional Environmental Meter.

For more detailed background information and methodologies for OSB properties, please see Appendix 3.

Protocol 3: Biomass Carbon

Focus of research for the biomass carbon:

Predicting carbon sequestration in a mixed species shelterbelt.

Within the farming and land use sector, tree planting is considered to make a vital contribution to climate change mitigation. The England Trees Action Plan state that agroforestry plays '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'. 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 (above ground) carbon and accompanies the protocol developed by FWAG-SW for the soil carbon. The soil carbon protocol will also include the impact of leaf fall and distribution on carbon sequestration across the trial field with both below ad above ground protocols using the 'T' design for data collection points.

The biomass carbon protocol has been developed with a 3-tiered approach to include more complicated modelling options (Table 2). 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 (CO2e) expressed as a total or per hectare.

Table 2: 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 (WWC) calculator (predictive estimate)	Allometric approach based on WCC Carbon Assessment Protocol	Allometric approach based on ORC modelling developed for agroforestry

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.

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 including species, height, trunk diameter and crown width and depth. It follows the Woodland Carbon Code Carbon Assessment Protocol (v2.0) (FC, 2018).

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.

It should be noted that there is currently a dearth of growth models developed specifically for trees in agroforestry systems in UK compared to those for woodlands or for urban environments. The use of Tier 3 in the OSB project would help to generate a tree growth model that would better reflect the OSBs growing conditions and contribute to the development of a model that would be of value for agroforestry in general and beyond the project.

Equipment: Tier 1/2: Diameter tape measure, measuring pole, clinometer for measuring tree heights. Tree height data can be shared between protocols one and three. Tier 3: Tape measure, data entry sheet, Excel calculator tool. The data entry sheet and calculator are available from agroforestry@organicresearchcentre.com.

For more detailed background information and methodologies for OSB properties, please see Appendix 4.

Protocol 4: Crop

For the crop theme, the four key levels of research interest are:

Crop growth

Crop damage from weather

Crop damage from pests and disease

Crop yields

Shelterbelts within agricultural fields may have impacts on the growth, health and productivity of the associated crops. These crops include arable, horticultural, permanent pastures or ley phases in arable rotations. OSB impacts on these crops may be positive from a milder microclimate e.g. reductions in wind speeds, warmer temperatures. They may also be negative from, for example, shading or competition.

The health of crops may also be influenced by the presence of the OSB acting, for example, as a barrier for windborne diseases or from changes in biodiversity, for example, from and increase in pest insects. The direction and magnitude of these effects may vary depending on the distance from the shelterbelt and location relative to prevailing winds. The sampling protocols described here are designed to account for these sources of variation when determining impacts of OSBs on crops. A summary of the protocols proposed for each type of crop is shown in Table 3.

The ‘T’ design will be used to assess each measure, with four samples taken in a symmetrical pattern at each point on the T. Much of the monitoring in crop research relies on visual assessment so Tier 1 measurements are also standard methods of data collection.

Table 3: A summary of measures for arable, horticultural and grass crops

	Arable crops (e.g. cereals, oilseed rape, potatoes)	Annual vegetables	Fruit trees and shrubs (if present in horticultural enterprise)	Grass/legume (permanent pasture or temporary ley)
Crop growth	Visual or NDVI[1]	Visual or NDVI	NA	Sward stick/RPM[2] or NDVI
Frost damage	Visual estimate following frost event	Visual estimate following frost event	Visual estimate following frost event	NA
Wind damage	Visual assessment of lodging pre-harvest	Visual assessment of damage pre-harvest	Visual assessment of damage pre-harvest	NA
Disease assessment	Visual estimate at GS61 for cereals; when blight risk is high for potatoes; critical growth stage for other crops	Visual assessment at critical growth stage (TBD for specific crop)	Visual assessment at critical growth stage (TBD for specific crop)	NA
Insect damage	Aphids in cereals when pressure is high; flea beetles in OSR; aphids in potatoes	Visual assessment based on in-field assessment of pest pressure	Visual assessment based on in-field assessment of pest pressure	NA
Crop yield	Grab sample or yield monitoring combine	Grab sample/point assessment by farmer	Grab sample/point assessment by farmer	Sum of measures measurements
Nutrient content				Sward analysis

[1]Normalised difference vegetation index
[2]Rising Plate Meter

Crop growth

Crop growth Tier 1 is a standard visual assessment of crop cover, reported as a percentage of cover (Fig. 5) or may include the use of the Canopeo app with the use of a smart phone. Tier 2 uses the normalised difference vegetation index (NDVI) which requires sensor equipment (handheld or drone). For the grass crops (permanent and temporary), NDVI, a sward stick or a rising plate meter can be used. The latter two pieces of equipment are in common use on farm but technique is very important for accurate readings.

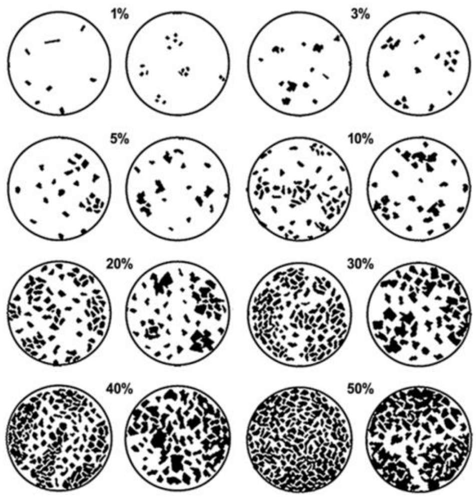

Figure 5. Visual aids for the assessment of percentage crop cover.

Frost damage

Frost damage is measured by a visual estimate of damage on leaves, fruits or flowers which are triggered by a frost event. Both incidence (percent of plants damaged at each sampling point) and severity (percent of affected area) are measured.

Wind damage

Wind damage is measured by a visual estimate of damage to leaves and stems pre-harvest. For lodging (the permanent displacement of a stem from a vertical posture), the percent of crop affected is reported alongside position of lodging in field and distance from OSB. For potatoes and vegetable crops the damage is reported as incidence and severity.

Disease and Insect damage

For each disease or insect damage, the incidence and severity are reported using visual estimates. For diseases, these visual estimates should be carried out at critical growth stages (GS), for example, GS61 for cereal crops, or when the risk of a disease is high, for example, blight for potatoes or tomatoes. Similarly, the assessments for insect damage should be carried out when the risk of crop-associated insect pressure is high. AHDB forecasts can be used to monitor local pressure. For oilseed rape (OSR), the damage from the Cabbage Stem Flea Beetle should be monitored at OSR emergence.

Crop yield

For Tier 1 data collection, samples (x 4) are harvested at each point on the T design. For cereals, for each sample, a row length of 0.5 metres is cut and weighed for total biomass and then the grains are threshed and weighed. For other 'seed' crops such as OSR and beans, the cereal method can be adapted. For potatoes, and other root crops, a one-metre row length is harvested for each sample and the roots are weighed. A combination of elements of these methods can be adapted for any other crop grown on trial sites. Tier 2 yield data collection uses yield mapping harvesting equipment. Some of the participating arable farmers already employ this technology.

Nutrient content

Livestock farmers typically carry out sward analysis to gauge nutritional content of grass and preserved forage for animal feed plans. This analysis may identify changes in protein and sugar content from changing light levels and mineral changes from leaf drop and distribution across the trial site. Tier 2 would include repeat samples along the T design, elevating analysis costs beyond normal farm practice.

For more detailed background information and methodologies for OSB properties, please see Appendix 5.

Protocol 5: Farmed animals

For the farmed animal theme, the key research interests are:

Mortality and morbidity (survival and disease)

Production measures (as an indicator of good welfare)

Animal use of resources

The target animals for research are beef and sheep, adults and youngstock.

Shade and shelter for grazing livestock is increasingly being recognised as necessary for good animal welfare in both hot and cold conditions. As with crops, the shelterbelts can support improvements in survival, growth, health and productivity of the farmed animals. It is important to state that, here, the focus on productivity is related to animal welfare. For example, increasing thermal comfort will reduce energy being 'wasted' on coping behaviours in hostile weather conditions. Alongside offering shade and shelter, the eighteen species present in the OSB include browsable trees such as field maple, hawthorn and hazel alongside goat willow which also offers an established source of salicin (e.g., for pain management) and condensed tannins (e.g., for internal parasite management).

The mixed farming systems in the project, with a predominance of arable agriculture, presents real challenges for meaningful data collection for the animal theme since, unlike plant crops, the animals will not always be grazed adjacent to the OSB making it difficult to attribute any longer term outcomes to the presence of the shelterbelt. It is nevertheless important to include them as a theme and to develop protocols that can be adapted to on-farm conditions. Several normal, on-farm management practices involve data collection that is relevant to the trial and this will be utilised where possible.

Mortality

Hypothermia (and starvation combined), is one of the biggest causes of lamb mortality and access to shelter for ewes at lambing time can significantly improve survival rates of their lambs at birth. With continued access to shelter it can also improve survival rates to weaning. On-farm records include both new-born and weaned survival figures and, if not already, cause of death will be included. Adult mortality rates and causes will also be recorded.

Morbidity

An increasingly large body of research on dairy cattle illustrate the strong link between compromised thermal comfort and a range of diseases. Furthermore, grazed animals are at risk of gastro-intestinal parasite burdens. On-farm health records and management will be used here, including treatments, faecal egg counts and production records for measures strongly linked to diseases (e.g., heat stress and fertility). Alongside health records, on-farm feed input and liveweight/growth rate records will support data on animal health status.

Animal use of resources

High welfare animal systems include offering animals an enriched environment where they can find what they need when they need it. Animal observations and use of resources would indicate whether the presence of shade and shelter supports the animals to behave normally (e.g., thermal stress compromises activity and feed intake) thus indicating low stress conditions. Tier 1/2 data collection relies upon the presence of a person recording animal activity for a set period of time using a prepared ethogram (repertoire of behaviours for species being observed) and a check sheet for data recording. Tier 2 includes use of activity and location data loggers such as Nofence collars (Fig. 6), which, with virtual fence programming disabled, would provide reliable, 24-hour data for field and resource use. Tier 2 could also include the use of the woodland herbivore assessment, alongside its use in the biodiversity protocol for assessing and measuring deer-OSB interactions.

An advantage of using technology is the reduction of time spent in the field recording data and the absence of humans, whose presence may influence how animals use the landscape. A drawback can be the loss of environmental data which may explain animal movements (e.g., aversive stimuli such as loud noises or the presence of a predator) though these are typically exceptional events. An additional measure for Tier 2 is the use of technology to measure skin temperatures. Standard thermal stress thresholds are largely assumed for all livestock species being based on losses in productivity rather than actual animal measures. Understanding when animals are choosing to seek shade and shelter would be a major step forward in our understanding of thermal comfort at the animal level.

Where animals are allowed direct access to trees in the shelterbelt, browsing (percent of accessible stems browsed and species selection) will be recorded alongside body rubbing as evidence of body care (either direct observation of rubbing behaviour or OSB indicators of worn patches of ground and dusty branches).

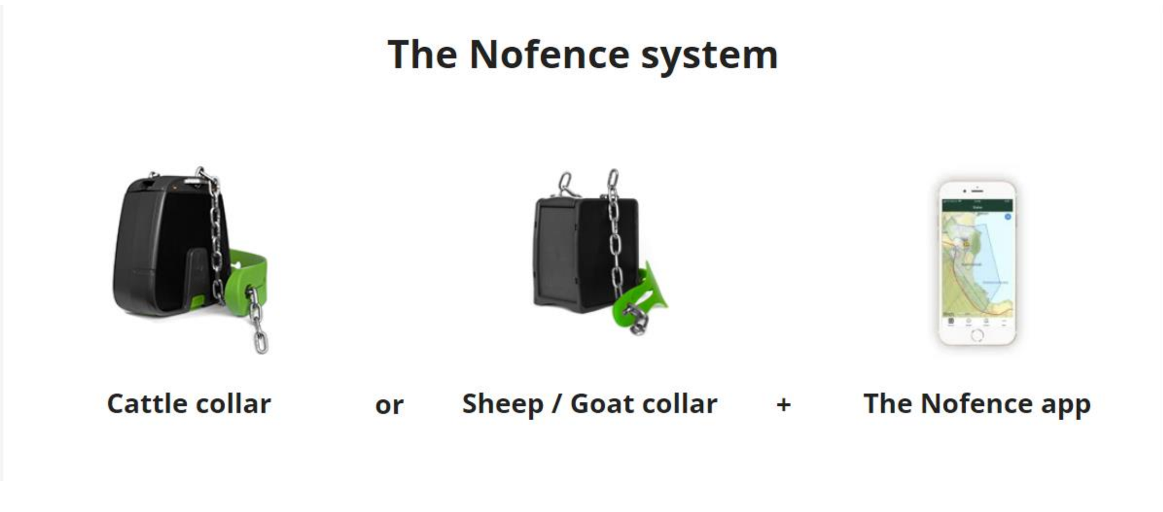

Figure 6: Nofence collars and app, a (virtual fence) GPS tracking system for livestock

Equipment: ethogram, check sheets, animal mounted data loggers with associated apps.

For more detailed background information and methodologies for OSB properties, please see Appendix 6.

Protocol 6: Biodiversity

Key areas of research and indicators in the biodiversity theme are:

Value of habitat for wildlife: structure, connectivity, composition (of both the OSB and ground flora), food sources and dead wood.

Presence of species groups: breeding birds, small mammals, butterflies, bumblebees, soil fauna and pest/invasive species.

Biodiversity is a measure of variation at the genetic, species, and ecosystem level. Its measurement therefore needs to encompass different scales, but as with the livestock theme, determining any direct influence of a single component in a wider landscape is far from straightforward. The biodiversity monitoring protocols focus on a complementary set of proxies and taxonomic groups that, together, are indicative of overall biodiversity value and provide a meaningful narrative about the food web. They are therefore also referred to as 'indicators', which must be practicable to measure, robust, and sensitive enough to pick up realistic changes over relatively short timespans.

There are many different biodiversity monitoring schemes and methods in existence and this current set of protocols is aligned to some of the most relevant including the Global Farm Metrics initiative, the ORC Hedgerow Biodiversity Protocol, the CEH hedgerow Favourable Conservation Status (FCS), and biodiversity sampling protocols developed in the European AGROMIX project. Tier 1 data collection is divided into 1a and 1b with the latter reflecting the option to record additional detail. The tiers of measurement for the 12 indicators are summarised in Table 4. There is also potential to include additional data where farmers are already engaged with these activities on farm and include barn owl and bat monitoring schemes. Where relevant, the sampling will use the T design.

Table 4: Biodiversity monitoring indicators and tiers of measurement.

Indicator	Measurement level		
	Tier 1a	**Tier 1b**	**Tier 2**
Habitat and food			
Habitat structure	Presence of standard trees, shrubs and other structural components	Quantification of structural components along the OSB, with height information	Calculation of foliage height diversity
Habitat connectivity	Presence of large gaps and connections between OSB & other semi-natural features	Continuity of canopy along hedgerow (% gaps)	Connectivity modelling using LandApp Wild Edge and Guidos toolkit
Vegetation composition – woody plants	Variety of woody plants	Species richness and abundance of woody plants	Species diversity of woody species per 30 m
Vegetation composition – ground flora	Cover/abundance of main plant types at centre and edge of OSB	Cover/abundance of plant species at centre and edge of OSB	Comparison of OSB plant communities with other on-farm habitats: NVC, ordination and similarity
Dead wood	*Dead good Deadwood* survey of quantity of deadwood	*Dead good Deadwood* survey of quantity and age of deadwood	*Dead good Deadwood* survey of quantity and age of deadwood with additional volume calculation
Food supply	Abundance of berries, nuts and flowers	Species diversity and abundance of berries, nuts and flowers	[No Tier 2 protocol]
Indicator groups:			
Birds	Abundance of birds using the OSB & adjacent field	Abundance of different species of birds using the OSB & adjacent field	Breeding Bird Survey counts
Small mammals	Density of runways and burrows made by small mammals	Additional search for dormice evidence (OSBs with hazel only)	Species identification using footprint tunnels
Butterflies	Abundance of butterflies using the OSB & adjacent field	Abundance of different species of butterflies using the OSB & adjacent field	UK Butterfly monitoring Scheme transect
Bumblebees	Abundance of bees using the OSB & adjacent field	Abundance of different species of bees using the OSB & adjacent field	BeeWalk monitoring
Soil fauna	Abundance of earthworms	Abundance and weight of the three main different types of earthworm	Soil Biological Quality Index (QBS)
Pest and invasive species	Levels of tree leaf browning and yellowing along the OSB as well as presence of grey squirrel and muntjac deer	Pests and diseases of specific tree species identified	Woodland herbivore impact assessment

Value of habitat

Habitat and structure

A 40-metre stretch of OSB is assessed for the presence of features: ditch, bank, marginal vegetation, basal vegetation, shrub layer and standard trees to determine FCS. Tier 1b includes component quantifications of length and height. Tier 2 includes a calculation of a metric used to describe the distribution of canopy cover across different height strata.

Equipment: data entry sheet, measuring tape, a 4-metre pole and a plastic disc that can pass up and down the pole.

Habitat connectivity

The whole length of the OSB is assessed for presence and lengths of any gaps and whether each end connects to an existing wooded habitat (e.g., hedgerow or woodland). Tier 1b includes the recording of horizontal gaps and percent ‘gappiness’ is calculated.

Equipment: data entry sheet, calculator.

Tier 2 requires a researcher lead and uses the Land App Wild Edge, Guidos toolkit and Condatis connectivity modelling approaches.

Vegetation composition- woody species

A good mix of woody species provides a range of resources benefitting bird species richness, pollinating invertebrates and invertebrate numbers in general. Dormouse population density in hedgerows is also strongly influenced by shrub diversity. For this reason one of the measures of the Countryside Survey for the quality of hedgerows is the mean number of native species per 30 metre length.

A 30-metre length of OSB is assessed for how many different woody species are present, including ramblers and climbers (e.g., ivy and honeysuckle). The survey is easiest to do when plants are in leaf. Tier 1b measures requires species identification for within species counts. Tier 2 uses Tier 1b data to calculate the Shannon Diversity Index (an online calculator).

Equipment: data entry sheet and species identification guides. Access to the online calculator.

Vegetation composition – herbaceous species

The ground flora is an important component of OSBs and can contribute significantly to species diversity. Ground flora also provides an important food resource to a wide range of wildlife such as butterflies and bees. The centre of a mature OSB may develop a ground flora (for example of some shade-tolerating species) that is distinct from that at the outside edge, and this is reflected in the sampling design.

The survey of two quadrats, 10-metres apart at edge of OSB should be carried out in May or June. The aim is to identify ground flora influenced by the OSB rather than the adjacent crop. Use the DOMIN scale (Table 5) to record cover (abundance) of each main type of flora (grasses, forbs, woody perennials and mosses/lichens) and bare ground. Parallel to these two quadrats, repeat the survey in the middle of the OSB. For Tier 1b, cover is recorded for plant species rather than plant group.

Equipment: data entry sheet, quadrat, plant identification guides.

Tier 2 is a researcher led protocol quadrat-based surveys will be undertaken of the flora of the OSB and comparison habitats (hedgerows, field margins, meadows) and the results studied through National Vegetation Classification (NVC) communities, ordination analysis and similarity indices.

Table 5: DOMIN scale.

Value	Visual estimate of cover
+	1 individual, with no measurable cover
1	<4% cover with few individuals
2	<4% cover with several individuals
3	<4% cover with many individuals
4	4-10% cover
5	11-25% cover
6	26-33% cover
7	34-50% cover
8	51-75% cover
9	76-90% cover
10	91-100% cover

Dead wood

Overtime, decaying wood originating from the OSB will become important for saproxylic fungi, invertebrates and other species. Its quality and abundance as habitat will be heavily influenced by shelterbelt management. The survey spans a 100-metre section of OSB and locations of large pieces of deadwood are mapped and categorised as veteran tree, tree stump, snag, windthrown tree or fallen log. For Tier 1b, the age of the dead wood is estimated. Tier 2 uses the measurements of the pieces of deadwood to calculate the volume.

