Developing practical techniques for quantitative assessment of ecosystem services on farmland

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Abstract

The application of the concept of ecosystem services in the context of environmental management of agricultural landscapes is a relatively new and developing topic. There is increasing demand for the delivery of ecosystem services, especially with respect to ensuring that outcomes from policy interventions are realised. Consequently, there is a need for knowledge, tools and techniques to aid the identification of appropriate options for the given circumstances. This paper presents the outputs from a study that aimed to derive practical approaches that could be used to quantify ecosystem services from features on farmland in Europe. More specifically it aimed to integrate the outputs from the Quantification of Ecological Services for Sustainable Agriculture project into an existing prototype software package (the Ecological Focus Areas Calculator). The ecosystem services explored are soil erosion; pollination; pest control; aesthetics; and carbon sequestration. Following an explanation of the methodology, case study landscape features are used to illustrate the outputs generated. The quantitative outputs are also compared to the outputs from the existing qualitative techniques in the Ecological Focus Areas Calculator to highlight the advantages and disadvantages of the two approaches. The study concludes that the development of more quantitative approaches is an improvement over more qualitative techniques. However, quantitative techniques are not available for all ecosystem services, whereas the qualitative approach covers more ecosystem services and thus provides a more holistic perspective. It will be important to further develop the techniques as new science emerges; to ground truth the techniques to confirm and improve their reliability; and to improve delivery tools to meet the requirements of different end users which may evolve in the future. As the intellectual, economic and technical capacity of the land management sector increases, the level of sophistication that is be deemed to be practical will also evolve, thus the tools and techniques available need to keep pace with this.

Keywords: aesthetics; carbon sequestration; ecosystem services; habitats; pest control; pollination; quantification; software; soil erosion; techniques; farmland

1.0. Introduction

The concept of ecosystem services is not new (Cairns and Pratt, 1995; Costanza and Daly, 1992; Ehrlich and Mooney, 1983; Gómez-Baggethun *et al*., 2010), but its application in the context of environmental management is relatively new and it is a developing topic (Hauck *et al*., 2013; Landis, 2017; Potts *et al*., 2016; Schulp *et al*., 2016; van Zanten *et al*., 2014). Agricultural landscapes and their management can affect the delivery of multiple ecosystem services (Mouchet *et al*., 2017; van Oudenhoven *et al*., 2012; van Zanten *et al*., 2014). Other than the provisioning services of food, fibre and fuel, this can include regulation services such as mass stabilisation and control of erosion rates; flood protection; chemical condition of freshwaters; climate regulation (via emission and sequestration of greenhouse gases); pollination; pest and disease control; and cultural services including: aesthetic, heritage, scientific, educational and recreational services.

There is scope to manage and evolve agricultural landscapes to increase ecosystem service benefits and minimise burdens. However, this requires knowledge, tools and techniques to aid the identification of appropriate options for the given circumstances. This includes techniques for assessing and quantifying ecosystem services, with the view that 'you cannot manage what you do not measure' (McAfee and Brynjolfsson, 2012). Although such a saying is not strictly true, the ability to quantify is inherently valuable for environmental management in order to be able to assess the significance of effects and impacts, and thus the potential benefits and burdens of management interventions. However, quantifying ecosystem services is not easy, and although there are many studies and projects that attempt to do this (ARIES, 2019; Farley and Costanza, 2010; Ingwall-King *et al*., 2016; InVEST, 2019; Holland *et al*., 2014; Moore *et al*., 2017; OpenNESS, 2019; OPERAs, 2019; Scheufele and Bennett, 2017; Swinton *et al*., 2007; Tallis and Polasky, 2009; Tzilivakis *et al*., 2016; Van Dijk *et al*., 2018; Villa *et al*., 2014) using a range of techniques because established or standardised approaches are yet to emerge. Additionally, many techniques although robust can require large amounts of data or the use of sophisticated tools and techniques that are more suited for bespoke scientific studies rather than as practical management tools.

What constitutes a practical management tool is dependent on the context of its use and those using it. The most likely way in which ecosystem services will be encouraged and supported is through agricultural policies, such as the Common Agricultural Policy (CAP) and agri-environment scheme funding. Thus there will be a demand from both farmers, land managers and policy makers for tools to support this, and what is practical for farmers is likely to be different to what is practical for policy makers. However, it is also important to acknowledge other stakeholders such as carbon credit schemes, crop assurance schemes and retailers, who may also require the identification of ecosystem service delivery or environmentally friendly farming systems – thus there could be a demand from these stakeholders for practical indicators and tools to support this. Consequently, there is likely to be a diversity of potential end users, each with their own requirements and, as highlighted by Rose *et al*. (2018), this will influence what is deemed to be practical and thus whether any tools or systems will be successfully adopted.