Equipment: data entry sheet, Deadwood survey booklet and field guide, tape measure.

Food supply

Late Spring/Summer surveys of tree blossom and flowering plants in the margin of the shelterbelt and an Autumn survey to capture nuts and fruit (hazelnuts, rose hips, etc.) The number of berries, nuts and flowers are estimated in 3 x 3 m stretches of OSB according to the following ranges: 0, 1-10, 10-100, 100-1000, > 1000. Tier 1b measures requires species identification for within species abundance.

Equipment: data entry sheet, survey guide, measuring tape and poles.

<u>Presence of species</u>

Breeding birds

Hedgerows are one of the most important surviving semi-natural landscape features for birds. They provide nesting, foraging and roosting sites and provide cover and facilitate movement across the landscape. Birds can be used as bioindicators due to their ecology being well understood and the existence of links between bird community, vegetation associations and territories. Birds are also easily detected giving not only presence but also abundance. One area of interest is the presence of nesting birds and to assess whether the sloping profile of the OSB attracts different species of nesting birds associated with both tree canopies (woodlands) and hedgerows. Protocols Tier 1a and 1b are adapted from the GWCT Big Farmland Bird Count and the TWECOM Hedgerow Biodiversity Protocol 2015.

The survey should be undertaken once in April/May and once in May/June, preferably on a sunny day. If possible, the walking survey should take place for 30 minutes between 6 and 9 am as this is when birds are most active. Number of birds in OSB and in open field recorded along with position of birds in OSB (ground level, shrub or canopy). Tier 1b includes the species identification and numbers within species. Tier 2 uses the BTO Breeding Bird Survey which can be used to monitor population changes of breeding bird species.

Equipment: data entry sheet, binoculars, bird identification guide. BTO, BBS recording form.

Small mammals

At three positions along the OSB, 2 x 2 m quadrats are inspected for the presence of runways, their total length estimated and the presence of active small mammal burrows recorded. Three more quadrats at increasing distance from the OSB (T design), are assessed. Tier 1b includes an additional search for dormice carried out in autumn or winter. Tier 2 includes species identification using low invasive, footprint tunnels at both ground and arboreal levels.

Equipment: data entry sheets, knowledge of dormouse evidence. Nine footprint tunnels have been purchase for the project (Fig. 7).

Figure 7: Footprint tunnels to capture presence of small mammal activity runways at ground and arboreal level

Butterflies

Shelterbelts and hedges are an important nectar source for a number of butterfly species. Butterflies also react very quickly to change in their environment which makes them good biodiversity indicators. Pressures such as agricultural intensification and loss of habitat have resulted in many common butterfly species having undergone serious declines.

The survey should be carried out on still and sunny days, once in July and again in August. One count is taken of butterflies in and around the OSB and a second is taken in the open field, at a distance of 20 metres from the shelterbelt. For Tier 1b both the species and numbers of butterflies are recorded. Tier 2 would follow and contribute data to the nationwide UK Butterfly Monitoring Scheme (UKBMS), however, this is a regular (weekly) and long-term (minimum 5 years) commitment.

Equipment: data entry sheet, binoculars, butterfly identification guide, UKBMS site and weekly recording forms.

Bumblebees

Hedgerows are particularly important in providing forage plants for bumblebees at the start and end of the nesting season, when flower-rich grassland areas are being grazed or cut. As with the butterflies, the survey should be carried out on still and sunny days, once in July and again in August. One count is taken of bumblebees in and around the OSB and a second is taken in the open field, as a distance of 20 metres from the shelterbelt. For Tier 1b both the species and numbers of bumblebees are recorded. Tier 2 would contribute data to Bumblebee Conservation Trust's 'BeeWalk', the national recording scheme to monitor bumblebee abundance across Britain with bumblebees being identified on a monthly survey (a fixed 1-2 km route) from March to October.

Equipment: data entry sheet, Bee identification guide

Soil fauna

Earthworms are an important indicator group for soil health and biodiversity. Hedgerows are known to improve soil conditions, including earthworm diversity, an effect that can extend into the field. Two surveys of earthworm counts should be carried out each year, in spring and autumn using the T design for sample locations. Tier 1b protocol identifies numbers of adult worms according to three types, namely, epigeic (litter-dwelling), endogeic (topsoil-dwelling) and anecis (deep burrowing).

Equipment: data entry sheet, spade, holding pot, rinsing bottle (water), plastic mat (approx. 1 x 1 m), weighing scale.

Invasive pests and diseases

Invasive plants can outcompete or smother low-growing herbs, reducing species richness, while invasive pests like grey squirrels and muntjac deer can have adverse impacts such as harming tree regeneration. Increasing landscape connectivity and milder microclimate conditions may potentially have undesirable consequences for the spread of tree pests and diseases as well as pests and diseases that attack crops.

The Tier 1a protocol is based on Activity 1 of the OPAL Tree Health survey (Fig. 8). The tree health survey should be completed between May and September when the trees are in full leaf along with records of the observed presence of grey squirrels and muntjac deer. Tier 2 is a researcher led protocol which follows the woodland herbivore assessment method that is part of the Woodland Grazing

Toolbox and has been devised to assess and monitor the impact of large herbivores on woodlands. It is relevant to understand deer interactions with OSBs, alongside livestock interactions.

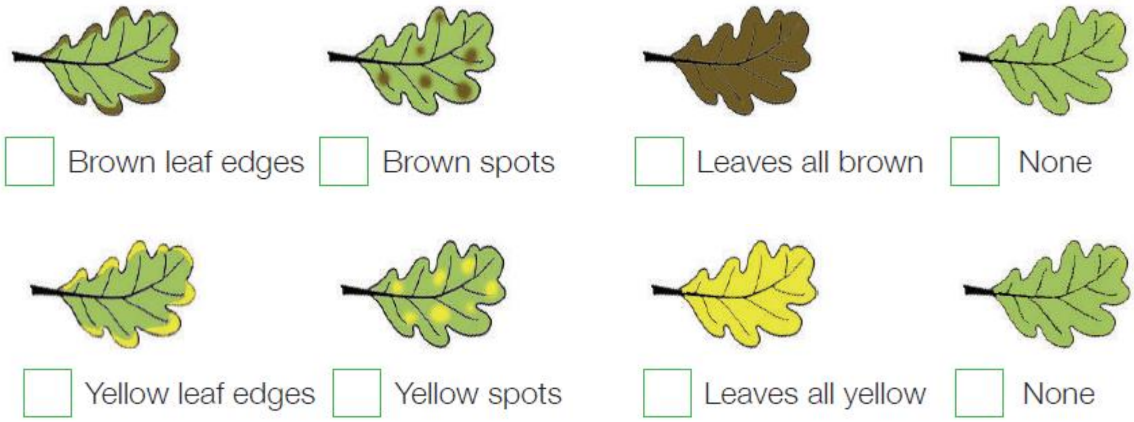

Figure 8: The Tree Health survey includes an assessment of leaf discoloration, leaf damage and galls.

Equipment: data entry sheet, OPAL Tree Health Survey Booklet, Pests and Diseases Identification Guide.

For more detailed background information and methodologies for OSB properties, please see Appendix 7.

Consortium protocol workshop

The OSB project group gathered together for a protocol workshop where each theme, and all related protocols, were presented for feedback and discussion (Fig. 9). The workshop had originally been planned to take place in the Autumn of 2023 and finally took place at the Rendcomb Village Hall in early March 2024. Farmers were also invited to bring along partners or key staff likely to engage with the OSBs and data collection.

A limited number of external people (including a Dulverton Trust representative) were invited to attend the workshop to both observe and participate in the discussion. Those who attended included a member of the Woodland Trust, a FIPL officer for the Wye Valley region (now engaged in planting OSBs) and a Trinity College emeritus fellow who supervised Nelmes' PhD upon which the testing of 's' is based.

Figure 9: OSB project group meeting, March 2024 in Rendcomb.

The protocols for each theme were presented by the ORC researcher responsible for their development (Fig. 10) and based on reviews of current and historic practices and methodological approaches in published literature. This included Dr. Lindsay Whistance for the Microclimate and Livestock protocols; Christian Gossel for the Shelterbelt properties protocol; Dr. Julia Cooper for the Crops protocol and Dr. Will Simonson for the Biomass Carbon and Biodiversity protocols. The meeting was an informal event where attendees could access refreshments, and raise questions and discussion points throughout.

Figure 10: ORC researchers Christian Gossel and Dr. Julia Cooper presenting protocols to the OSB consortium.

All consortium members and attending external people were provided with handouts of each theme and protocol presentation. For specific themes, some questions and discussion points were raised about the wider value of collected data for validating models and the use of more equipment such as video cameras for livestock monitoring and canopy cameras for measuring porosity (leaf area index). Further points raised were the extending of on-farm analysis of nutritional content for crops other than grass (using Spad meter; Brix or refractometers); and whether the data collected for biodiversity in OSBs could be compared to that in traditional hedgerows. The absence of water measures was discussed but attendees did not think there was much value in adding this measure to the overall narrative.

At the end of the event, the farmers, in particular, were asked if they considered any measures to be missing in the protocols, or whether they thought that some measures ought to be more prominent and covered in more detail than they currently are in the protocols. The unanimous response was one of approval where the overall approach was considered to be '*pretty comprehensive and balanced*' between included themes.

Finance

Thanks to the Dulverton Trust, a total of £20,000 was available specifically for protocol development and the purchase of equipment identified as important at the beginning of the project (Table 6). For the equipment, a total of £2,991 was spent on 9 anemometers with tripods and a Bluetooth connection. Ten footprint tunnels were purchased for £159. ORC activity in the first year focussed on a review of the literature relevant for the development of each protocol. In the second year, activity was centred on the development of protocols and the identification of equipment required for each proposed tier of data collection.

Table 6: Researcher activity and expenditure for the development of OSB protocols

Activity	**Total**	**2021/22**	**2022/24**
27 days researcher time for protocol development and consortium interaction and knowledge exchange @ £550/day*	£14,850	£4,950	£9,900
Researcher travel costs for farm visits (10 x £50)	£500	£0	£500
Farmer travel expenses for workshop days (15 x £100)	£1,500	£0	£1,500
Equipment:	£3,150		
Anemometer x 9	£3 000	£2,991	£0
Footprint tunnels x10	£150	£0	£159
Total	**£20,000**	**£7,941**	**£12,059**

*Day rates include overhead contribution

One category of costs that remained unspent was the £1,500 set aside for farmer travel expenses. Despite making it clear that these were funds available to cover travel costs related to attending the protocol meeting in March 2024, none of the farmers chose to do so and in-so-doing, donated their expenses to ORC. An effort was made to find a venue that was both suitable and close to the consortium farms which may have influenced their decision not to claim these expenses.

Next Steps

The establishment, protection and maintenance activity of the OSB project continues with FWAG-SW and the Tree Shop fundraising for these activities. For the research element, the next step is to trial each protocol on farm and to identify the modifications required for each specific OSB and the related management on-farm practices and potential. Furthermore, the adoption of higher tiers of data collection will be investigated subject to the procurement of equipment and the ability to carry out more intensive data collection compared to Tier 1 protocols. These refinements will help ensure the accuracy and reliability of long-term data collection, leading to important knowledge on how enriched hedgerows/shelterbelts can be managed to optimise benefits for crops and animals in the farmed landscape and for wider ecological health. The results will be an important resource both for trial farmers and the wider farming community seeking to carry out best practice at both farm and landscape levels.

Knowledge Exchange and Stakeholder engagement

The OSB Consortium continue to engage with stakeholders on the potential for implementing shelterbelts and their benefits on farms. This includes engaging with policy makers, foresters, advisors and practitioners. The results from establishment and protection trials are being shared across FWAG groups and will be made publicly available once the establishment phase is fully completed. As part of the wider discourse, an article on OSBs was produced for the Quarterly Journal of Forestry in 2023:

Davis J, Whistance L, Lewis D (2023) The role and benefits of shelterbelts on farm. A vision for the adoption of OSBs 'Optimal Shelterbelts'. *Quarterly Journal of Forestry*. 117 (2): 115-121.

Acknowledgements

ORC is indebted to the Dulverton Trust for funding to enable the development of protocols to be used in the trial alongside the purchase of some key equipment data for collection, namely Bluetooth linked weather stations and small mammal footprint tunnels. We also extend gratitude for an extension to the report submission date to allow a farmer group meeting to take place after the initial meeting had to be rescheduled.

Appendix 1

Optimal Shelterbelts Project

Mid-term short report for Dulverton Trust, November 2022

Lindsay Whistance, ORC

Optimal shelterbelts (OSBs) are designed to optimise the available shelter for crops and animals with minimal land taken out of production. They are multi-species shelterbelts with a sloping profile made up of four-rows and five metres wide. Although there is some evidence indicating the benefits and productivity increases of shelter provision abroad, minimal research has been carried in UK conditions.

Supported by funding from multiple sources for tree planting and maintenance, the OSB project has now reached its third planting season in 2022/23, with over 6,5 km of shelterbelts (20,000 trees and shrubs) already planted on 11 farms, all based in the Cotswolds (Oxfordshire, Gloucestershire and Wiltshire).

OSB establishment

Newly planted trees require protection from predation and competition to help them establish and the type of protection employed on each of the 11 farms was influenced by farming style (organic/conventional), levels of predation (e.g., local deer population), farmer preferences and cost. Four tree protectors were trialled which were spiral guards, 1.2 m guards, 1.5 m guards and deer fencing. The spiral guards were predominantly used for the outer shrub rows and were the cheapest option but also offered the lowest protection. Deer fencing was the most expensive option trialled but was also the most successful in preventing damage (Figure 1).

Figure 1: OSBs with spiral guards and deer fencing as protection and chemical spraying as weed control

To reduce competition from weeds, the management options were spraying, strimming, compostable weed control membrane (Ecotex roll and mats) and woodchip mulch. The mulch options also promoted the retention of soil moisture content. The membrane rolls were more successful than the mats, though the mats were initially attractive to farmers wishing to interplant with wildflower mixes. Wood chip mulch utilised existing on-farm waste wood but, despite the input of volunteers helping with this task, it was time-consuming to chip and to spread in sufficient quantities for effective weed control (Figure 2). Other unpublished trials have found wood chip mulch to be very effective if applied and maintained at sufficient (minimum 10 cm) depth.

Figure 2: On farm 'waste' wood chipped for use as a mulch

Spraying and strimming required prompt and timely action and some, but not all, of the farmers struggled to do this alongside competing demands for their time. Where OSBs were planted to incorporate existing degraded hedgerows, the contribution of nettles, brambles and activated weed seed banks to tree losses was notable. Further support will be given to the farmers in the coming year to help prevent loss of trees to management factors.

Weather has also played an increasingly important role in tree establishment with both excessively wet and dry spells during the trial period contributing to losses of establishment. Additionally, as well as offering the least protection, the spiral guards overheated in the summer further contributing to establishment losses. Overall, tree losses from predation and weather, even with moisture retention from mulching (Figure 3), reached 37% (range 6% - 69%) which was higher than expected but unsurprising given the drought conditions in summer 2022 making tree establishment particularly challenging. Other tree planting schemes have anecdotally experienced up to 80% losses in the same timeframe. In terms of species differences, losses were seen in all species planted, primarily from weather stress, though the Scots pine established particularly poorly in the first year (2020/21) and the highest losses in 2021/22 were in the goat willow.

Figure 3: Moisture retention promoted with the use of a mulch and evidence of debarking of young tree in a spiral guard

Beating up (replacement of dead and damaged trees) for 2021 plantings will take place in December 2022 with secured funds and volunteers. Determining the proportion of losses due to materials, management and weather will continue into the coming planting and establishment season to help generate practical planting and maintenance guides for on-farm tree care during the establishment phase.

Protocol establishment

Five protocols are being established for the OSB trial to look at shelterbelt attributes, production outcomes and biodiversity outcomes. Shelterbelt attributes are divided into two categories with one protocol measuring shelterbelt properties and one to measure the shelterbelts influences on local climate. Production outcomes are also divided into two categories to cover crop and livestock productivity measures. Current activity is focussed on literature reviews for all parameters of existing and current approaches to inform methods to be used here.

1. Shelterbelt properties

Alongside the careful selection of native and naturalised tree species aimed at offering shelter, browse opportunities and biodiversity benefits, a key attribute for optimal shelter is maintaining 50% porosity, thus reducing both wind flow and turbulence. Whilst species selection will aid in maintaining desired porosity, some management (e.g., thinning or pruning) will likely be required as the OSBs mature. The key to this protocol is to develop an on-farm measure for assessing porosity and we are currently investigating the potential of using a drone for image capture and the value of visual porosity as a tool.

2. Shelterbelt influences on climate at field level

As the OSBs become established, they will influence airflow and thus local climate on both the leeward and windward sides. The measures to be included in the protocol have been identified and include temperature, humidity, wind speed and evaporation rates. These measures will be recorded at set points on both sides of the OSB and at set intervals into the leeward side to assess the full extent of climate change into the field. To this end, nine anemometers have been purchased. Each of these anemometers has a tripod and weathervane so that they can be set up as weather stations at fixed distances and heights. Data can be uploaded electronically from the anemometers via Bluetooth to avoid human errors. Gaining technical proficiency using the anemometers is the next step for this protocol.

3. Crop outcomes

The crop protocol development is ongoing but will include measures relating to establishment and yield. For example, before the waxy layer has fully developed on the leaves of young crop plants, strong winds can cause damage which then increases the risk of disease so an assessment of leaf health at critical times will be one component. Growth rates will be measured and interpreted with the aid of the OSB property and climate data collected within the trial. For harvest data, where possible, this will utilise normal, on-farm management practices (e.g., yield and moisture content) supplemented with nutritional analysis. The latter component is included as limited research suggests that protein content may be higher in grain grown in shade.

4. Livestock outcomes

Livestock protocols are yet to be developed but will include measures for beef cattle and sheep. Since those farms in the trial with a livestock enterprise are all mixed farms (with arable being the major enterprise), these measures will be tailored to suit the typical seasonal interactions according to normal, on-farm practices once they are determined and may include the overwintering of lambs and the summer grazing of cattle. Where possible, on-farm data collection will be utilised including health records, liveweights and body condition scoring. The development of measures of behaviour such as the use (and resulting condition) of the field and its resources will be investigated.

5. Biodiversity

Biodiversity is promoted by healthy hedgerows and other linear structures in the farmed landscape, offering sources of feed, nesting and shelter for insects, birds and mammals. They also promote landscape utilisation as wildlife corridors and are therefore an important component to investigate. However, available literature indicates that biodiversity is difficult and complicated to measure in terms of appropriate level of detail and scale. Determining any direct influence of a single component in a wider landscape is far from straightforward. Since connectivity is a key factor in landscape use, the use of OSBs as wildlife corridors will be included in the protocol. Footprint tunnels will be used to assess the movement of smaller mammals at ground level and are yet to be purchased for this purpose. A further area of interest is the presence of nesting birds and to assess whether the sloping profile of the OSB attracts different species of nesting birds associated with both tree canopies and hedgerows. Further inclusions in the protocol are yet to be identified.

Equipment

Nine Kestrel 5200 Environmental Meter+Link Weather Stations and Dongle have been purchased to record changes in local climate (https://r-p-r.co.uk/kestrel/5200-weather-station.php). For these, a research and education discount of three percent was secured from Richard Paul Russell Limited, UK, costing a total of **£2,991.36** not including VAT (see outline budget below).

Appropriate footprint tunnels for assessing wildlife traffic in OSBs are yet to be identified and purchased.

Delivery of a training course

Appropriate training for farmers and volunteers to collect data any use of technical equipment is planned to begin in the latter half of 2023.

Knowledge Exchange

Outcomes of using the different tree protectors and weed suppressants will continue to be updated with the results from each planting season. Preliminary results are currently being shared with FWAG and their advisors across the UK with the intention to share them wider, particularly among farming and advisory groups, once data collection is completed.

The project also produces quarterly newsletters for FWAG advisors and other interested parties. The most recent newsletter is a preview of an article accepted for publication in the January 2023 edition of the Quarterly Journal of Forestry.

Outline budget November 2022:

Activity	**Total**	**2021/22**	**2022/24**
27 days researcher time for protocol development and consortium feedback meeting @ £550/day*	£14,850	£4,950	£9,900
Researcher travel costs for farm visits (10 x £50)	£500	£0	£500
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Footprint tunnels x10	£150	£0	£159
Total	**£20,000**	**£7,941**	**£12,059**

*Day rates include overhead contribution

Appendix 2

Optimum Shelter Belts

How to Guide

Monitoring the characteristics of your Optimum Shelter Belt

Christian Gossel, Farm Sustainability Researcher

Introduction

The role of porosity in shelterbelts/windbreaks (hereafter referred to as shelterbelts) is well recognised with numerous studies exploring how a change in porosity affects the qualities of the associated shelterbelt[1,2]. Many projects, such as Nelmes[3], attempt to explore this relationship through models in wind tunnels, subsequently extrapolating their calculations to be applicable to in-field scenarios. Utilising wind tunnel models allows for greater flexibility in exploring characteristics that can summarise shelterbelt qualities, thus reducing workloads when taking in-field assessments. Nelmes identified a single value, S, which requires only a handful of measurement to provide a general view of the aerodynamic impact of any shelterbelt. Specifically, S expresses the relationship between upstream velocity and downstream velocity through the equation:

$$s = \sqrt{\frac{Mean\ velocity\ downsteam^2 + RMS\ velocity\ downstream^2}{Mean\ velocity\ upsteam^2 + RMS\ velocity\ upstream^2}}$$

During this work she found that S has no relationship with porosity, suggesting that the ratio of upstream and downstream wind velocity in unaffected by the amount of air that can flow through the shelterbelt. In addition Nelmes suggests that porosity has little effect on the distance over which a change in velocity is felt.

These results are in stark contrast to other studies which show that at low levels of porosity there is a large drop in velocity, but this effect is only felt over a small distance[4]. Likewise, at high porosity there is a smaller drop in velocity but over a larger area. This relationship, however, only holds for narrow shelterbelts and weakens as the shelterbelt width expands. Further work is needed to explore these differences by collecting data from in-field scenarios, testing S and its relationship to porosity, and confirming the association with porosity, velocity reduction, and area impacted. This will also help identify an optimal porosity to maximise protection effects, although this may vary between seasons.

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[1] Cleugh, H. 1998. Effects of windbreaks on airflow, microclimates and crop yields. Agroforestry Systems. 41. p55-84.

[2] Mahgoub, AO & Ghani, S. 2021. Numerical and experimental investigation of utilizing the porous media model for windbreaks CFD simulation. Sustainable Cities and Society. 65. 102648.

[3] Nelmes, S. 1999. The aerodynamic characterisation of shelterbelts. PhD Thesis. University of Oxford.

[4] Ma, R et al. 2020. A wind tunnel study of the seasonal shelter efficiency of deciduous windbreaks. American Society of Agricultural and Biological Engineers. 63(4). p913-922.

Previous work has explored the topic on seasonal variations in shelterbelt quality, however the work utilising in-field experiments and measuring porosity variation over the seasons is limited[4,5,6]. The utilisation of a mix of deciduous and evergreen species if often recommended in shelterbelt planting. This mitigates some of the seasonal porosity changes but how the ratio of species can be optimised to offer the appropriate levels of protection at different times of the year is still unclear. Similarly, pruning, thinning, and other management activities are commonly only recommended when the shelterbelt becomes too dense or for tree health issues. Knowledge and data around how different approaches to tree management in shelterbelts relate to porosity is another area that needs further research.

An additional aspect related to tree management which has yet to be explored through on-field experiments is the angle of tapering from lower to upper edges of the shelterbelt. Previous modelling experiments suggest that the shape (i.e. triangle or square face) doesn't affect the sheltering qualities of the barrier[7], however, an edging technique is common practice in commercial forestry to reduce the chance of windthrow[8], particularly at the edges of the plantations. Having a tapered edge may therefore reduce damage to the shelterbelt from strong winds, however, how to optimise this effect in shelterbelts is unknown. By measuring the angle of taper, this methodology will be able to explore if the angle of taper has an impact upon shelter quality. Similarly over longer periods when storm may occur, noting the damage caused to the shelterbelt could be related to the angle.

Finally, these protocols are developed to be used, in part, by farmers and landowners themselves. To this end, where possible they have been designed to be simple in approach and using basic equipment. Simple measurements such as tree height, however, can be done using an assortment of different methods, some of which may be more accurate than others. Previous work has compared technical methods of measuring tree height i.e. LiDAR against Clinometers[9], however there is little research into comparisons of non-technical methods. Using a Clinometer is considered a standard method of measuring tree height and will be used as a reference value. Additional methods will also be used to measure tree height for comparison, the first using a spirit level mobile app as a proxy for measuring the viewing angle, much as a dedicated clinometer would. The second approach uses a piece of A4 paper folded to create a 45 degree angle from which the height can be deduced. Details of the methods used are detailed in the protocols below.

General Approach

This methodology aims to explore these areas by:

1. Testing the relationship between porosity and S on in-field examples.
2. Capturing the link between porosity, windspeed reduction, and impacted area.
3. Identifying the temporal variation in shelterbelt porosity.

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[5] Koh, I. et al. 2014. Seasonal effectiveness of a Korean traditional deciduous windbreak in reducing wind speed. Journal of Ecology and Environment. 37(2). p91-97. http://dx.doi.org/10.5141/ecoenv.2014.011
[6] Baker, T. P. et al. 2021. Temporal, environmental, and spatial changes in the effect of windbreaks on pasture microclimate. 297. 108265. https://doi.org/10.1016/j.agrformet.2020.108265
[7] Wang, Hao, and E. S. Takle. 1997. Model-simulated influences of shelterbelt shape on wind-sheltering efficiency. Journal of Applied Meteorology. 36 (6). pp695-704. DOI:10.1175/1520-0450-36.6.695.
[8] Gardiner, B., Stacey, G. 1996. Designing Forest Edges to Improve Wind Stability. Forestry Commission. Technical Paper 16.
[9] Ganz, S., Käber, Y., Adler, P. 2019. Measuring Tree Height with Remote Sensing—A Comparison of Photogrammetric and LiDAR Data with Different Field Measurements. Forests. 10 (8). pp694. DOI: 10.3390/f10080694.

4. Exploring the impacts of different tree management strategies and tree types on seasonal porosity and other longer-term qualities.

The output of this work will allow offer greater clarity of the desired porosity for protection, which times of year this protection is at its maximum/minimum, and how management types and species selection can support this maximum/minimum protection. This can then be related to specific location climate and agricultural qualities i.e. crop disease vulnerability, livestock birthing, etc.

Protocols

Measuring optical porosity with a camera

Rationale

Optical porosity is a frequently used, low cost method of analysing the density of shelterbelts[10]. There are more detailed and vigorous approaches, such as LiDAR, are possible however the equipment is expensive and requires extensive training to use[11]. The below method describes a way of calculating the porosity without complex machinery, simply using a phone and online software. The software used has been used in other studies for this purpose and is free to access online[12].

Repeating the process across the seasons creates an understanding of how porosity and thus shelter effects change over the year, feeding into future recommendations around optimal design for maximising shelter effect at certain times of year.

Method

Take 3 identical sets of photos which capture the full height of the shelterbelt without any obstructions. Where possible try to take the photo positioned perpendicular to the shelterbelt. The photo should not be angled up or down, being perpendicular to the ground. In addition try to minimize the level of blurring or other artefacts in the photo and capture the highest resolution possible. 3 photos are required to account for any changes in opacity due to leaves moving in the wind and to provide a more accurate final value. Ensure the sky is visible through the trees and no buildings are situated directly behind the shelterbelt in the photos.

Transfer the photos to a computer and open Fiji/imageJ or visit https://ij.imjoy.io/ - will take a few minutes to load.

File > open… > select local file, then browse to where you have the photos saved and open one.

Once the photo has loaded select the rectangle on the menu and then draw the rectangle over the trees so that the top of the trees is at the top of the rectangle, and the bottom of the trees is at the bottom of the rectangle. This is to remove any excess sky or crops/pasture that would lead to an incorrect analysis.

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[10] Wu, Tonggui., Zhang, Peng., Zhang, Lei., Wang, Jingyuan., Yu, Mukui., Zhou, Xinhua., Wang, Geoff. Relationships between shelter effects and optical porosity: A meta-analysis for tree windbreaks. 2018. Agricultural and Forest Meteorology. 259. pp 75-81. https://doi.org/10.1016/j.agrformet.2018.04.013.
[11] Nowak, Maciej M., Pędziwiatr, Katarzyna., Bogawski, Paweł. Hidden gaps under the canopy: LiDAR-based detection and quantification of porosity in tree belts. 2022. Ecological Indicators. 142. 109243. https://doi.org/10.1016/j.ecolind.2022.109243.
[12] Marais, Zara E., Baker, Thomas P., A. Hunt, Mark., Mendham, Daniel. Shelterbelt species composition and age determine structure: Consequences for ecosystem services. 2022. Agriculture, Ecosystems & Environment. 329. 107884. https://doi.org/10.1016/j.agee.2022.107884.

Image > Type > 8-bit

This will convert it to a black and white-style image.

Process > binary > make binary

This will convert it to a full binary (black and white pixels only) image.

Analyze > Histogram

If a box pops up then just press continue/OK until you get to a graph. The graph will appear blank but this is just because there are only two values on the spectrum, pure black and pure white.

Click "List" on the lower left of the graph. This will provide a list of the number of pixels at each colour. 0 is the number of black pixels and 255 is the number of white pixels.

To work out the porosity:

$$\frac{No.of\ white\ pixels}{No.of\ black + No.of\ white\ pixels}$$

This gives a value for porosity between 0 (no porosity) and 1 (full porosity). To convert it to a percentage, times by 100.

Repeat for the other two photos. Once you have the 3 porosity values, add them together and divide by 3 to get an average porosity.

Repeat this methodology for a few different days in the week, aiming to capture photos in a range of light levels with cloudy and sunny backdrops. This will help remove error when calculating the number of object vs background pixels. The values of porosity under these different conditions can then be averaged.

Repeat this process for each of the 4 seasons to get an understanding of how porosity varies across the year.

Equipment

Camera (can be phone or dedicated camera)

Computer with access to internet

Additional Comments

Timings are non-critical – as long as most farms capture the seasons within a few weeks of each other.

Could be done my farmers (particularly the photo taking). They could then just email images over with dates for researcher analysis.

Measuring optical porosity with a drone

Rationale

Drones are becoming increasingly affordable and user friendly, providing another tool that can capture suitable imagery[13]. The ease with which drones allow for photo or video capture in a 3D space offers the opportunity to take picture at 90 degrees to the shelterbelt, increasing the accuracy of porosity calculations as well as allowing for images to be taken in areas where ground conditions may make it difficult to take photographs on the ground.

Method

Hover the drone at half the height of the trees (see measuring tree height for identifying this value). Position the drone so it is perpendicular to the shelterbelt and images are taken flat on (i.e. not aimed towards the sky/ground). Take a 3 second video or 3 still images.

Transfer the video/images to PC. If using video isolate 3 frames, 1 for each second, resulting in 3 still images.

Open Fiji/imageJ or visit https://ij.imjoy.io/ - will take a few minutes to load.

File > open… > select local file, then browse to where you have the photos saved and open one.

Once the photo has loaded select the rectangle on the menu and then draw the rectangle over the trees so that the top of the trees is at the top of the rectangle, and the bottom of the trees is at the bottom of the rectangle. This is to remove any excess sky or crops/pasture that would lead to an incorrect analysis.

Image > Type > 8-bit

This will convert it to a black and white-style image.

Process > binary > make binary

This will convert it to a full binary (black and white pixels only) image.

Analyze > Histogram

If a box pops up then just press continue/OK until you get to a graph. The graph will appear blank but this is just because there are only two values on the spectrum, pure black and pure white.

Click "List" on the lower left of the graph. This will provide a list of the number of pixels at each colour. 0 is the number of black pixels and 255 is the number of white pixels.

To work out the porosity:

$$\frac{No.\,of\ white\ pixels}{No.\,of\ black + No.\,of\ white\ pixels}$$

This gives a value for porosity between 0 (no porosity) and 1 (full porosity). To convert it to a percentage, times by 100.

Repeat for the other two photos. Once you have the 3 porosity values, add them together and divide by 3 to get an average porosity.

[13] Torresan, Chiara., Berton, Andrea., Carotenuto, Federico., Filippo Di Gennaro, Salvatore., Gioli, Beniamino., Matese, Alessandro., Miglietta, Franco., Vagnoli, Carolina., Zaldei, Alessandro., Wallace, Luke. 2017. Forestry applications of UAVs in Europe: a review. International Journal of Remote Sensing. 38 (8-10). pp 2427-2447. https://doi.org/10.1080/01431161.2016.1252477

Repeat this methodology for a few different days in the week, aiming to capture photos in a range of light levels with cloudy and sunny backdrops. This will help remove error when calculating the number of object vs background pixels. The values of porosity under these different conditions can then be averaged.

Repeat this process for each of the 4 seasons to get an understanding of how porosity varies across the year.

Equipment

Drone with camera

Computer with internet access

Additional comments

Timings are non-critical – as long as most farms capture the seasons within a few weeks of each other.

Drones would need to be flown by trained individuals, however the image analysis steps could be done by anyone.

Measuring windspeed values using anemometers

Rationale

Windspeed is the primary indicator for shelter effect of shelterbelts. Methods to measure windspeed in field vary, however, Nelmes (1999) identified a simplified measurement model for windspeed which requires fewer readings. This methodological approach will allow for testing of the model's performance in field settings, while also collecting the necessary data to associate windspeed with optical porosity.

Additional readings to those required for S will also need to be taken to validate S and provide a greater understanding of the size of shelter effect across the field.

Method

As per Nemes 1999:

The value of s is determined from a simultaneous measurement of horizontal velocity at two positions. The measuring positions are $1h$ upstream and downstream of the shelterbelt and $0.4h$ above ground level although instrument positioning is not critical. Mean and turbulent velocities must be measured at a sampling rate of not less than 0.5Hz, for a sampling period of 10 minutes. Any anemometer with a distance constant less than or equal to 2.3m can be used to measure the velocities. Either the component of horizontal magnitude perpendicular to the shelterbelt or the horizontal magnitude itself can be used to determine s without significant difference in results. To measure s, the wind direction must be within 25° of perpendicular to the shelterbelt. For most accurate evaluation, particularly for very non-uniform shelterbelts, s values should be averaged over the whole 50° sector.

In addition readings should be taken at 5, 10, 15, and 20H distance however these don't have to be simultaneous if the number of anemometers is limited. The same methodology for the S readings should be used to take these readings i.e. 0.4h height for 10 minutes.

Ideally these will be repeated near the middle of every season, resulting in 4 sets of readings per year.

Equipment Required

Anemometers (minimum of 2)

Additional Comments

Wind measurements should be taken on days that are not extremely windy, but also not extremely still.

Anyone could carry out these measurements, but given the time and equipment required a researcher may be best suited.

As access is only guaranteed on both sides of the shelterbelt for 15 sites. Of those 15 only 10 are angled roughly perpendicular to the prevailing wind, potentially limiting the number of samples that can be taken.

Measuring windspeed values using a drone

Rationale

While relatively novel, the notion of measuring windspeed via drone has been trialled in multiple scenarios[14,15,16]. This approach offers the ability to access windspeed at any 3D point in space across the shelterbelt. Current drone capabilities limit recordings to under 10 minutes and recording cannot be taken simultaneously unless multiple drones are used. Despite these limitations the potential of this method should be explored

Method

Numerous approaches could be taken to calculate the windspeed from drones[13,14,15].

The positioning of the drone to collect data should be independent of the method used to extract windspeed, however the time required at each location and the number of locations may be limited by battery availability.

Taking readings for 0.4H in height should be done at 1, 5, 10, 15, 20H distance from the shelterbelt on the leeward side.

Equipment Required

Drone

Additional Comments

Timings are non-critical, Wind measurements should be taken on days that are not extremely windy, but also not extremely still. However, since these data are of importance to other measures included in the research, they will be aligned with relevant times of day/year for key moments in these protocols such as seed germination or animal shade/shelter.

Drones would need to be flown by trained individuals.

Measuring tree height with a clinometer

Rationale

A near universal standard for measuring trees is to use a clinometer. Other options are available such as laser-based height measurers, however these are more expensive and pose additional risks for the user. Tree height is required to calculate various other values, such as the positioning of anemometers/drones. The height also plays and important role in determining the sheltering effect[17].

Method

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[14] Simma, M., Mjøen, H., Boström, T. 2020. Measuring Wind Speed Using the Internal Stabilization System of a Quadrotor Drone. Drones. 4 (2). https://doi.org/10.3390/drones4020023.

[15] Thielicke, W., Hübert, W., Müller, U., Eggert, M., and Wilhelm, P. 2021. Towards accurate and practical drone-based wind measurements with an ultrasonic anemometer. Atmospheric Measurement Techniques. 14 (2). pp 1303-1318. https://doi.org/10.5194/amt-14-1303-2021.

[16] Crowe, D.; Pamula, R.; Cheung, H.Y.; De Wekker, S.F.J. 2020. Two Supervised Machine Learning Approaches for Wind Velocity Estimation Using Multi-Rotor Copter Attitude Measurements. Sensors. 20 (19). 5638. https://doi.org/10.3390/s20195638.

[17] Zhou, X.H., Brandle, J.R., Mize, C.W, Tackle, E.S. 2005. Three-dimensional aerodynamic structure of a tree shelterbelt: Definition, characterization and working models. Agroforestry Systems. 63. pp133-147. https://doi.org/10.1007/s10457-004-3147-5.

Place a tape measure in the middle of the windbreak (i.e. if 5m deep then place at 2.5m). with the tape measure, walk in a perpendicular line out into the field until you can comfortably look up and see the top of the tree line. Raise the clinometer to your eye and match the line/site with the top of the treeline (use an average of the treeline, not an individual tree). Note the percentage measurement on the clinometer and the distance on the tape measure.

The height of the treeline can be calculated via

$$Height\ of\ shelterbelt = Distance\ from\ shelterbelt * \left(\frac{Percentage}{100}\right) + Height\ of\ eye\ level$$

Repeat for 5 sections along the shelterbelt to get an average height.

A single reading should suffice for each year.

Required Equipment

Tape measure (10m+)

Clinometer

Additional Comments

This is not time critical and can be done at any time of year.

Anyone can complete this work.

Measuring tree height with a spirit level mobile app

Rationale

Similar in method to the Clinometer, a sprit level mobile app aims to measure the angle of viewing. This approach is of interest as mobile phones are a common item that could replace the role of a dedicated tool (clinometer), reducing cost and equipment for surveyors.

Method

Following the protocol described by Gabriel Henry[18]. Download a spirit level app to the smartphone. Place a tape measure in the middle of the windbreak (i.e. if 5m deep then place at 2.5m). with the tape measure, walk in a perpendicular line out into the field until you can comfortably look up and see the top of the tree line. Hold the phone up to one eye so that you are looking along the phone to the top of the tree line (use an average of the treeline, not an individual tree) and take a note of the angle shown on the spirit level. It may be preferable to get an app which allows you to “pause” the measurement to make reading easier.

The height of the treeline can be calculated via

$$Height\ of\ shelterbelt = \tan(angle) * Distance\ to\ tree + Height\ to\ eye$$

Repeat for 5 sections along the shelterbelt to get an average height.

A single reading should suffice for each year.

[18] https://gabrielhemery.com/how-to-calculate-tree-height-using-a-smartphone/

Required Equipment

Tape measure (10m+)

Smartphone with spirit level app

Additional Comments

This is not time critical and can be done at any time of year.

Anyone can complete this work.