This paper presents the outputs from a study that aimed to derive prototype approaches that could be used to practically quantify ecosystem services from features on farmland in Europe. It draws upon the outputs from the Quantification of Ecological Services for Sustainable Agriculture (QuESSA) project (Holland *et al*., 2014; QuESSA, 2017) which were adapted to integrate them into an existing software package, the Ecological Focus Area calculator (AERU, 2018; Tzilivakis *et al*., 2015). The existing prototype software employs largely qualitative techniques for assessing the performance of land use and landscape features on ecosystem services (such as those defined by Haines-Young and Potschin, 2013) and biodiversity (defined as populations of different species or species groups for the Ecological Focus Area calculator study). Consequently the integration of more quantitative approaches has the potential to provide more robust methods and thus strengthen the overall tool. However, in order to ensure the revised tool remained widely accessible, practical, low cost and easy to use, the techniques developed needed to have minimal data input and avoid the need for geospatial mapping, thus providing additional constraints on the approaches that could be taken and implemented.

The ecosystem services explored are soil erosion; pollination; pest control, aesthetics; and carbon sequestration. The methods used to quantify these are explained and then applied to some case study land uses and landscape features to illustrate the outputs they generate. They are also compared to the outputs from the existing qualitative techniques to highlight the advantages and disadvantages of the two approaches and explore the hypothesis of whether simpler and more practical qualitative approaches (e.g. simple metrics, that are easy to measure, have low data and time demands, and do not require advanced skills and expertise) can provide a reliable alternative to more complex quantitative methods (e.g. complex algorithms and sophisticated tools, such as Geographical Information Systems (GIS), that are data and time demanding, and require advanced skills and expertise).

2.0. Methods

2.1. Introduction and overview

In the last reform of the CAP in Europe in 2013 (EC 2013a, b, c, d), a number of "greening" measures were introduced, including a requirement for farms with more than 15ha of arable land to dedicate at least 5% of their arable land to Ecological Focus Areas (EFAs). EFAs are land uses and landscape features that potentially provide ecological benefits. As these benefits can vary with location and management, a prototype indicator framework and relative performance index system (Tzilivakis *et al*., 2016) has been developed to assess the potential impact of EFAs in Europe. Based on collated evidence from an extensive literature review, the framework estimates potential impacts of different EFA types on ecosystem services and biodiversity, accounting for spatial and management characteristics. The performance can be calculated for an individual field or landscape feature, group of features, or the farm as a whole. The outputs from the tool are not quantified impacts (absolute values) but a relative performance index (on a scale of -100 to +100).

The indicator framework has been embedded in a prototype software tool named the 'EFA calculator' (AERU, 2018) – version 1.0.5.3 was used in this study, using impact data dated 04/04/18 and QuESSA data dated 15/05/17. The software uses quantitative data for the dimensions of EFA features in combination with qualitative parameters (and associated classes and scores) to calculate ecosystem service and biodiversity performance scores for each EFA feature on a farm. In total, 230 impacts were identified for 20 EFA features, and these are characterised using 138 parameters and attributes, containing 708 descriptive classes, accounting for regional and local parameters and the attributes of the EFA. The various parameters/attributes and classes are scored and weighted based on their influence on the performance of the feature with respect to each ecosystem service (this has been derived from a range of empirical studies – see Tzilivakis *et al*., 2015). Consequently, for example, selecting attribute classes which lead to greater positive impacts on an ecosystem service will increase the relative performance score. For each feature on a farm, a performance index is calculated for each ecosystem service based on the attributes of the feature, these values are scaled up using the area of the feature and then normalised to the -100 to +100 scale.

The purpose of this study was to integrate techniques (which aim to quantify ecosystem services) into the existing indicator framework and associated software. This needed to be done in way that ensured they were practical to use, i.e. relatively simple with low data requirements, whilst also being scientifically robust and reliable.