Measuring tree height with a piece of paper

Rationale

Another simple method of measuring tree height is using a paper folded to make a right angle. This eliminated the requirement for a mobile phone or dedicated device i.e. clinometer, however, also requires a clear space around the tree in order to stand at the correct distance. As such this approach wouldn't be effective in a woodland setting, however for this scenario with fields surrounding the shelterbelt there should be little to no obstructions allowing the required distance to be measured easily.

Method

Based on the protocol described on WikiHow[19]. Fold a piece of A4 paper to create a right angle where you can look along the hypotenuse. Place a tape measure in the middle of the windbreak (i.e. if 5m deep then place at 2.5m). With the tape measure, walk in a perpendicular line out into the field until you can look along the hypotenuse, with the bottom of the triangle parallel to the ground, and see the top of the tree line (use an average of the treeline, not an individual tree).

The height of the treeline can be calculated via

$$Height\ of\ shelterbelt = Distance\ to\ tree + Height\ to\ eye$$

Repeat for 5 sections along the shelterbelt to get an average height.

A single reading should suffice for each year.

Required Equipment

Tape measure (10m+)

Piece of A4 paper

Additional Comments

This is not time critical and can be done at any time of year.

Anyone can complete this work.

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[19] https://www.wikihow.com/Measure-the-Height-of-a-Tree#Using-a-Piece-of-Paper

Measuring shelterbelt profile

Rational

Shelterbelt profile is unlikely to impact the sheltering effect itself, however a gently sloping profile is frequently recommended in traditional forestry to reduce windthrow. By measuring the slope profile the aim is to identify any correlation between windfall/damage and slope profile. This will require longer-term monitoring of the shelterbelt with particular focus at times of extreme wind.

Method

There are two possible angles to measure depending on the shelterbelt design. The first assumes that a single tree defined the edge of the shelterbelt. In this case, using a clinometer stand at the base of the furthest outreach of the canopy base and point the clinometer to the top of tree (orange line on Figure 1). If the top cannot be seen then estimate where the top of the tree would be. Repeat this at each point that a height reading is taken.

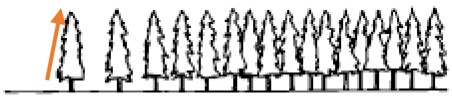


Figure 1. Diagram modified from Gardiner & Stacey, 1996.

The second design uses multiple rows of the trees at an increasing height until the top of the shelterbelt is reached. In this scenario, out from the smallest tree until you can look across the tree tops up to the highest point (orange line on Figure 2). Use the clinometer to measure this angle. Repeat this at each points that a height reading is taken.

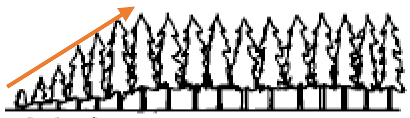


Figure 2. Diagram modified from Gardiner & Stacey, 1996.

Equipment Required

Clinometer

Additional Comments

This is not time critical and can be done at any time of year.

Anyone can complete this work.

Measuring shelterbelt depth

Rational

Shelterbelt depth is required to measure height and also adds to the visual understanding of shelterbelt characteristics that may impact the sheltering effect[16].

Method

If access to both sides of the shelterbelt is possible with the ability to move through the undergrowth, then place one end of the tape measure on the leeward side at the point where the canopy reaches out the furthest. Take the tape measure through the understory of the shelterbelt and place the end at the point where the canopy reaches out the furthest. Note the distance on the tape measure. Repeat this at least 3 more times along the shelterbelt to get an average width.

Equipment

Tape measure (10m+)

Additional Comments

This is not time critical and can be done at any time of year.

Anyone can complete this work.

Measuring species ratio

Rational

There is likely to be seasonal variation in porosity, however this will be impacted by the ratio of evergreen in the shelterbelt. By categorising the ratio of deciduous to evergreens, the species mix can be related to optical porosity and windspeed, feeding into the future recommendations for shelterbelt planting.

Method

If known from planting then:

$$\frac{Number\ of\ decidious\ trees}{Number\ of\ evergreen\ trees}$$

The greater the number is above one, the more deciduous species are present. The smaller the number is to zero, the greater the dominance of evergreens.

If the species planted and ratio isn't already known, then measurements will have to be taken. Walk along a 20m stretch of the leeward side of the shelterbelt and tally the number of deciduous and evergreen trees visible. Do the same for the windward side. If time allows then repeat these steps for 2 additional sections of the shelterbelt. The results can then be entered into the equation.

Equipment Required

Notebook, pen, calculator

Additional Comments

Timings are non-critical.

Anyone can carry out these measurements.

Data Analysis

Variables

For each shelterbelt:

- Windspeeds at:
    - Windward
        - 1H distance, 0.4H height
    - Leeward
        - 1H distance, 0.4H height
        - 5H distance, 0.4H height
        - 10H distance, 0.4H height
        - 15H distance, 0.4H height
        - 20H distance, 0.4H height
- Porosity – 4 readings a year with dates, averaged from multiple repeats.
- Tree height – 3 values per year (3 different methods)
- Shelterbelt Profile – 1 value per year
- Shelterbelt depth – 1 value per year
- Species Ratio – 1 value

Calculated Variables

D70

Plotting the Windspeeds from 1H, 5H, 10H etc. up to 20H will provide a relationship between windspeed and distance for a specific porosity. An appropriate equation should be identified to describe this relationship. This equation can then be utilised to calculate 70% of the velocity measured at 1H on the windward side (or whichever value was taken as a representation of this).

This can be repeated for each site allowing for D70 and velocity relationship equations to be calculated for different porosities.

Relative windspeed reduction

$$\frac{Windspeed\ at\ Leeward}{Windspeed\ at\ Winward}$$

S

$$s = \sqrt{\frac{Mean\ velocity\ downsteam^2 + RMS\ velocity\ downstream^2}{Mean\ velocity\ upsteam^2 + RMS\ velocity\ upstream^2}}$$

Plots and analysis

- Plot Porosity against D70 – calculate correlation co-efficient
- Plot Porosity against windspeed reduction – calculate correlation co-efficient
- Plot porosity against S – calculate correlation co-efficient
- Plot Porosity for each season – ANOVA with seasons as the group
- Plot Porosity for each season with an additional grouping of species ratio

Appendix 3

Optimum Shelter Belts

How to Guide

Monitoring the microclimate changes from the presence of an Optimum Shelter Belt

Lindsay Whistance, Senior Livestock Researcher

Introduction

A key intention for planting a shelterbelt on farmed land is to improve the shelter available for both animals and crops. The presence of shelter can influence microclimate conditions including wind, temperature and moisture levels across a field tempering conditions for both crops and animals (e.g., Cleugh, 1998). Shelterbelt establishment and growth and the accompanying changes in height, profile and density (and thus porosity) will influence microclimate changes overtime, alongside the seasonal variation, with changing leaf cover, and associated seasonal changes in weather patterns. The outcomes of these changes will be measured using the microclimate protocol whilst the shelterbelt properties (height, profile and porosity) will be covered in the Shelterbelt Characteristics protocol.

Protocol

Measuring microclimate using in-field weather stations

Rationale

The data collected here plays a central role in the research on OSBs not only adding to our understanding of how the presence of the shelterbelt changes the local climate but also to help interpret the findings from data collected following the crop, animal and biodiversity protocols. It is important to measure weather and microclimate differences at each data collection point simultaneously across the trial field to ensure that any differences measured can be attributed to the shelterbelt. Additionally, these data will also inform OSB management practices and used to test the value of 's' as a simplified in-field measure of shelter. In order to standardise the data from all OSBs, to ensure accuracy and reliability of data, and to optimise the use of available equipment across sites, it is recommended that this protocol be researcher led. This is also the preferred approach for data transfer and collection purposes, managing the one dongle linked to the equipment.

Following the 'T' design of data collection points (Fig. 1) developed for all appropriate OSB measures including the biomass Carbon and soil Carbon samples, the weather stations will be set up to record microclimate measures across the trial field. The bar of the 'T' represents several points close to and parallel with the shelterbelt and the 'leg' of the T includes several sampling points perpendicular to the shelterbelt and across the trial field. Alongside the sample data points, there will also be a control data point included.

The position of the control weather station may change from trial field to trial field depending on access/ownership of both sides of the OSB and the crops grown on each side. Where the windward side of the OSB is not an appropriate control position, due to e.g., ownership/ topography/

infrastructure/ crop differences compared to the leeward side, a distant point in the trial field (along the same line of the perpendicular T measures) will be selected where the shelterbelt has no impact on the local microclimate. If placed on the windward side, the position of the control weather station will be sufficiently distant from the shelterbelt to avoid any changes in wind patterns related to the presence of the shelterbelt.

Figure 1: Position of sampling points developed for the Carbon above- and below ground data collection. The same positions will be used to collect microclimate data with three additional positions in the same 'T' shape. (Image: FWAG-SW)

The microclimate data gathered will develop a picture of how conditions change across the trial field in the moment as well as over seasons and time, and the protocol will be appropriate for data collection at different stages of OSB presence in the field, namely, 1) establishment, 2) established, 3) mature and 4) impacts of maintenance practice.

Climate measures

In all, ten measures of weather contributing to microclimate are included in the data collection investigating elements of wind (speed and direction), ambient temperature and effective temperature (wind chill and relative humidity) and moisture content (humidity, dew point and wet bulb). These climate measures will be supported with soil temperature measures which indicate the impact of weather on soil conditions relevant to crop establishment and early growth, animal resting comfort and soil biodiversity.

Recording time, frequency and duration.

For this protocol, there are some challenges to optimal data collection which include sharing equipment between 22 OSB sites thus limiting the amount of data that can be gathered at each site. A further challenge is the proximity of some OSBs to public access areas where vandalism has already been experienced and where equipment is at risk of theft or vandalism if left unguarded. A third challenge may be the presence of livestock and potential damage/loss of data from unwanted interactions with equipment.

Option 1:

Following the T design, for data collection, microclimate measures are recorded each month (12 datasets) with hourly intervals (24 data points) to measure annual and daily patterns of microclimate changes. Hourly data capture can be programmed to record a single moment in time or a set length of time (e.g., 15 secs.) where the mean is recorded. The latter option may be useful in very changeable, blustery weather.

Option 1 would provide important knowledge on seasonal and daily changes in microclimate conditions but is a high risk option for equipment safety. Furthermore, with 22 OSBs in total, and therefore, 22 days of data recording each month, and the necessary time lag from travelling between sites and setting up equipment, this option will likely not be possible across all sites but may be carried out on a selected subset of sites and in combination with Option 2 and Option 3.

Option 2:

Following the T design, for data collection, microclimate measures are recorded each quarter (4 datasets) with hourly intervals (24 data points) to measure seasonal and daily patterns of microclimate changes.

Option 2 is a simpler, less sensitive set of data, compared to Option 1, but will deliver basic knowledge of shelterbelt influence on microclimate overtime. Nevertheless, the risk of theft or vandalism would still be present at some OSB sites.

Variations of Options 1 and 2 in terms of time of year (monthly or seasonal) but with a reduced number of data points collected (e.g., daytime only) is also possible but important knowledge of circadian rhythms in weather and microclimate will be limited or lost.

Option 3:

A further option for data collection is to focus on the seasonally important times identified in other protocols. These might include crop germination and establishment times, lambing time or outwintering conditions, alongside key times for biodiversity surveys.

Options 1 or 2 and 3 are not mutually exclusive and the basic protocol will need to be tailored to suit different crops or animal system on each of the farms once use of field and crop selection is determined for that year.

Option 4:

A fourth option for microclimate data collection is related to flash weather events such as storms and heavy rain. Though important for assessing the impact of OSB presence in more severe conditions, they will be challenging to measure since they would require activity with minimal notice and may put people at risk when setting up equipment in field. They may also occur when the equipment is being used to collect data elsewhere and are therefore unavailable. The next phase of project activity, i.e., trialling protocols in the field, will determine whether this focus area can reasonably be addressed and at what level within the OSB project.

Soil temperatures

Soil temperature measures are included here since this strongly influenced by the microclimate and is a key measure for some aspects of crop germination and growth as well as animal thermal comfort and soil biodiversity. The soil temperature of the top 5 cm of soil will be measured at the same time as the microclimate data collection and following the 'T' design.

Tatter flags

Alongside the more technological equipment, Tatter Flags, a traditional visual method of assessing wind damage, may be used (see Fig. 3 below). These flags may be permanently erected at each point on the T design and periodically assessed for damage and wear.

Table 1: climate measures recorded by the Kestrel 5200 Professional Environmental Meter

Direction	Compass heading in true or magnetic North.
Wind speed	Wind Speed is the measurement of the wind passing through the impeller. For greatest accuracy, point the back of the Kestrel directly into the wind.
Crosswind	Crosswind uses the internal compass and a user selected heading to calculate the crosswind component of the full wind.
Headwind	Headwind uses the internal compass and a user selected heading or target direction to calculate the headwind component of the full wind.
Temperature	Ambient Temperature is the temperature measured at the thermistor. For best results, ensure the thermistor is not exposed to direct sunlight and is exposed to good airflow.
Wind chill	Wind Chill is a calculated value of the perceived temperature based on temperature and wind speed.
Humidity	Relative Humidity is the amount of moisture currently held by the air as a percentage of the total possible moisture that the air could hold.
Heat index (THI)	Heat Index is a calculated value of the perceived temperature based on temperature and relative humidity
Dew point	Dew Point is the temperature at which water vapour will begin to condense out of the air.
Wet bulb	Wet Bulb is the lowest temperature that can be reached in the existing environment by cooling through evaporation. Wet Bulb is always equal to or lower than ambient temperature.
Moisture/ humidity ratio	Moisture Content or Humidity Ratio is the ratio between the mass of water vapour measured in the air to the mass of dry air with no water vapour.

Equipment

The microclimate data will be collected using the nine, purchased Kestrel 5200 Professional Environmental Meter weather stations (Fig. 2) which include an anemometer with adjustable tripod and weather vane. These anemometers have data storing options and are Bluetooth enabled so data can be downloaded for analysis, thus extending data collection capabilities as well as minimising human errors in data transfer. These anemometers also support the use of rechargeable batteries. Six of the nine available weather stations will be used for microclimate data and the remaining three will be used to test 's'

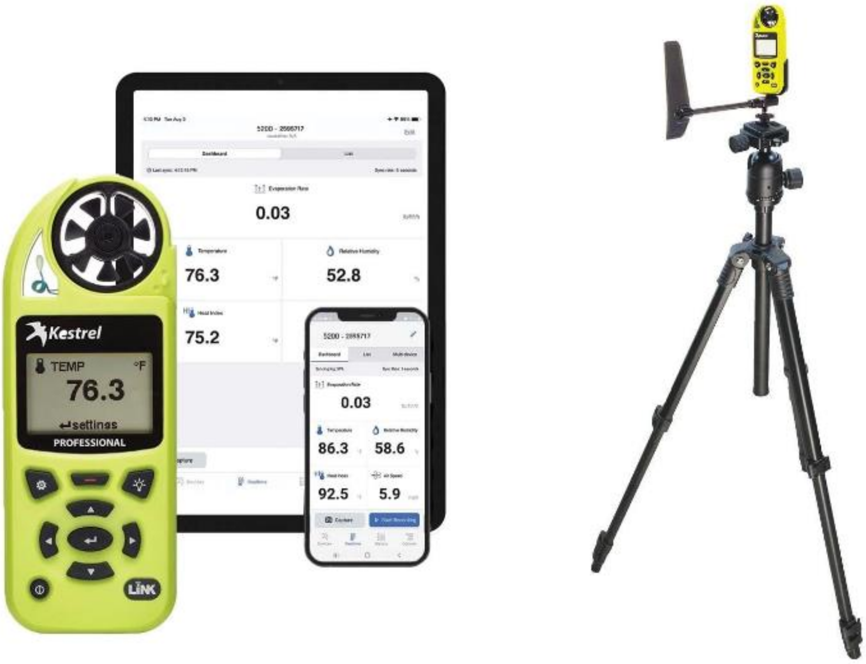


Figure 2: Kestrel 5200 Professional Environmental Meter

Soil thermometer

A digital soil thermometer (Fig. 3) will record the temperature of the top soil. The trial will require a robust thermometer to cope with the rigours of the soil types in the trial which includes Cotswold brash.

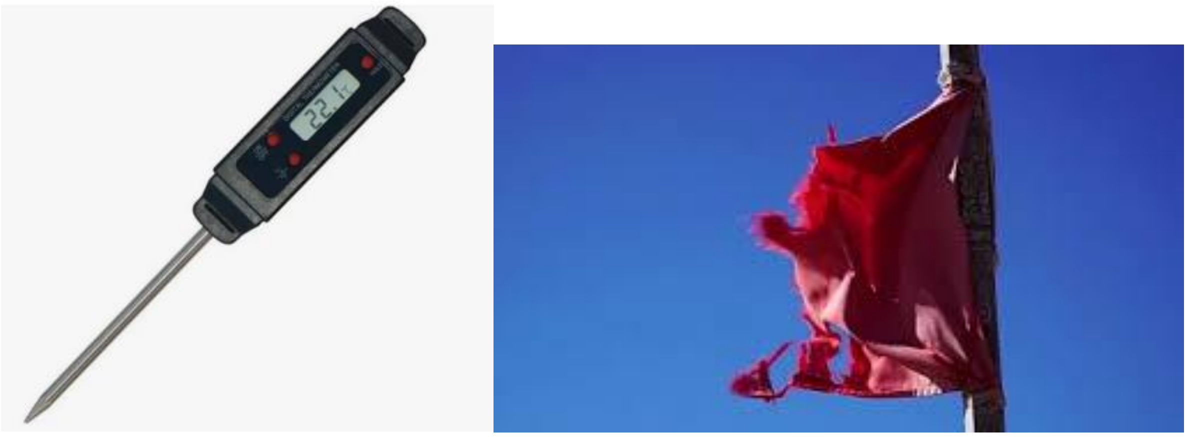


Figure 3: a soil thermometer for measuring the temperature of topsoil and a weather worn Tatter Flag.

Appendix 4

Optimum Shelter Belts

How to Guide

Monitoring the carbon benefits of your Optimum Shelter Belt:

Above and below ground carbon

Will Simonson, Principal Researcher in Agroforestry

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).

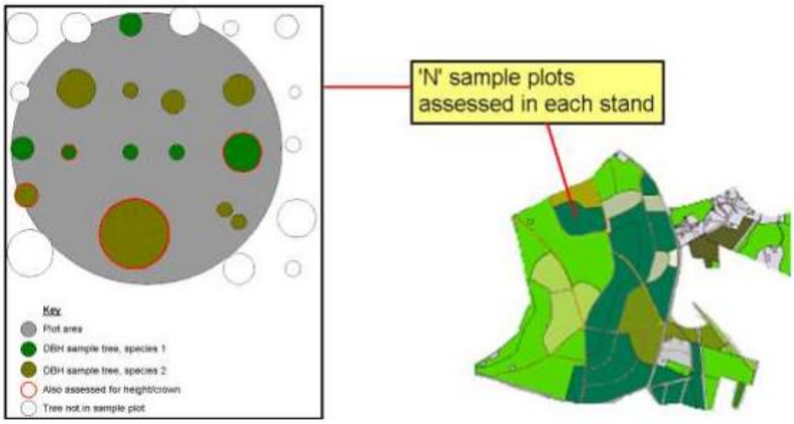


Figure 1.4 Illustration of basic principles of a plot-based survey for estimation of carbon stocks in a small forest estate. An example of assessments taken in a circular-shaped plot is shown.

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.

Appendix 5

Optimum Shelter Belts

How to Guide

Monitoring the crop impacts of your Optimum Shelter Belt

Julia Cooper, Head of Research

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 biodiversity. They offer sources of feed, nesting and shelter for insects, birds and mammals, and provide habitats and corridors for wildlife that are becoming the theme of many national biodiversity strategies. This how to guide supports the standardised monitoring of the crop impacts of establishing OSBs at 22 sites. It is hoped that the results, quantifying any changes attributable to the presence of the OSB, will be of great interest to landowners and many categories of professionals.