Techniques for quantifying ecosystem services were drawn from the recently completed QUESSA project (Holland *et al*., 2014; QuESSA, 2017). The outputs from this project included a number of equations and sophisticated analyses (e.g. using GIS) that required adaptation in order to be integrated into the existing indicator framework and software. In some instances this required the addition of new dimension data to be included in the EFA Calculator software (when describing EFA features) and other instances new factors needed to be added. The integration process also presented an opportunity to more finely 'tune' some of the QuESSA calculations. Some of the factors used in the equations outlined below had single values for some land uses. Given the 138 parameters and 708 descriptive classes available in the EFA Calculator, it was possible to derive a range of values for these factors, thus making the outputs from the calculations responsive to the qualitative description of the feature.

2.2. Techniques for quantifying ecosystem services

2.2.1. Soil erosion

Soil erosion is a burden and/or threat to many other ecosystem services. The cost of soil erosion is difficult to estimate due to the multifaceted nature of the issue, i.e. the loss of soil as a resource and its consequent impact on other environmental media. However, it has been estimated that the annual cost of soil degradation, including erosion, in Europe is €575-2641 million (Robinson *et al*., 2014). This is less than the estimates for pollination and pest control but nevertheless it is still a significant value.

The ecosystem service of interest is mass stabilisation and control of erosion rates, which falls under the regulation and maintenance services using the Common International Classification of Ecosystem Services (CICES) (Haines-Young and Potschin, 2013). Consequently, the focus is on activities and features that increase mass stabilisation and/or reduce erosion. It is generally not feasible to measure quantities of soil lost from different land uses in a practical management context. Consequently there is a reliance on modelling approaches.

There are many soil erosion models which vary in their scope and complexity. Karydas *et al*. (2014) identified 82 water-erosion models for different spatial/temporal scales, so there are plenty to choose from. The most commonly used erosion model (Panagos *et al*., 2015b) is the Universal Soil Loss Equation (USLE) (Wischmeier and Smith, 1978) and its revised version (RUSLE) (Renard *et al*., 1997). The equation does have weaknesses (Bosco *et al*., 2015), but it is widely used because it is relatively simple, robust, and provides standardised approach that can be easily integrated into more complex models, including those using GIS (e.g. Panagos *et al*., 2015b) where different sets of spatial data can be used to derive the data for each of the variables in the USLE.

The USLE forms the foundation for the approach adopted in this study. The main challenge was to find ways to derive the required data in a non-GIS environment using quantitative and qualitative parameters to describe farmland features and thus estimate soil loss.

Soil erosion (t ha^{-1} yr^{-1}) is calculated for each feature using Equation 1 derived from van der Knijff *et al*. (2000).

$$\text{Soil erosion} = \text{LS} * \text{K} * \text{R} * \text{C}$$

Equation 1: Soil erosion

Where:

LS = Slope length and steepness factor
K = soil texture
R = rainfall erosivity
C = land cover management factor

Equation 2 is used to calculate the LS factor, based on Stone and Hilborn (2012). The user enters the gradient (%) and slope length (m) of the slope of land on which the feature is located. If the land is flat, a value of zero is entered.

$$LS\ Factor = (0.065 + 0.0456 * G + 0.006541 * G^2) * ((SL/22.1)^{NN})$$

Equation 2: Slope length and steepness (LS) factor

Where:

G = Gradient as a percentage
SL = Slope length in metres
NN = Varies with gradient: <1% = 0.2; =>1 and <3% = 0.3; =>3 and <5% = 0.4; and =>5% = 0.5

The factors for soil texture are presented in Table S1. These do not vary with the type of feature. However, land cover factors do vary with feature, thus any potential differences in erosion are determined by the cover management factors (C), which have been derived by expert opinion for the QuESSA project (Rossing and Yalew, 2017) and then varied based on the parameters available within the EFA Calculator. The land cover factors for each feature are provided in Table S2.

The rainfall erosivity value can be directly entered by the user in the software. Alternatively, if the value is not known, a clickable map of rainfall erosivity (from Panagos *et al*., 2015a) is provided to determine this value.

2.2.2. Pollinators

Pollination is a critical ecosystem service and one which has direct economic impacts. For example, it has been estimated that insect pollination in the EU alone has an economic value of €15 billion per year (Gallai *et al*, 2009). However, directly measuring or even modelling the pollination benefits of a feature or landscape is not easy due to the highly localised nature of the service, thus an established technique is yet to emerge. Consequently, there is a reliance on proxy methods that account for key aspects including land use, habitats and distance (Crossman *et al*., 2013). A similar proxy approach has been adopted here, with the aim of quantifying pollinator abundance, rather than actual pollination, on the basis that the greater the abundance of pollinators, the greater the potential for pollination.