General approach

Shelterbelts within agricultural fields may have impacts on the growth and productivity of the associated crops. Associated crops may be permanent pastures or ley phases of arable rotations, or arable or horticultural crops. Impacts on these crops may be positive, due to impacts on microclimate e.g. reductions in wind speeds, warmer temperatures, or negative, due to shading and competition. The direction and magnitude of these effects may vary depending on the distance from the shelterbelt and location relative to prevailing winds. The sampling protocols described here are designed to ensure that these sources of variation are accounted for when determining impacts of OSBs on crops.

A summary of the protocols proposed for each type of crop is shown in

Table 1. Details of the protocols to follow for each of these assessments are provided in Protocols.

Table 1 Summary of proposed protocols for monitoring shelterbelt impacts in a range of crop types

	Large field arable crop (e.g. cereals, oilseed rape, potatoes)	Annual vegetables	Fruit trees and shrubs	Grass/legume (permanent pasture or temporary ley)
Crop growth	Visual or NDVI[20]	Visual or NDVI	NA	Sward stick/rising plate metre or NDVI
Frost damage	Visual estimate following frost event	Visual estimate following frost event	Visual estimate following frost event	NA
Wind damage	Visual assessment of lodging pre-harvest	Visual assessment of lodging pre-harvest	Visual assessment of lodging pre-harvest	NA
Disease assessment	Visual estimate at GS61 for cereals; when blight risk is high for potatoes; critical growth stage for other crops	Visual assessment at critical growth stage (TBD for specific crop)	Visual assessment at critical growth stage (TBD for specific crop)	NA
Insect damage	Aphids in cereals when pressure is high; flea beetles in OSR; aphids in potatoes	Visual assessment based on in-field assessment of pest pressure	Visual assessment based on in-field assessment of pest pressure	NA
Crop yield	Grab sample or yield monitoring combine	Grab sample/point assessment by farmer	Grab sample/point assessment by farmer	Sum of RPM measurements

Sampling design

Assessments of crop health and development may be conducted at the same time and using the same locations as other assessments such as carbon and biodiversity. The sample locations for these assessments have been selected taking into account directions of prevailing winds as shown in Figure 3. Three locations are identified for crop assessments at progressively further from the tree row.

[20] Normalised difference vegetation index

Figure 3 Proposed sampling design for impacts of OSBs on crop growth and development

Protocols

Crop Growth

<u>Rationale</u>

There is an expectation that trees within a field can have multiple positive and negative impacts on crop growth and development. Some measure of crop growth is therefore important to better understand these effects.

<u>Tier 1 Visual estimates – arable crops and annual vegetables</u>

A simple estimate of crop cover is to visually estimate the percentage of crop cover relative to bare ground. This method is very inaccurate and subjective and should only be used as a last resort.

Typically, images liked the ones shown in Annex 1 are used to provide guidelines for these estimates. These estimates should be taken early in the season when it is most likely that differences between sample locations will be identified. For cereals, this would be at GS31 (beginning of stem extension), for other crops (oilseed rape, beans) assessments could be made in early spring e.g. late April/early May.

As an alternative to visually estimating percentage crop cover the app “Canopeo” (https://www.canopeoapp.com/#/login) can be installed on a phone with the iOS (Apple) system and used to estimate cover using algorithms linked to photo image analysis.

<u>Tier2 NDVI – arable crops, annual vegetables</u>

For cereals and annual horticultural crops, NDVI is the most appropriate method for estimating crop growth.

Normalised difference vegetation index (NDVI) has been used to estimate plant biomass since its introduction in the 1970s. It is a relatively simple index obtained by measuring the reflectance of light from growing plants in the Red (visible) and NIR (near-infrared) regions. The index is calculated as:

NDVI = (NIR – Red)/(NIR + Red) and has a value between -1 and +1

Reflectance can be measured using satellite images, UAV mounted cameras, tractor mounted or handheld devices. For the purposes of this study, a hand-held sensor[21] is recommended, unless you have access to a tractor mounted GreenSeeker™ or a UAV-mounted device which can measure visible and NIR regions.

Timing Measurement should be taken at a stage when biomass is highly correlated with yield. For cereal crops, this is milk grain stage (GS71-77[22]) (Marti et al. 2007). For vegetables, the most appropriate time will depend on the type, but ideally measurements should be taken at maximum leaf development i.e. pre-senescence, to assess relative size of the crop canopy.

Method To get a reasonable estimate of NDVI several readings should be taken at each location. Stand at the sample location and take four readings, each at 90° to the previous one (Figure 4). Penn State University[23] provides some useful guidance on how to collect accurate measurements with the GreenSeeker. Their guidance on how to take a point measurement are as follows:

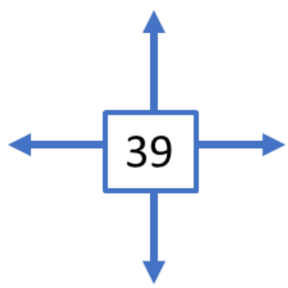


Figure 4 Schematic showing approach to assessments at each sample location; a measurement should be recorded in each of the four directions or points indicated by the perpendicular arrows.

1. Hold the Greenseeker sensor to the side of the body at arm's length, at a constant high between two and four feet above the top of the crop canopy.
2. Pull the trigger on the handle and the sensor will start flashing red and infrared LED lights onto the cover crop canopy. Depress the trigger for several seconds while holding the sensor over the sample location. The digital display on the top of the sensor will read the NDVI measurement several times a second. Once the trigger is released, the average NDVI value measured while the trigger was pulled will be displayed for a few seconds. Remember this number or write it down, as there is no way to retrieve it once the display goes blank.
3. Occasionally the sensor display will show an error code rather than the NDVI. Most often this is because the sensor is either too close, or too far away, from the canopy. If an error code occurs, adjust the sensor distance from the canopy to between two and

[21] Recent searches of the internet indicated that a handheld sensor (GreenSeeker 2) is available from Manterra for ~£572.25; a drone mounted sensor, e.g. from DroneAg, costs about £3,250. Alternatively, a company could be contracted to obtain drone imagery.
[22] Cereal growth guides for all major cereals and information on how to assess cereal growth stages are provided by the Agricultural and Horticultural Development Board on their website: https://ahdb.org.uk/knowledge-library/the-growth-stages-of-cereals
[23] https://extension.psu.edu/using-an-ndvi-sensor-to-estimate-cover-crop-nitrogen-content

four feet. If this does not correct the problem, consult the user manual to determine if the error code is due to other issues.

Equipment: Hand-held sensor - GreenSeekerTM (Trimble Inc., Sunnyvale, CA,

United States)

Crop growth in permanent pastures/leys

The AHDB has produced a useful summary of various methods to assess forage biomass at this link.

Tier 1 Compressed sward stick or rising plate meter

A simple way to estimate forage biomass is through using a sward stick which has been correlated to biomass. The AHDB or forage seed companies can provide these sticks for now charge. The protocol is to rest a flat object (e.g. a clipboard) on the grass and read off the corresponding height from the calibrated sward stick.

Rising plate meters can be mechanical or electronic and work in a similar way to sward sticks, but take into account the height and density of the sward to give a potentially more accurate estimate of biomass. Some plate meters give a compressed height in cm, whereas other convert this height directly to kg DM/ha and have the option of uploading the data to a computer via a USB stick.

Tier 2 NDVI in permanent pastures/leys

As described above, NDVI can also be used to estimate forage biomass either by using a handheld sensor, tractor mounted sensor, or drone operated sensor.

Timing of Forage Biomass Assessments

Forages may be harvested several times during a season, either through mechanical harvesting for hay or silage, or through periodic grazing by livestock. It is therefore important to measure the biomass before each harvest event; these figures can later be summed over the season to give total forage dry matter yield.

Method

As described above, at each sample location four measurements should be taken, each at 90^{o} to the previous one.

Frost damage

Rationale

The microclimate benefits of shelterbelts may be most evident after extreme weather events including periods of frost. Some crops are very susceptible to frost, e.g. maize, potatoes, strawberry blossoms, whereas others are not at risk from frost damage. Monitoring for frost damage should be focussed on those crops that are at risk.

Tier 1 – Visual assessment of damage (leaves, fruit, flowers)

This assessment will be triggered by a recorded frost event and the assessment should take place within 48 hours of that event. The damage should be reported as both:

- Incidence - % of plants in the field that have been damaged
- Severity - % area of affected plant's leaves/flowers that is damaged

Figure 5 Images of crops damaged by frost. Top left: apple blossoms showing characteristic "burning" around the flower edges. Top right: a maize seedling experiencing severe frost. Bottom: a potato plant with frost burn on many of the leaves.

Timing

As stated above: this monitoring would be on an *ad hoc* basis triggered by a recent frost event.

Method

Frost damage should be assessed at each of the three crop assessment locations described above. At each location make four assessments by observing an area ~2x2m square, each at 90^{o} to the previous one (see Figure 4).

Wind damage

Rationale

Shelterbelts should protect the crops from damage due to high winds. The sum effect of wind over the growing season can be made prior to the crop harvest.

Protocols

Tier 1 Visual estimate of damage pre-harvest

Wind damage can cause broken stems, particularly in vegetables and fruit, as well as damage to leaves and lodging in cereals.

Method

In cereals, lodging usually becomes evident later in the season. At some point prior to harvest an estimate should be made if there is some visible lodging in the field. Record this at each sample location; it is not necessary to record at each of the four points of the compass. Instead, record a value for the level of lodging within 5 m of that location.

For horticultural crops like potatoes, report incidence and severity of wind damage in the same way as for frost damage (Figure 6).

Figure 6 Examples of wind damage. A potato plant showing damage from wind on its leaves (left) and a cereal crop suffering from lodging (right).

Disease assessments

Rationale

Diseases may be affected by microclimate, thus shelterbelts may have an impact on disease levels and distance from the trees may moderate this effect. Disease assessment techniques in arable crops are well developed, particularly by organisations such as NIAB. General recommendations for protocols follow.

Protocols

There are a number of foliar diseases commonly monitored in cereals. The main ones for each cereal are listed in Table 2.

Table 2 Main diseases of cereals to monitor in the UK

Cereal	Main diseases
Spring and Winter wheat	*Septoria tritic*i blotch, Yellow rust, Brown rust, Powdery mildew
Winter and Spring barley	Powdery mildew, Brown rust, *Ramularia* leaf spot, *Rhynchosporium* (leaf scald) and Net blotch (*Dreschslera teres*)
Oats	Crown rust, Powdery mildew
Triticale	Yellow rust, *Septoria tritici*, Powdery mildew, *Rhynchosporium* (leaf scald), Brown rust, *Fusarium*
Rye	Brown rust, Powdery mildew, Ergot

Tier 1 Disease assessment

For cereals, an assessment of the disease incidence and severity on the flag leaf, F-1[24], and F-2 leaves at each sample location (at the four points of the compass shown in Figure 4) should be conducted at GS61 (flowering stage). As described above, an estimate of the percentage of leaves affected by the disease should be made (incidence) as well as an estimate of the percentage of leaf area affected (severity).

For potatoes, late blight is the main disease of concern; this is very affected by microclimate. An assessment should be conducted when the blight risk is high (use the Blightspy https://blightspy.huttonltd.com/#/forecast website to assess local risk). Incidence and severity of blight affecting the whole plant at each sample location and point should be recorded.

Figure 7 Potato leaf exhibiting late blight symptoms

For other crops (annual vegetables or perennial fruit trees and shrubs) impacts of any major diseases should be assessed at a critical growth stage.

Insect damage

Rationale

Insects pests may be positively or negatively affected by the presence of shelterbelts, so it is important to monitor their levels. Aphids are particularly a concern for cereals, potatoes and brassicas.

Protocols

Tier 1 - Visual estimates

Cereal aphids are only a problem in some years. Use the AHDB Aphid Monitoring Network to monitor local pressure and assess when pressure is high. This can be done by counting numbers of aphids on ears at flowering.

Peach-potato aphids are pest of brassicas (oilseed rape) and potato aphids are pests of potatoes that transmit viruses. Use AHDB forecasts to determine timing of assessments; and monitor

[24] One leaf below the flag leaf; F-2 is the second leaf below the flag leaf.

when pressure is high. This can be done by mounting a sticky trap[25] on a stake in the field at each of the monitoring locations. Leave the trap for 24 hours, then return and count the number of aphids caught on the trap.

Cabbage Stem Flea Beetle (CSFB) causes serious damage to OSR seedlings soon after they emerge. Monitor damage (Figure 8) at OSR emergence by recording incidence and severity of damage to the seedlings at each of the four points of the compass at each monitoring location.

Figure 8 Oilseed rape seedling showing characteristic shot-holing from cabbage stem flea beetle feeding.

Final Yield

Rationale

The most important indicator of impacts of the shelterbelts on crops will be the final yield of the crop.

Protocols

Tier 1 Hand harvesting

Yields of cereals at each sample location and point can be estimated by taking a “grab sample”. This is normally done by harvesting 1 m of row, cutting at the base of the plant stem. The whole plants should be dried and total biomass recorded. Ideally, the ears should then be cut off and threshed to separate the grain from the chaff. Total grain weight for each location should be weighed.

Total biomass in t/ha and total grain yield in t/ha can be obtained if the row width is known. Typical row widths are 12.5 cm, but make sure to check this before doing the calculation. Below is an example of the calculation for a 1 m row of wheat planted in 12.5 row widths.

1. First, determine the number of 1 m lengths of row in a square meter (100 cm x 100 cm).
   # rows = 100/12.5 = 8

[25] Eco Sticky Insect Traps shown here: https://dragonfli.co.uk/products/large-yellow-eco-sticky-traps?variant=42098660507906&currency=GBP&utm_medium=product_sync&utm_source=google&utm_content=sag_organic&utm_campaign=sag_organic&src=GAds&gad_source=1&gclid=Cj0KCQjwir2xBhC_ARIsAMTXk86pBQsi2QVePwNR8NDqtj0ZS_3CtU4gJcPcICfN0ho_sXHe0wAfwfIaAgceEALw_wcB could be suitable

2. Now multiply the yield for the 1 m length of row by 8.
3. This gives you g/m^2. There are 1 million grams in a tonne and 10,000 m^2 in a hectare, so you need to take the weight in g for 1 m^2 and divide by 100 to get t/ha of grain.
4. The same calculation can be used for the total biomass of the wheat.

Oilseed rape could be harvested by hand in the same way as described for the cereals.

For potatoes, dig a 1 m row in foru locations and record the fresh weight of tubers. Calculation to convert to t fresh weight/ha would be the same as above, using the row width for potatoes.

Adapt these methods for other crops if harvesting by hand.

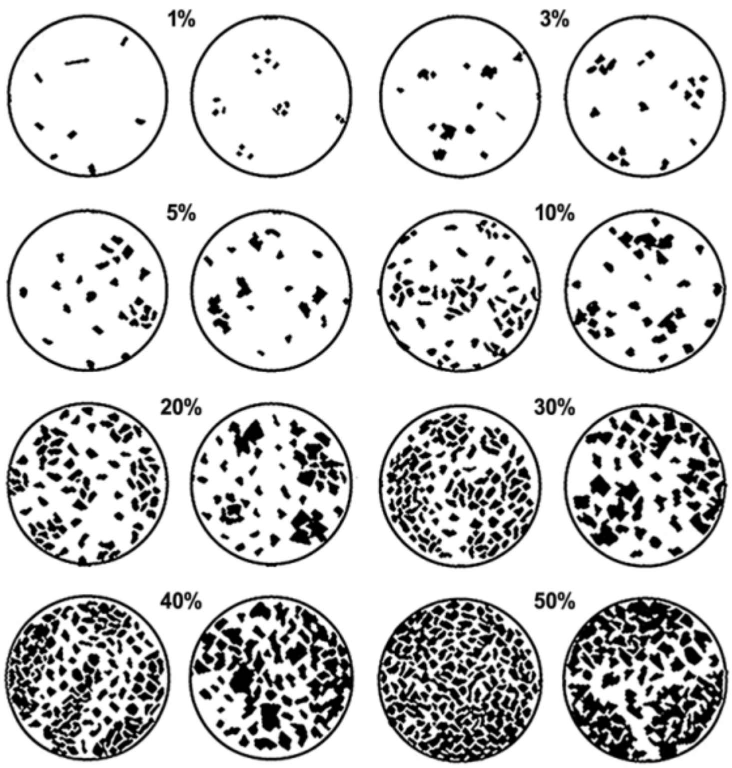
Tier 2 Yield mapping equipment

If yield mapping combines are available, then use the yield maps provided by these to determine the yields at the sample points.

Likewise, if the farm has automated equipment for precision determination of yields, then use this equipment.

Annex 1 Chart for estimating % cover of crops or % disease on leaves

From: Government of Nova Scotia. 2010. Forest Ecosystem Classification for Nova Scotia, Part 1: Vegetation Types



Appendix 6

Optimum Shelter Belts

How to Guide

Monitoring the impacts of Optimum Shelter Belts on farmed animals

Lindsay Whistance, Senior Livestock Researcher

Introduction

The behaviour of domestic animals can be broadly placed into six categories, namely locomotion, maternal, nutritional, reproductive, resting and social behaviour (Phillips, 1993). Access to trees and shrubs can offer benefits to all behaviour categories either directly (e.g., nutritional) or indirectly (e.g., improved ground conditions on locomotory behaviour). The presence of trees also play an important role in the maintenance of homoeostasis since thermal comfort is a key element of this and the subsequent utilisation of energy resources (e.g., Fisher, 2007). Greory (1997) states that '*providing shelter is a moral responsibility*' and whilst shelter is important for animals of all ages, the impacts of inadequate or no shelter are clearest at the start of life.

Lambs born outdoors can lose as much as 10 °C of body heat in the first thirty minutes of life with lamb losses to exposure and starvation combined recorded between 30 to 60 percent, and higher, depending on continent, farm management and seasonal weather conditions (McCutcheon et al., 1981; Kerslake et al., 2005). The presence of good shelter from a well-designed shelterbelt (Fig. 1) can further promote survival to weaning since shelter encourages the ewe to remain at the birth site for longer and the ewe-lamb bond is strengthened resulting in a higher level of care, alongside ongoing temperate conditions for the growing offspring (Alexander et al., 1984).

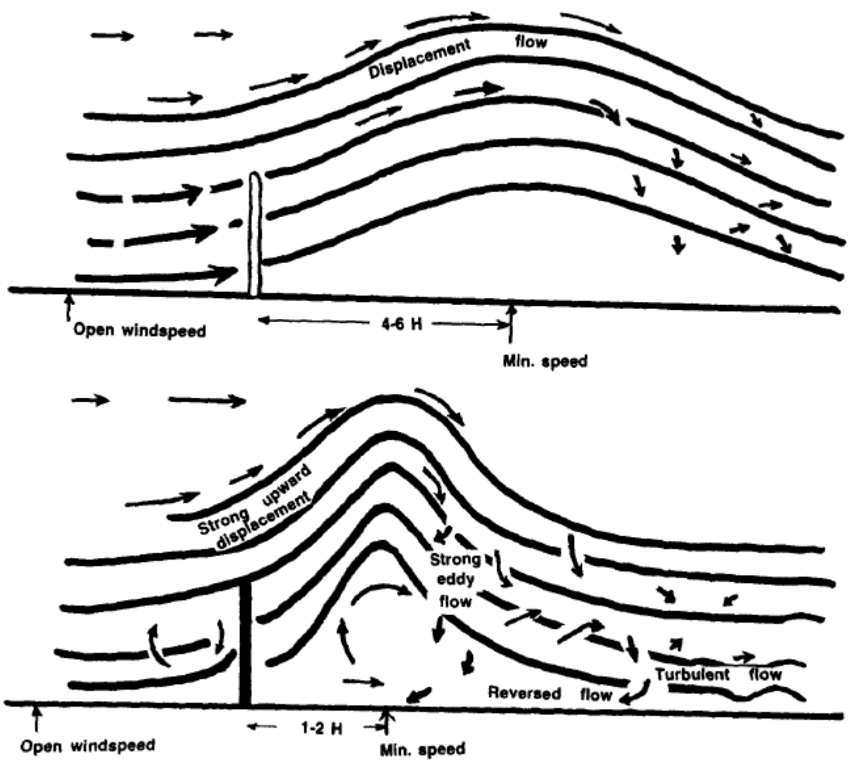


Figure 1: Windflow profiles through a permeable and dense barrier (Gregory, 1995, after Sturrock, 1969).

At a global level, the single most important role that trees play in livestock welfare is the provision of shade. Cooling can take place from reduced solar radiation and from leaf moisture evaporation (Shasua-Bar et al., 2009). When animals are heat stressed, they slow down or stop eating to limit the production of metabolic heat adding to their stress. Non-essential systems (digestion and reproduction) begin closing down, compromising animal and foetus health, alongside productivity e.g., growth rates and milk quality and yield (Fischer et al., 2008; Mitlohner et al., 2001). Digestive issues (a leaky gut from redirecting blood to cooling systems) results in an inflammation cascade and higher levels of mastitis and lameness in dairy cows (Bertocchi et al., 2014).

Although classed as preferential grazers, all livestock species will browse when there is access to trees and shrubs. At the annual level, the average intake of browse for cattle, sheep and goats is 12 percent, 20 percent and 60 percent respectively (Woodland Grazing Toolbox). As Pulido-Santacruz and Renfiro (2011) state, 'living fences' offer good browsing opportunities as well as providing habitat for native flora and fauna. At times, for example, in hot and dry seasons such as UK experienced in the summer of 2018, intake of browse can increase substantially to become the dominant component of the diet at 55 percent for cattle, 76 percent for sheep and 93 percent for goats (Dicko and Sickena, 1992).

In general, browse is a good source of nutrition for farm animals with energy and protein levels in several species comparing well with conventional feeds such as lucerne and ryegrass (e.g., Emile et al., 2016) and offers further benefits including pain relief and parasite control from the presence of plant secondary metabolites. Condensed Tannins (CTs) have a direct anthelminthic effect on gastro-intestinal parasites by limiting the number of larvae maturing to adults, the size of maturing adults and thus the number of eggs produced (e.g., Williams et al., 2014). Studies on sheep and goats show that feeding on tannin-rich browse can reduce faecal egg counts (indicating worm burden) by 50 percent (Min and Hart, 2003). There is increasing evidence of of farm animals being capable of making associations between food containing medication and the treatment of disease (Villalba and Provenza, 2007). The plant secondary metabolite, salicin, is a recognised pain suppressant that humans recognise as aspirin. Salicin has further medicinal properties including anti-inflammatory, antibiotic and antifungal and although it is present across the plant kingdom, it is abundant in some plants including willow and poplar trees.

The shelterbelt is composed of four rows of trees with a total of eighteen different species. A primary objective of the shelterbelt is to offer shelter to crops and livestock and to achieve this, the shelterbelt is composed of 18 species of trees of different heights. There are six trees each of tall, medium and shrub heights which, when planted in rows of increasing height on the side facing the predominant wind, create a sloping profile which minimises turbulence by lifting the wind smoothly up and over the shelterbelt. The six tall trees also offer extended shelter across the landscape (Fig. 1) before the airflow through the shelterbelt and the elevated air re-join and continue at the speed of unimpeded wind. Together with sheltering properties, the eighteen species are also intended to offer browse opportunities to livestock. For livestock, the eighteen species include browsable species such as field maple, hawthorn and hazel alongside goat willow which also offers an established source of the PSMs salicin and condensed tannins.

Focus animals

The dominant species of farm animals present on the OSB project farms are beef cattle and sheep. Therefore, the target animals are these two species considering both adults and youngstock, where present and where possible.

Rationale

The mixed farming systems in the project, with a predominance of arable agriculture, presents challenges for meaningful data collection for the animal focussed data collection since, unlike plant crops, the animals will not always be grazed in the presence of the OSB making it difficult to attribute any longer term outcomes to the presence of the shelterbelt. Nevertheless shorter term impacts can be monitored with protocols developed and adapted to on-farm conditions. Several standard, on-farm management practices involve data collection that is relevant to the trial and this will be utilised/adapted where possible.

It will be important to recognise the level of 'choice' animals face, particularly for the behaviour elements of the protocol, and if there are possible conflicts causing trade-offs between resources. Here, for example, the use of shade/shelter may be compromised by distance to water/feed or the presence of biting flies. Therefore, a clear description of management, available resources and distances between them will be highly relevant to the correct interpretation of results.

The animal protocols will be focussed on evidence of OSB influence on welfare and productivity. Here, productivity is measured as an 'outcome' of welfare status since animals living in low-stress conditions will reduce the 'wasting' of energy on coping mechanisms and thus can better achieve their genetic potential. Evidence of OSB influence will include measuring health status, recording daily activity patterns and social behaviours.

Mortality

Hypothermia (and starvation combined), is one of the biggest causes of lamb mortality and access to shelter for ewes at lambing time can significantly improve survival rates of their lambs at birth. With continued access to shelter it can also improve survival rates to weaning.

Where relevant and possible, the same data will be collected for cattle though block calving and year-round calving will need to be distinguished form each other. In both species, adult mortality rates and causes will also be recorded.

Equipment: Data sheets. On-farm records typically include both new-born and weaned survival figures and, if not already, cause of death will be included.

Morbidity

An increasingly large body of research on dairy cattle illustrate the strong link between compromised thermal comfort and a range of diseases. Furthermore, grazed animals are at risk of gastro-intestinal parasite burdens. Tier 1 will utilise on-farm health records and management including treatments, faecal egg counts and production records for measures strongly linked to diseases (e.g., heat stress and fertility). Alongside health records, on-farm feed input and liveweight/growth rate records will support data on animal health status.

Equipment: On-farm records (paper or app-based) modified to include required data:

Health records (illness and treatment);

Fertility records (number of attempts/length of time and number of barren animals);

Anthelminthic treatments FEC records;

Liveweight/growth rate records

Feed records

Animal use of resources

High welfare animal systems include offering animals an enriched environment where they can find what they need when they need it. As Sommerville and Jones (2013) stated, '*achieving a high quality of life for farm animals requires provision rather than deprivation*'. Animal observations and use of resources would indicate whether the presence of shade and shelter supports the animals to behave normally (e.g., thermal stress compromises normal, daily patterns of activity and feed intake) thus indicating low stress conditions.

Tier 1/2 data collection relies upon the presence of a person recording animal activity for a set period of time using a prepared ethogram (repertoire of appropriate behaviours for species and age groups being observed) and a check sheet for data recording. This level is recorded as both Tiers 1 and 2 since, whilst it is not overly difficult to measure behaviours, (particularly with a detailed ethogram as guidance and a well-designed check sheet), it can be time consuming and requires long bouts of directed focus regardless of weather conditions. It also requires some knowledge of the animal being observed to maintain the safety of both animals and humans. Tier 2 includes use of activity and location data loggers such as Nofence collars (Fig. 2), which, with virtual fence programming disabled, would provide reliable, 24-hour data for field and resource use. Alongside GPS tracking data, temperatures in specific locations could be measured either with the use of anemometers (where available) or with thermometers designed for use with livestock and wildlife which are more robust and can be left in situ reducing human presence and influence on the animals (Fig. 3). Tier 2 could also include the use of the woodland herbivore assessment, alongside its use in the biodiversity protocol for assessing and measuring deer-OSB interactions.

Figure 2: Nofence collars and app, a (virtual fence) GPS tracking system for livestock

An advantage of using technology is the absence of humans, whose presence may influence how animals use the landscape. A drawback can be the loss of environmental data which may explain animal movements (e.g., aversive stimuli such as loud noises or the presence of a predator) though these are typically exceptional events. An additional measure for Tier 2 is the use of technology to measure skin temperatures. Standard thermal stress thresholds are largely assumed for all livestock species being based on losses in productivity rather than actual animal measures. Understanding when animals are choosing to seek shade and shelter would be a major step forward in our understanding of thermal comfort at the animal level.

Figure 3: examples of existing animal temperature data loggers. The Kestrel data logger is focussed on heat stress where the Tinytag measures a range of -40 to +85 ^{o}C allowing for cold stress to be measured.

The gathering of behavioural data will indicate location, time spent in location and the activity in each location including behaviours such as resting, grazing, and social behaviour. These data will indicate overall use of space and available resources. This may provide information at two levels, depending on length of time spent in fields adjacent to the shelterbelt. The first level is 'whole picture' information showing daily and seasonal changes in behaviour and patterns of use. The second level is 'key episodes' which may be of animal-based or weather related and of shorter duration compared to the whole picture data. These key episodes include lambing or calving periods and, for example, a heatwave.

Since the presence of trees is considered to have a positive and calming influence on animal groups, the data collected will also include social behaviour, both positive and negative, such as grooming and head-butting respectively. A repertoire of expected social behaviours will be developed in an ethogram and recorded as counts data.

Equipment: ethogram of different behaviour patterns including daily activity and social interactions alongwith maternal/juvenile behaviour, check sheets for recording behaviour in person, animal mounted data loggers with associated apps, environment mounted temperature data loggers.

Direct access to the OSB

Where animals are allowed direct access to trees in the shelterbelt, evidence of browsing will be recorded alongside body rubbing on branches as evidence of individual body care.

Browsing behaviour can be measured by direct observations or by independent inspection of the OSB for browse damage. Here tree and shrub species should be recorded and an assessment of the percentage of available stems browsed. The diameter of browsed stems can also be recorded to indicate changes in browsing behaviour over time. The number/frequency of observations will be determined by season, how often and how long the animals have access to the trees. Recording of browse behaviour may be supplemented with nutritional analysis of browsed species alongside grazed fodder analysis.

Body rubbing reduces an animal’s heart rate thus contributing to a low-stress state. The physical act of rubbing reduces dead hair and skin (helping with thermoregulation) and removes external parasites and seeds which can penetrate the skin (contributing to overall health). When they have access to rubbing posts, animals spend time every day on body maintenance. In the absence of rubbing posts, anecdotal evidence shows that sheep are more likely to use the ground for rubbing increasing the risk of getting cast and being attacked/blinded by corvids. As part of the daily repertoire of behaviours, body maintenance behaviours will be recorded along with the object being rubbed on. An independent record of rubbing spots can also be taken, noting evidence of dusty, hairy branches and loss of grass where the animals are standing to rub.

Equipment: Ethograms of specific behaviours, check sheets for data entry.

As an additional illustration of animal interactions, for each category, photographs will be taken where possible.

Equipment: camera or camera app on smart phone.

Appendix 7

Optimum Shelter Belts

How to Guide

Monitoring the biodiversity benefits of your Optimum Shelter Belt

Will Simonson, Principal Researcher in Agroforestry

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 stress. They beautify the landscape and also support biodiversity. They offer sources of feed, nesting and shelter for insects, birds and mammals, and provide habitats and corridors for wildlife that are becoming the theme of many national biodiversity strategies. This *How to* guide supports the standardised monitoring of the biodiversity benefits of establishing OSBs at 20 sites. It is hoped that the results, quantifying any changes attributable to the presence of the OSB, will be of great interest to landowners and many categories of professionals.

General approach

Biodiversity is a measure of variation at the genetic, species, and ecosystem level. Its measurement therefore needs to encompass different scales, but clearly not everything can be recorded. For this reason the biodiversity monitoring protocols focus on a complementary set of proxies and taxonomic groups that, together, are indicative of overall biodiversity value and provide a meaningful narrative about the food web. They are therefore also referred to as 'indicators', which must be practicable to measure, robust, and sensitive enough to pick up realistic changes over relatively short timespans (several years).

There are many different biodiversity monitoring schemes and methods in existence and this current set of protocols is aligned to some of the most relevant. Of particular note are:

- the biodiversity indicators being developed as part of the Global Farm Metrics initiative. These are still being finalised but include areas of habitats, connection to off-farm habitats, and birds as an indicator species for habitat quality;
- the Hedgerow Biodiversity Protocol developed by ORC in 2105 under the TWECOM project;
- work by Centre for Ecology and Hydrology (CEH) in defining hedgerow Favourable Conservation Status (FCS);
- the AGROMIX project (Horizon 2020) biodiversity sampling protocols.

Eleven indicators have been selected, comprising six indicators that describe the habitat and its value for wildlife, and six indicators focussing on important groups of species. The habitat indicators are habitat structure and connectivity, vegetation composition (of both the woody species in the shelter belt as well as the ground flora at its base), dead wood, and berries and flowers (as food sources). The species group indicators are breeding birds, small mammals, butterflies, bumblebees, soil fauna, and pests and invasive species.

The protocols also recognise the varying level of interest and knowledge of those undertaking the monitoring, addressing this by providing, for each biodiversity attribute, a two-tiered approach. Tier

1 represents a basic measurement providing the minimum level of detail needed to track change over time. It is divided into Tier 1a and 1b with the latter reflecting the scope to record additional, valuable detail. Tier 2 represents a more advanced measurement and therefore methodology, sometimes requiring additional equipment. The tiers of measurement for the 12 indicators are summarised in Table 1.

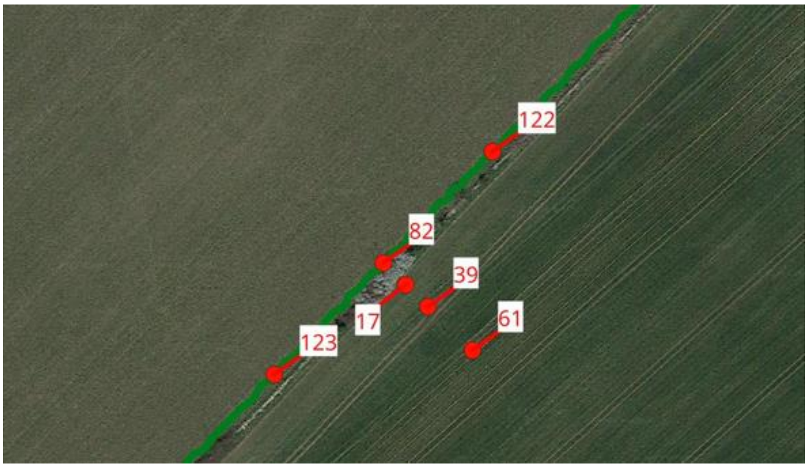
Table 1: Biodiversity monitoring indicators and tiers of measurement.

Indicator	**Measurement level**		
	Tier 1a	**Tier 1b**	**Tier 2**
Habitat and food			
Habitat structure	Presence of standard trees, shrubs and other structural components	Quantification of structural components along the OSB, with height information	Calculation of foliage height diversity
Habitat connectivity	Presence of large gaps and connections between OSB & other semi-natural features	Continuity of canopy along hedgerow (% gaps)	Connectivity modelling using LandApp Wild Edge and Guidos toolkit
Vegetation composition – woody plants	Variety of woody plants	Species richness and abundance of woody plants	Species diversity of woody species per 30 m
Vegetation composition – ground flora	Cover/abundance of main plant types at centre and edge of OSB	Cover/abundance of plant species at centre and edge of OSB	Comparison of OSB plant communities with other on-farm habitats: NVC, ordination and similarity
Dead wood	*Dead good Deadwood* survey of quantity of deadwood	*Dead good Deadwood* survey of quantity and age of deadwood	*Dead good Deadwood* survey of quantity and age of deadwood with additional volume calculation
Food supply	Abundance of berries, nuts and flowers	Species diversity and abundance of berries, nuts and flowers	[No Tier 2 protocol]
Indicator groups:			
Birds	Abundance of birds using the OSB & adjacent field	Abundance of different species of birds using the OSB & adjacent field	Breeding Bird Survey counts
Small mammals	Density of runways and burrows made by small mammals	Additional search for dormice evidence (OSBs with hazel only)	Species identification using footprint tunnels
Butterflies	Abundance of butterflies using the OSB & adjacent field	Abundance of different species of butterflies using the OSB & adjacent field	UK Butterfly monitoring Scheme transect
Bumblebees	Abundance of bees using the OSB & adjacent field	Abundance of different species of bees using	BeeWalk monitoring

		the OSB & adjacent field	
Soil fauna	Abundance of earthworms	Abundance and weight of the three main different types of earthworm	Soil Biological Quality Index (QBS)
Pest and invasive species	Levels of tree leaf browning and yellowing along the OSB as well as presence of grey squirrel and muntjac deer	Pests and diseases of specific tree species identified	Woodland herbivore impact assessment

Sampling design

Where relevant to the indicator concerned, sampling for each OSB should follow the T-shaped design shown below. This is further described in the introductory material for the the OSB monitoring protocols.



Protocols

Habitat structure

<u>Rationale</u>

More structural complexity results in a greater range of habitat niches, a pattern observed for many different taxonomic groups (Simonson et al 201). For hedgerows, structural complexity is known to be a key attribute for invertebrates, birds, mammals and plants, with the multiple structural components (including associated banks, ditches and other features) allowing more species to complete their life cycles. For example, the majority of invertebrates benefit from denser, more complex hedgerow structures (e.g. Maudsley, Seeley and Lewis 2002).

Trees in shelterbelts and hedgerows add to this important habitat heterogeneity and Merckx et al. (2009) found that the presence of hedgerow trees resulted in a substantially higher abundance

(+60%) and species richness (+38%) of larger moths in the immediate landscape compared to similar landscapes without hedgerow trees. Slade et al. (2013) showed that trees outside woodlands – especially when part of a hedgerow network - act as “stepping stones” for macro-moths moving across an agricultural landscape. For this reason trees have been described as ecological keystone structures with a disproportionate effect on ecosystem functioning. Trees provide habitat for lichens, are a rich source of seed, fruit and invertebrate food, and provide song posts and cavity nesting sites for birds.

The Tier 1 protocols are adapted from the PTES Great British Hedgerow Survey guidelines and draws from the Definition of Favourable Conservation Status of Hedgerows (Staley et al 2020). The Tier 2 protocol is based on the method of calculating Foliage Height Diversity (FHD) described by Simonson et al (2012) *Conservation Biology*.

Tier 1a protocol

For a typical 40 m stretch of the OSB, walk down its length and record which of the following structural components are present (noting definitions):

1. Ditch;
2. Bank;
3. Marginal vegetation: a strip of developed perennial ground vegetation to the side of the OSB, differing from the vegetation of the adjacent field. It may include brambles, grass or other perennial herbs;
4. Basal vegetation: a developed ground layer of vegetation at the bottom of the OSB;
5. Shrub layer: woody plants and small trees in the height range 0.5-4 m;
6. Standard trees: trees > 4 m high and emerging from the canopy of the shrub layer.

The resulting score will be in the range 0-6. For hedgerows, three criteria for the achievement of Favourable Conservation Status are the presence of one standard tree per 40 m length, and the presence of at least three of the structural components. Additionally, a gap between the ground and the base of the shrubland canopy should be < 0.5m. Note down if this is the case for the OSB.

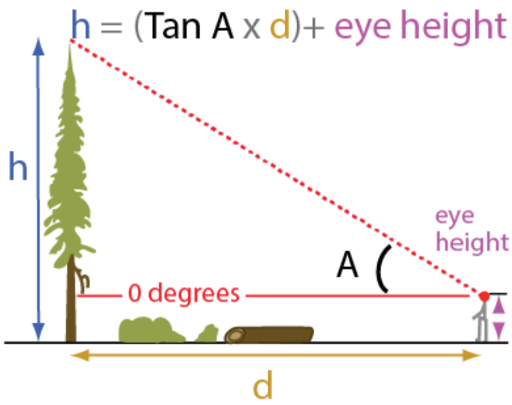
Equipment/resources: Data entry sheet.

Tier 1b protocol

In this version of the Tier 1 protocol the presence of the six different structural components is quantified over the length of the whole OSB, and some height information is also recorded.

Walking along the OSB and every 10 paces (equating approximately to 10 m) record which of the structural components are present. Also count the number of standard trees.

Within each 10 m section, also estimate the average top height of any tree canopy and the top and bottom height of the shrub canopy. The latter can be measured with the help of a 2 m pole marked in 10 cm intervals. Top heights above 2 m can be estimated by eye to the nearest m. For the tree height, first select a tree that appears to represent the average tree height within the 10 m section. The easiest way to then measure the height is with a clinometer or inclinometer, following the maker's instructions.



Credit: University of British Columbia

In the absence of this equipment, the following method using a ruler is an alternative method. Stand far enough away from the tree where you can see the entire tree in your field of view. Hold the ruler upright in your hand with your arm extended out fully. Line the ruler up with the tree so the top of the ruler aligns with the highest point of the tree; mark on the ruler with your thumb the tree base. Keeping your arm extended, turn the ruler 90 degrees. Either have your measuring assistant stand at the point on the ground out from the tree where you see the ruler end or note the point where the ruler ends. Measure the distance from either the person or the spot to the tree base, this distance is equivalent to the tree's total height.

Tip: It would be efficient to combine this survey with that for habitat connectivity.

Equipment/resources: Data entry sheet, in(clinometer) or ruler, long measuring tape, 2 m pole.

Tier 2 protocol

This protocol is for the calculation of a metric used to describe the distribution of canopy cover across different height strata: Foliage Height Diversity (FHD). The diversity index is calculated by the Shannon Diversity Index equation used for species diversity.

At the three sampling points along the OSB (see sampling strategy), three replicates of the following method are to be undertaken, at 10 randomly chosen spots, each at least 1 m apart. See Equipment (below) for a description of the pole and disk needed for this method. Stand the pole vertically and pass the disk up it noting if it makes contact with vegetation (branches, twigs and leaves) as it passes up through each height interval of: 0–25 cm, 25–50 cm, 50–100 cm, 1–2 m and 2–4 m. Then looking up the pole, estimate if the disk would make contact with vegetation higher than 4 m.

Sum the number of vegetation contacts in each height interval for the 3 x 10 sampling points in the OSB and then calculate the Shannon diversity index using the formula:

$$\sum_{i=1}^{S} (pi \ln pi)$$

where p is the proportion of contacts with the sampling disk for a given height interval to the total number of contacts for all height intervals. The Excel data sheet makes this calculation for you once the data is entered.

Equipment/resources: Data entry sheet. A 4 m pole made of bamboo or similar, marked off in the height intervals 25 cm, 50cm, 1 m, 2 m and 4 m. A plastic disk of approximately 20-25 cm diameter with a hole cut in the middle so that it can pass up and down the pole.

Habitat connectivity

Rationale

Optimum Shelter Belts, as part of a wider network of hedgerows and other linear semi-natural features, represents an important ecological infrastructure allowing movement of species across the landscape. This may be for daily foraging, as in the case of mobile species such as bumblebees, bats and small mammals. But there is also (more limited) evidence of migration and population dispersal using these woody ecological corridors, for example in response to climate change.

For OSBs to function well in allowing species movement, good connectedness is important. For example, some species of bats and small mammals avoid hedgerows with gaps (Feber et al. 2019).

It is worth noting that there can be a downside to connectivity to the extent that it may allow the spread of pests, diseases and even (e.g. for linnets) predation (e.g. by corvids).

The Tier 1a and 1b protocols are based on connectivity criteria for the Favourable Conservation Status of hedgerows; no gaps > 5m and horizontal gappiness < 10% of total length. The Tier 1b protocol is based on the Hedgerow Survey Handbook (Defra).

Tier 1a protocol

Walk the whole length of the OSB and note down the presence and length of any gaps in the woody cover of greater than 5 m, estimated by one pace = 1 m. At each end of the OSB, also note whether it connects (i.e. there is a gap of no more than 5 m) to a hedgerow, woodland, or other wooded habitat feature.

Tip: Access points are not included as gaps for the purposes of condition assessment for this attribute, because 5m is about the standard gate width in some areas

Equipment/resources: Data entry sheet.

Tier 1b protocol

As per Tier 1a, but in this case record gaps of greater than 1 m. From knowledge of the total length of the OSB, on the recording form use your data to calculate the total horizontal gappiness in % (total length of gaps/total length of OSB x 100).

Tip: Gaps must be complete breaks in the canopy; overlapping canopies (trees, shrubs) are not considered as gaps.

Equipment/resources: Data entry sheet, calculator for calculation of horizontal gappiness.

Tier 2 protocol

In this researcher led protocol, Land App Wild Edge, Guidos toolkit and Condatis (circuit theory based) connectivity modelling approaches will be used to study the increase in landscape connectivity on the farm resulting from the establishment of the OSB. The four measures of semi-natural habitat developed by Wild Edge are: connectedness (%), unconnected components (total number), core to edge (%, and indication of proportion of farmland close to semi-natural habitat and benefiting from their beneficials) and semi-natural habitat amount (%).

Vegetation composition – woody species in the shelter belt

Rationale

A high diversity of animal species is often associated with the richness of the flora. For an Optimum Shelter Belt, the flora consists of the woody species (trees and shrubs) and the ground flora of herbaceous species. These two components are largely independent, and the latter are the focus of the separate protocol below.

A good mix of woody species provides a range of resources and has been shown to benefit bird species richness (Arnold 1983), pollinating invertebrates (Staley et al. 2018) and invertebrate numbers in general (Garratt et al. 2017). Dormouse population density in hedgerows is strongly influenced by shrub diversity.

For this reason one of the measures of the Countryside Survey for the quality of hedgerows is the mean number of native species per 30 m length. The average for England is 3.7 (Carey et al 2008), and this is an attribute included in the Hedgerow Survey Handbook (Defra 2007). Research in Devon, Lincolnshire, Cambridgeshire, Huntingdonshire and Northants, has found that hedgerows, on average, gain one woody species roughly every 100 years, per 30 metre length (Pollard et al, 1974).

Tier 1a protocol

The woody species survey can be undertaken at any time of year but will be easiest when the deciduous shrubs and trees are in leaf.

Walk 30 m along one side of the OSB and, looking across its width, note down how many different kinds of woody species you see. For this purpose, a woody species will be at least 0.5 m high (seedlings are to be excluded).

Tip: Include ramblers and climbers such as bramble, honeysuckle and ivy, even though they are ubiquitous and not an indicator of shelterbelt quality.

Equipment/resources: Data entry sheet. A list of woody species native to England (and Wales) can be found in the Hedgerows Regulations 1997 (Schedule 3). This information can also be found in the Hedgerow Survey Handbook (Defra 2007, Appendix 11).

Tier 1b protocol

As for Tier 1a, walk a 30 m length along one side of the OSB, but this time record which woody species you see and how many there are of each. For trees/shrubs which are not immediately recognisable, give them a descriptive short name, take a leaf/flower/fruit sample in a bag, and try to ID the sample on return from the survey.

On the recording form and with recourse to a guide or online source, note which species are not native. (A quality indicator for hedgerows is that non-native species make up <10% of the total.)

Tip: You may find it easiest to demarcate short sections of the OSB with long tapes that you peg across its width as you go along, to aid counting.

Equipment/resources. As per Tier 1a, plus an identification guide for shrubs and trees such as the Collins Tree Guide by Owen Johnson, or a plant identification app.

Tier 2 protocol

The difference between species richness and species diversity is that the latter takes into account not only how many species are present but also how evenly distributed the numbers of each species are. This Tier 2 protocol collects the same information as Tier 1b, but calculates the Shannon Diversity Index, a commonly used index in ecology.

To calculate the index for your shelterbelt either enter your Tier 1b data into the online Shannon Diversity Index Calculator (see link below) or else into the Excel spreadsheet calculator tool provided with this protocol.

Tip: With this index, 1 represents infinite diversity and 0, no diversity. Don't expect high numbers!

Equipment/resources: as per Tier 1b, plus the online calculator (https://www.omnicalculator.com/ecology/shannon-index) or OSB Excel calculator.

Vegetation composition – herbaceous species in the bottom

Rationale

High animal species richness is linked to high plant species richness, both of woody species (trees and shrubs) and of herbaceous plants.

The ground flora is an important component of OSBs and can contribute significantly to species diversity. Ground flora also provides an important food resource to a wide range of wildlife such as butterflies and bees. The centre of a mature OSB may develop a ground flora (for example of some shade-tolerating species) that is distinct from that at the outside edge, and this is reflected in the sampling design.

For example, those next to ungrazed grasslands or arable fields may be dominated by tussocky grasses, while those next to fields that receive high levels of fertilizer input are often dominated by nettles (Urtica dioica) or goosegrass (Galium aparine). Occasionally, hedge bottom floras are remnants of former species-rich grassland (Wilson 2019). In other instances, the flora is rich in herbs that include ancient woodland indicators (Garbutt and Sparks 2002), as with many lane-side ancient Devon banked hedges (Devon County Council and The Devon Hedge Group 1997). There is evidence the number of woodland indicator species in some hedgerows is reducing (Smart et al. 2001, Garbutt and Sparks 2002).

Protocols Tier 1a and 1b are adapted from the TWECOM Hedgerow Biodiversity Protocol 2015 and the AGROMIX biodiversity protocols.

Tier 1a protocol

The survey should ideally be carried out between May and June.

Identify a representative section of the OSB and place two 2m x 1m quadrats 10 m apart at the edge. Aim to survey the ground flora influenced by the OSB rather than by the adjoining land use, by placing the quadrats as close to the woody stems as possible.

For each quadrat, use the DOMIN scale (Table 2) to record the cover/abundance of each main type of ground flora: grass-like plants (grasses/sedges/rushes), forbs (broadleaved herbaceous plants), woody perennials (e.g. tree seedlings), mosses/lichens, as well as the cover of bare ground.

Table 2: DOMIN scale.

Value	Visual estimate of cover
+	1 individual, with no measurable cover
1	<4% cover with few individuals
2	<4% cover with several individuals
3	<4% cover with many individuals
4	4-10% cover
5	11-25% cover
6	26-33% cover
7	34-50% cover
8	51-75% cover
9	76-90% cover
10	91-100% cover

Repeat the method for a further two quadrats located as close as possible to the centre line of the OSB, parallel to the original two quadrats. For these quadrats, continue to focus on the ground vegetation and not the shrub/tree layer.

Alternatively (from FCS report): Critchley et al. (2013), using more recent Countryside Survey data, developed an alternative, functional, classification of herbaceous hedgerow flora, to guide restoration work. Thirteen different vegetation types in six broad groups were identified. The broad groups were woodland herbs, species-rich or semi-improved grassland, rank grassy vegetation, species-poor pasture, disturbed arable and sparse vegetation.

Equipment/resources: Data entry sheet, 2 m x 1 m quadrat.

Tier 1b protocol

As per Tier 1a, but for each quadrat, use the DOMIN scale to record the cover/abundance of plant species present with a cross or tick mark on the ground flora data entry sheet. The species list on the ground flora data entry sheet is not exclusive. The list may need to be adapted to include frequently occurring species in your locality. Space has been left to record other species present. From the list and supplementary information, note down which species are non-native. The threshold for Favourable Conservation Status of hedgerows is <10% non-native. Additionally, what is the combined cover within the quadrats of nettles, cleavers and docks? The FCS threshold is < 20% for nutrient enrichment.

Tips: If the species cannot be identified, either note the genus or family or give the plant a name/short descriptor. Specimens can be collected for identification if that is a possibility later.

Equipment/resources: Data entry sheet, quadrat, Plant identification guide (e.g. The Wild Flower Key: How to identify Wild Flowers, Trees and Shrubs in Britain and Ireland by Francis Rose, 2006, and

Grasses, Sedges, Rushes and Ferns of Britain and Norther Europe – a Collins Picket Guide by Richard Fitter and Alastair Fitter, 1984), Plant ID apps (e.g. Seek).

Tier 2 protocol

In this researcher led protocol, quadrat-based surveys will be undertaken of the flora of the OSB and comparison habitats (hedgerows, field margins, meadows) and the results studied through National Vegetation Classification (NVC) communities, ordination analysis and similarity indices.

Dead wood

Rationale

Decaying wood originating from shelter belt shrubs and trees is important for saproxylic fungi, invertebrates and other species including threatened and scarce species. Its quality and abundance are heavily influenced by shelterbelt management. Retention of any veteran trees in the line of the shelterbelt is obviously critical, but other dead wood associated with snags, windblown trees, stumps and fallen branches also provides valuable habitat.

Tier 1a, 1b and 2 protocols are all based on The Conservation Volunteers *Dead good Deadwood* survey and UK Forestry Standard for deadwood.

Tier 1a protocol

Walk 100 m or 100 paces of the shelterbelt and look across its width mapping on a data sheet the locations of large pieces of deadwood. Large pieces are defined as being more than 20 cm in diameter and 2 m long. Each piece should be recorded as one of five categories: veteran tree, tree stump, snag, windthrown tree or fallen log. See the survey booklet (link below) for further information.

Equipment/resources: Data entry sheet, Deadwood survey booklet, field guide, tape measure.

https://www.tcv.org.uk/scotland/dead-good-deadwood-survey/

Tier 1b protocol

For this protocol, the Tier 1a survey is carried out but with the recording of additional information (Form B of the Deadwood survey protocol) that helps estimate the age of each piece of deadwood. This involves measuring the piece of deadwood, looking at the surface of the deadwood and inside the deadwood. See the survey booklet (link below) for further information.

Equipment/resources: Data entry sheet, Deadwood survey booklet and field guide, tape measure.

Tier 2 protocol

Carry out the survey as per Tier 1b. Additionally, using the measurements of the pieces of deadwood, calculate the volume of each by assuming cylinder shape and applying the equation Volume = length x $(\text{diameter}/2)^2$ x 3.14. Estimate the total deadwood volume per hectare (10,000 m^2) by summing the volumes of the pieces and multiplying the total by 20. This assumes a 100 m transect and that the OSB is at the specified 5 m width. For comparison, Scottish Forestry advises a threshold of 20 cubic metres of deadwood (excluding stumps) per hectare for woodland.

Equipment/resources: Data entry sheet, Deadwood survey booklet, field guide, tape measure.

Food supply: berries, nuts and flowers

Rationale

A plentiful supply of nectar and pollen, provided by diverse species of woody and herbaceous plants from early spring to late summer, is desirable. So too, is a plentiful winter supply of berries from multiple woody species.

Hedgerow flowers are used by a wide range of invertebrate species, feeding on pollen, nectar and the petals. The quantity of hedgerow flowers was included in a recent assessment of farmland floral resources needed to support six focal pollinator species (Dicks et al. 2015), demonstrating their role in supporting pollinator populations. Also, the length of season that flowers are available is important, e.g. willow catkins and blackthorn flower early in the season, through to late-flowering ivy (Staley et al. 2018). Pollinators emerging in early spring (e.g. queen bumblebees) may be particularly dependent on early hedgerow floral resources, due to the shortage of other flowering resources at this time in the wider agricultural landscape (Dicks et al. 2015). Hedgerow berries provide a food resource for overwintering bird, mammal and invertebrate species, with hawthorn berries favoured by thrushes species (Sparks and Martin 1999). Many invertebrate species feed on the fleshy fruits of woody hedgerow species, around a quarter of which are classified as rare or scarce (Jefferson 2004). Ten of the 18 most threatened mammals in Britain rely on the fruits and berries of hedgerows (OPAL Biodiversity Survey Guide).

Tier 1a protocol

Carry out the following survey twice in the year: in the late Spring/Summer to capture flowering plants in the margin of the shelterbelt and autumn to capture nuts and fruit (hazelnuts, rose hips, etc.)

Following the OPAL Citizen Science Biodiversity Survey guide, estimate the number of berries, nuts and flowers in a 3 m stretch of OSB according to the following ranges: 0, 1-10, 10-100, 100-1000, > 1000. Repeat for two more 3 m stretches. Record the results separately for the basal/marginal ground vegetation and the woody vegetation of the shelterbelt.

Tip: Placing two poles at either end of the 3 m section and then standing back to study the vertical profile of the OSB, can help the count estimation. Count inforescences of small flowers and fruits (e.g. elder flowers and berries) as one unit.

Equipment/resources: Data entry sheet, OPAL Citizen Science Biodiversity Survey guide, measuring tape and poles

Tier 1b protocol

In this version of the Tier 1 protocol, note down the different species of berry, nut and flower as well as the abundance score for each separately for the OSB and its base/margin (as per 1a). Shannon diversity index using the formula:

$$\sum_{i=1}^{S}(pi\ln pi)$$

where p_i is the proportion of the entire number of food items made up of species i. For the purposes of this calculation the media value of each abundance range should be used (i.e. 5, 55 and 550; above 100 try to arrive at a visual estimate to nearest 500). The Excel data sheet makes this calculation for you once the data is entered.

Equipment/resources: As per Tier 1a. Standard field guides are the best means of identifying plant species from the leaf if not flower and fruit.

INDICATOR GROUPS

Breeding birds

Rationale

Hedgerows are one of the most important surviving semi-natural landscape features for birds. They provide nesting, foraging and roosting sites and provide cover and facilitate movement across the landscape. Birds can be used as bioindicators due to their ecology being well understood and the existence of links between bird community, vegetation associations and territories. Birds are also easily detected giving not only presence but also abundance. One area of interest is the presence of nesting birds and to assess whether the sloping profile of the OSB attracts different species of nesting birds associated with both tree canopies and hedgerows.

As many as 16 out of the 19 birds used by Government to assess the state of farmland wildlife are associated with hedgerows, with 10 using them as a primary habitat (Staley et al 2020).

Protocols Tier 1a and 1b are adapted from the Game and Wildlife Conservation Trust (GWCT) Big Farmland Bird Count and the TWECOM Hedgerow Biodiversity Protocol 2015.

Tier 1a protocol

The survey should be undertaken once in April/May and once in May/June, preferably on a sunny day. If possible, the survey should take place between 6 and 9 am as this is when birds are most active. If at another time, try to make this consistent across years/counts.

Spend 30 minutes walking down one side of the total length of the OSB recording the number of birds seen (a) in the OSB and its immediate environs, and (b) in the open field on your other side. Enter the data as you go using the bird data entry sheet. In the case of (a), the data entry sheet will prompt you to distinguish the birds observed in the marginal/basal ground vegetation, the shrubby layer, and (if relevant) the taller tree canopy. Note the start and finish time of the survey and make additional notes where indicated in the data entry sheet on observations of interest, such as nests observed, any dead birds or signs of a bird kill.

Tip: Walk the length of the OSB at a slow, methodical pace, not lingering in hotspots to improve your count. Some birds may be flushed from their resting places and move along the OSB ahead of you. As far as possible, try not to repeat count these birds. For the OSB count, don’t record birds flying overhead (i.e. birds not obviously using the OSB) although do note them under additional observations (see above).

Equipment/resources: Data entry sheet, Binoculars.

Tier 1b protocol

As per the Tier 1a protocol, but in this case record both the species and number of birds seen.

Equipment/Resources: Data entry sheet, Binoculars, Bird survey sheet listing common farmland bird species and Biodiversity Action Plan (BAP) species, Bird identification guide (e.g. RSPB Birds of Britain and Europe by Rob Hume (2014) or Collins Bird Guide by Lars Svensson and Killian Mullarney (2010), Bird identification app (e.g. Merlin).

Tier 2 protocol

BTO Breeding Bird Survey: BBS monitors the population changes of 118 breeding bird species across the UK, involving almost 3,000 volunteers who survey their randomly selected 1-km square each spring[26]. The survey involves two early-morning spring visits to a local 1-km square, to count all the birds you see or hear while walking two 1-km lines across the square. Further instructions and a recording form can be found here. Opportunities should be sought to integrate data from relevant BBS survey squares with the Tier 1a and 1b OSB bird monitoring results.

Small mammals

Rationale

Shelterbelts and hedgerows are important habitat and transport corridors for small mammals including wood mouse, yellow-necked mouse, bank vole and common shrew. Species such as harvest mice, field voles, pygmy shrews and water shrews may also venture into these areas. Dormouse, a Biodiversity Action Plan species, is associated with good quality hedgerows in southern Britain, while the group as a whole is of conservation importance due to recent declines. The amount of ground cover, and hedgerow condition (lack of gaps) has been found to be important for some small mammal species (Kotsageorgis and Mason, 1997).

The Tier 1b protocol is based on the PTES Dormouse Nut Hunt. The footprint tunnel (Tier 2 Protocol) is based on the survey of urban hedgerow mammals by Atkins et al (2008).

Tier 1a protocol

Typical habitat for small mammals is a matrix of interconnecting runways through grass and leaf litter that they use in both the day and night (Barnett & Dutton 1995). In this Tier 1a protocol, the idea is to assess the density of runways within quadrats, comparing the centre of the OSB with the grassy margin at its edge and the crop or pasture field to its side.

Using the sampling scheme shown in Figure 1, at each of the three positions along the OSB, mark out a 2 x 2 m quadrat using pegs and measuring tape. Within the quadrat, look for the presence of runways. What do they look like? For voles they are usually 40-50 mm wide and typically lie slightly below the surface of the ground, as voles keep runways clear by clipping vegetation and create small ruts through repeated use (Cook et al 2004). Runways of other small mammals will be similar.

Having identified any runways, estimate their total length using a tape measure or by visual comparison with the 2 m side of the quadrat.

Also note down the number of any active small mammal burrows that you find within the quadrat.

Having undertaken the six quadrats along the OSB, carry out three more in the field at increasing distance from the OSB as shown in Figure 1.

Tip: To assess if a burrow is being actively used, peer into its entrance and see if there is an accumulation of detritus in it or if it is covered with a spiderweb or other tell-tale signs of disuse.

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[26] https://www.bto.org/our-science/projects/breeding-bird-survey/taking-part

Equipment/resources: Data entry sheet, long tape measure, pegs (e.g. tent pegs).

Tier 1b protocol

Carry out the Tier 1a method but for the three quadrats in the centre of the OSB, make a careful search for hazelnuts that have been gnawed by mice and voles, noting the different characteristics of nuts gnawed by dormice in comparison to those gnawed by the other small mammals (see figure below).

The best time to carry out the survey is during the autumn and winter when there are no leaves on the trees and the discarded nut shells are easiest to find on the woodland floor.

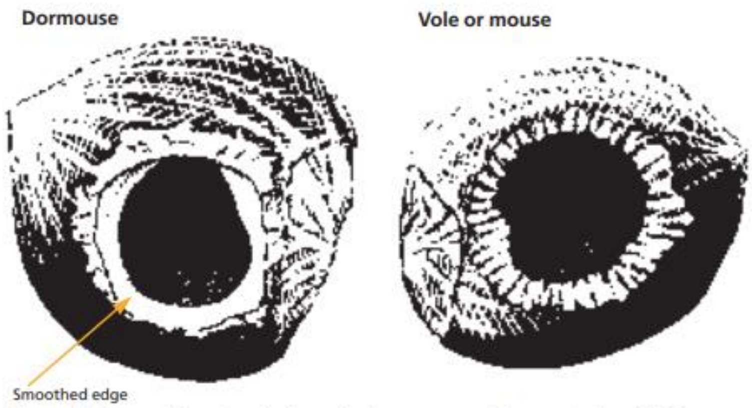


Figure 5 Gnawed hazel nuts. Dormice leave a smooth round hole with few toothmarks on the surface. Mice and voles may also leave a round hole, but with transverse toothmarks on the cut edge.

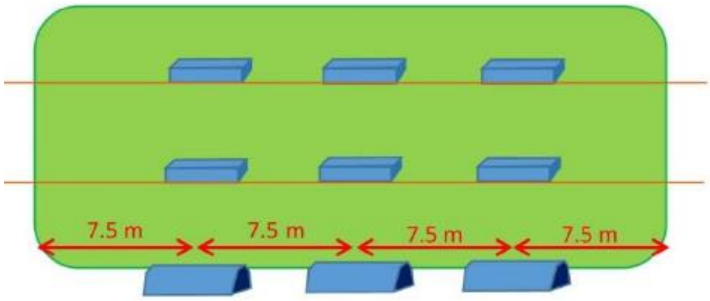
Tip: You may find it easier to take the hazel nuts home and use a magnifying glass to identify what has been nibbling them.

Equipment/resources: As per Tier 1a, magnifying glass.

Tier 2 protocol

Small mammals not only use runways on the ground, but also “arboreal” runways along the branches of a shelterbelt or hedgerow. The following method samples mammals moving through the canopy of the shelterbelt as well as on the ground using footprint tunnels, a low invasive survey method.

Bait and prepare the tracking plate of each footprint tunnel as per the maker’s instructions (see also Equipment/resources below). Nine footprint tunnels are required for each OSB and sampling session. Taking a 15 m length of the OSB, place three tunnels 7.5 m apart at ground level as well as at heights 1 m and 2 m (see figure below). Secure those on the ground with metal pegs and those at height to a branch using cable ties. Leave all tubes in the OSB for four nights before removing. Try to identify any footprints on the paper using a guide and record the species.



Tip: It can be difficult to distinguish between some species of smaller mammals. Atkins et al (2008) note: *During pilot studies, tracing paper was found to be less palatable to slugs and snails, and the ability to overlay this on example footprints made identification more accurate.*

Equipment/resources: Footprint tunnels and Identification Guide. We recommend the footprint tunnel (dimensions c. 120 cm x 71 cm) available from NHBS which come with charcoal powder and metal fixing but require additional purchase of masking tape, vegetable oil, bait (e.g. dog/cat food) and cable ties. Also available at NHBS is the FSC *A Guide to British Mammal Tracks and Signs* (included with a set of footprint tunnels).

Butterflies

Rationale

Shelter belts and hedges are an important nectar source for a number of butterfly species. Butterflies also react very quickly to change in their environment which makes them good biodiversity indicators. Pressures such as agricultural intensification and loss of habitat have resulted in many common butterfly species having undergone serious declines.

Protocols Tier 1a and 1b are adapted from the TWECOM Hedgerow Biodiversity Protocol 2015.

Tier 1a protocol

The survey should ideally be carried out once in July and once in August (with at least 10 days between the two visits) and between 11am and 5pm on a still, sunny day.

Walk one side of the length of one side of the OSB at a slow, methodical pace noting down the numbers of butterflies you see in and around the OSB. Return along a transect through the adjacent field at a distance of 20 m from the OSB, and within 2.5m either side of the survey line, 5m ahead and 5 m from ground level up, again noting down the numbers of butterflies seen. Record the start and finish time for each survey. This data should then be entered into the butterfly data entry sheet.

Tip: Try to avoid double counting where possible, for example when an individual butterfly repeatedly flies in and out of your recording area. Do not linger in hotspots to improve your count, as this will bias results, and do not count butterflies behind you.

Equipment/resources: Data entry sheet.

Tier 1b protocol

As per the Tier 1a protocol, but in this case record both the species and number of butterflies seen.

Tips: A butterfly net may prove useful to capture and then ID species that are unfamiliar.

Equipment/resources: Data entry sheet, Binoculars, Butterfly identification guide (e.g. Guide to the Butterflies of Britain by John Bebbington or Collins Butterfly Guide by Tom Tolman and Richard Lewington (2008)), Butterfly net.

Tier 2 protocol

UK Butterfly Monitoring Scheme: A new transect encompassing the OSB can be set up as a contribution to this nationwide monitoring scheme. This involves selecting the site, designing the route, filling in and submitting a UKBMS F1 Site details form, and recording data on a UKBMS F2 Weekly recording form. However, this is a regular and long-term commitment, requiring that there are only a very few missed weeks each year, and that the transect is continued for at least 5 consecutive years. Further instructions and a recording form can be found here.

Bumble bees

Rationale

Although bumblebees contribute over £400 million a year to the British economy through pollinating crops, they are facing large declines across the country. Hedgerows are particularly important in providing forage plants for bumblebees at the start and end of the nesting season, when flower-rich grassland areas are being grazed or cut.

Protocols Tier 1a and 1b are adapted from the TWECOM Hedgerow Biodiversity Protocol 2015 and mirror the methodology for butterflies.

Tier 1a protocol

The survey should ideally be carried out once in July and once in August (with at least 10 days between the two visits) and between 11am and 5pm on a still sunny day.

Walk one side of the length of one side of the OSB at a slow, methodical pace noting down the numbers of bumblebees you see in and around the OSB. Honeybees should also be noted if possible. Return along a transect through the adjacent field at a distance of 20 m from the OSB, and within 2.5 m either side of the survey line, 5 m ahead and 5 m from ground level up, again note down the numbers of bumblebees (and honeybees) seen. Record the start and finish time for each survey. This data should then be entered into the butterfly data entry sheet.

Tip: Try to avoid double counting where possible, for example when an individual bee repeatedly flies in and out of your recording area. Do not linger in hotspots to improve your count, as this will bias results and do not count bees behind you.

Equipment/resources: Data entry sheet, Pen or pencil.

Tier 1b protocol

As per the Tier 1a protocol, but in this case record both the species and number of bees seen.

Tip: Although the bumblebee survey sheet includes illustrations of a number of common bumblebees you may wish to take an additional field guide with you (see below).

Equipment/resources: Data entry sheet, Pen or pencil, Bee identification guide (e.g. Field Guide to the Bumblebees of Great Britain and Ireland by Mike Edwards and Martin Jenner, 2009, A Pocket

Guide to the Bumblebees of Britain and Ireland by Pinchen, 2006; What's that Bumblebee by the Bumblebee Conservation Trust, 2010.

Tier 2 protocol

BeeWalk monitoring for the Bumblebee Conservation Trust: This is the national recording scheme to monitor the abundance of bumblebees across Britain. It involves volunteers identifying and counting bumblebees seen on a fixed route walked each month from March to October inclusive. Specialist knowledge is not required but a training session is organised. The fixed route is required to be 1 to 2 km in length and the records are submitted through the BeeWalk website. Further instructions and a recording form can be found here.

Soil fauna

Rationale

Earthworms are an important indicator group for soil health and biodiversity. Hedgerows are known to improve soil conditions, including earthworm diversity, an effect that can extend into the field. Many other organisms inhabit a healthy soil and contribute to its health the Tier 2 protocol is designed to capture this wider faunal diversity.

Tier 1a, 1b and 2 protocols are based on those used in the Horizon Europe project ReForest.

Tier 1a protocol

For this methodology, samples should be taken at six stations according to the T-shape arrangement of sampling (see Sampling design, above). Two surveys should be undertaken per year, in autumn and spring.

Dig a soil pit measuring 25 x 25 x 25 cm and place the soil on a mat. Hand-sort the soil, separating whole earthworms. Count and record the total number of whole earthworms and enter the data into the earthwork data entry sheet. Return all earthworms and back-fill the soil pit.

Equipment/resources: Data entry sheet, Spade, Plastic mat (approx. 1 x 1 m).

Tier 1b protocol

As per Tier 1a, samples should be taken at six stations according to the T-shape arrangement of sampling (see Sampling design) and two surveys undertaken per year, in autumn and spring.

Dig a soil pit measuring 25 x 25 x 25 cm and place the soil on a mat. Hand-sort the soil, placing each whole earthworm into a pot. Count and record the total number of whole earthworms. Separate adult and juvenile earthworms (see survey sheet for identification), returning juvenile earthworms to the soil pit. Separate adult earthworms according to three types: epigeic (litter-dwelling), endogeic (topsoil-dwelling) and anecis (deep burrowing) (see survey sheet). Count the number of adult earthworms of each of the three types and record in the survey sheet the overall weight of each type. Return all earthworms and back-fill the soil pit.

Equipment/resources: Data entry sheet, Spade, Holding pot, Rinsing bottle (water), Plastic mat (approx. 1 x 1 m), Weighing scale.

Tier 2 protocol

As per Tiers 1a and 1b, samples should be taken at six stations according to the T-shape arrangement of sampling (see Samping design). Two surveys should be undertaken per year, in autumn and spring.

At each sample location, dig a soil sample of 10 x 10 x 10 cm using a spade or a square corer. Seal the sample in a ziplock plastic bag. Within 48 hours, the samples should be put into a Berlese-Tullgren extractor (see image below). This involves putting the soil into a funnel fitted with a 2mm mesh. The collection jar below should contain a liquid preservative of 2/3 alcohol and 1/3 glycerol. The extraction process should continue for at least 7 days, depending on soil moisture. After extraction, an optical microscope should be used to record presence of each order/class within each collection jar (note: abundance / counts within each class are not needed). Based on the presence of each order/class, the Ecological-Morphological Index (EMI) can be calculated (see survey sheet).

Equipment/resources: Spade; Trowel; Ziplock bags; Funnels and collection vessels; 2mm mesh; Alcohol and glycerol solution; Optical microscope. See for more information: https://doi.org/10.1016/j.apsoil.2017.05.020).

Example of a Berlese-Tullgren extractor (light bulbs are not required).

Invasive pests and diseases

Rationale

Invasive plants can out compete or smother low-growing herbs, reducing species richness, while invasive pests like grey squirrels and muntjac deer can have adverse impacts such as harming tree regeneration. Pathogens like ash dieback disease can have serious deleterious consequences. Increasing landscape connectivity provided by OSBs may potentially have undesirable consequences for the spread of tree pests and diseases as well as pests and diseases that attack crops.

The following protocols focus on tree pests and disease as wel as the presence of grey squirrels and muntjac deer. Crop pests and disease are covered in the crop production protocols.

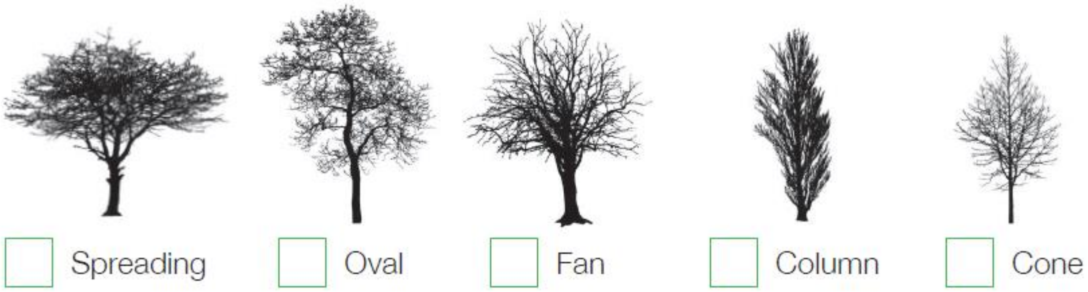
The Tier 1a protocol is based on Activity 1 of the OPAL Tree Health survey and Tier 1b is based on Activity 2 of the OPAL survey.

Tier 1a Protocol

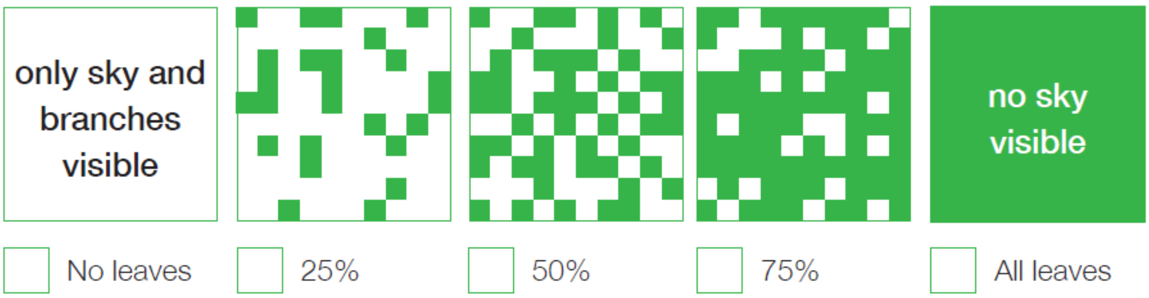
From your knowledge of visits to the OSB, note down if grey squirrel and muntjac deer have been seen, and what was the highest number of individuals seen of each as well as the approximate greatest distance observed from one end of the OSB (or ‘throughout’ if that is the case).

Complete the tree health survey between May and September when the trees are in full leaf. For each of the distances 10, 20, 30, 40 and 50 m from one end of the OSB, take the nearest standard tree and undertake the following assessment, recording the data on the form provided.

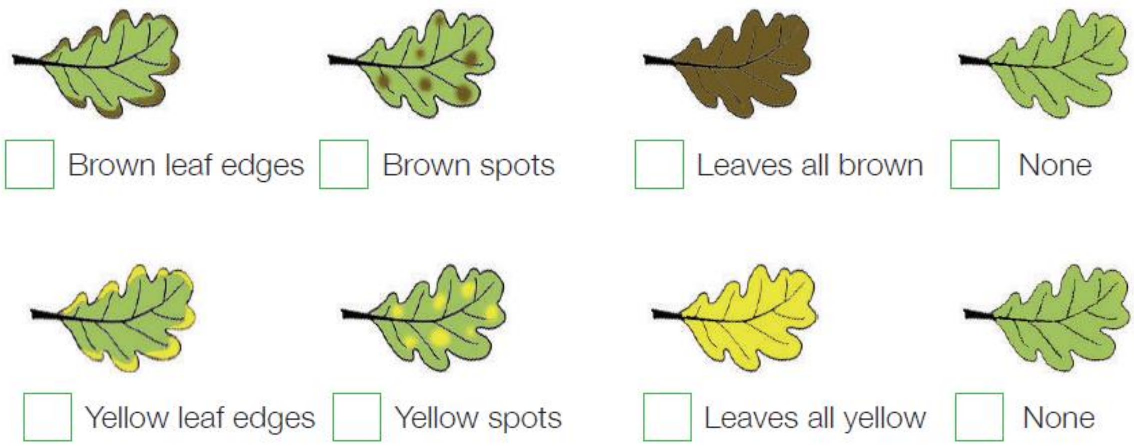
Firstly, note the species of tree, girth (measured with a tape measure) and approximate height to the nearest 1 m. Describe the shape of the crown as one of the following:



Stand under the tree next to the trunk and look up to estimate how much of the view is made up of leaves, to the nearest value in this key below.



Look to see which types of leaf browning and leaf yellowing are visible and record the presence (yes/no) of each.



For each of browning and yellowing, estimate the proportion of affected leaves as one of: less that a quarter of the tree, between one quarter and one half, between one half and three quarters, and more than three quarters.

Additionally, note any signs of insect damage such as: leaf holes (holes all the way through the leaf), leaf mining (green tissue inside the leaf has turned brown or disappeared) and lead galls (bumps and growths on the leaves).



Tip: For a more robust measure of tree height see the method described in the Tier 1b Habitat structure protocol.

Equipment/resources: Data entry sheet, OPAL Tree Health Survey Booklet and Pests and Diseases Identification Guide.

Tier 1b Protocol

Carry out the Tier 1a survey but for any trees that are oak, ash or horse chestnut, additionally record the presence of the diseases and pests below. If these trees are present in the OSB but missing from the surveyed sample, select at least one tree of each species present to undertake this search.

Oak:

☐ Oak mildew

☐ Knopper gall

☐ Tortrix roller moth

☐ Oak decline

Ash:

☐ Ash bud moth

☐ Ash key gall

☐ Nectria canker

☐ Ash decline

Horse chestnut:

Horse Chestnut leaf blotch

Horse Chestnut leaf-miner

Bleeding canker of Horse Chestnut

Horse Chestnut scale

Tip: The Most Unwanted pests are covered by plant health legislation which means that if you find them you must notify Forest Commission officials so that they can take any necessary action to control them. The easiest way to do this is through the TreeAlert App: www.forestry.gov.uk/treealert.

Equipment/resources: Data entry sheet, OPAL Tree Health Survey Booklet and Pests and Diseases Identification Guide, pen and paper.

Tier 2 Protocol

Woodland herbivore assessment method: As part of the Woodland Grazing toolbox of Scottish Forestry, the Woodland herbivore assessment method has been devised to assess and monitor the impact of large herbivores on woodlands. It is a relevant method for understanding the level of deer use of the OSB and impact on its vegetation, alongside livestock interactions where they are present, but is proposed to be trialled by a researcher. Further instructions and a recording form can be found here.