A Functional Plant Cover Index for pollination ($FPCI_{poll}$) is calculated using Equation 3, which is an adaptation of the approach developed by Rega *et al*. (2016) and is used in combination with the approach used in the EFA calculator. It results in an indicator (e.g. a score of 0 – 100) of floral plant composition suitable for pollinators.

$$FPCI_{poll} = \left(\left(\left(\left(\frac{(FA + NS)}{2}\right) * 100\right) * CW\right) * \left(\frac{(E1 * (FRP - D1))}{A1}\right)\right) + \left(\left(\left(\left(\left(\frac{(FA + NS)}{2}\right) * 100\right) * CW\right) * \left(\frac{(E2 * (FRP - D2))}{A1}\right)\right) * B\right)$$

Equation 3: Pollination

Where:

FA = Floral availability
NS = Nest suitability
E1 = Length of feature edge that is adjacent or parallel to arable land with no barriers
FRP = Forage range of pollinators (by default set at 1500m)
D1 = Distance to arable land with no barriers
A1 = Arable area of the farm
E2 = Length of feature edge that is adjacent or parallel to arable land with barriers
D2 = Distance to arable land with barriers
B = Barriers (1 = no barriers; 0 = vertical barriers)
CW = Connectivity weight - determined using Equation 4:

$$CW = \frac{FRP}{DTSNH}$$

Equation 4: Connectivity weight: pollination

Where:

FRP = Forage range of pollinators (by default set at 1500m)
DTSNH = Distance (metres) to the nearest high quality semi-natural habitat

The factors for floral availability (FA) and nest suitability (NS) range from 0 to 1 and were originally derived for each CORINE land use (Zulian *et al*., 2013). CORINE is too coarse to apply at small spatial scales, therefore these factors have been adapted using the parameters and classes available within the EFA Calculator to make them more responsive to the attributes of the features and the local circumstances. Additional factors for carabid suitability (from the boundary and with the crop) has have also been derived for pest control (see Section 2.2.3). Table 2.1 lists the EFA features that have been assessed and shows the range in values for each factor (note: some EFAs, such as ancient monuments and stones, archaeological sites, garrigue, natural monuments and terraces, have not been assessed for their pollination benefits due to a lack of specific knowledge on this topic, so are not listed in Table 2.1). Tables S3 and S4 list each of the parameters that are used for each feature to adapt the FA and NS respectively.

Table 2.1: EFA features assessed for floral availability, nest suitability and carabid suitability

EFA feature	Floral availability	Nest suitability	Carabid suitability (boundary)	Carabid suitability (crop)
Agroforestry (Af)	0.26 - 0.71	0.29 - 0.5	0.31 - 0.88	0.31 - 0.88
Catch crops or green cover (C)	0.05 - 0.9	0.15 - 0.54	0.34 - 0.62	0.34 - 0.62
Ditches (D)	0.2 - 0.97	0.3 - 0.75	0.24 - 0.8	-
Fallow land (F)	0.25 - 0.98	0.2 - 0.74	0.52 - 0.86	-
Grassland (Gr)*	0.2 - 0.98	0.2 - 0.92	0.37 - 0.8	-
Hedges or wooded strips (H)	0.7 - 0.9	0.44 - 0.95	0.29 - 0.93	-
Isolated trees (I)	0.32 - 0.74	0.2 - 0.55	0.45 - 0.82	-
Land strips (L)	0.2 - 0.98	0.26 - 0.75	0.35 - 0.86	-
Nitrogen fixing crops (NFC)	0.01 - 0.58	0.15 - 0.54	0.4 - 0.94	0.4 - 0.94
Ponds (P)	0.4 - 0.89	0.4 - 0.85	-	-
Short rotation coppice (SRC)	0.26 - 0.71	0.29 - 0.5	0.33 - 1	0.33 - 1
Stonewalls (SW)	0.02 - 0.1	0.2 - 0.38	0.33 - 0.75	-
Trees in a line (TL)	0.65 - 0.89	0.5 - 0.95	0.3 - 0.71	-
Woodland (W)	0.04 - 0.93	0.11 - 0.91	0.29 - 0.95	-

* Grassland (and arable land) have been added to the EFA Calculator as QuESSA calculations are available for these, but these are not EFAs.

It should also be noted that in the QuESSA project, FA and NS values were allocated to arable land, with values ranging from 0 to 0.9 and 0 to 0.6 for FA and NS respectively (Zulian *et al.*, 2013). The EFA Calculator seeks to assess the provision of pollination services to crops that need pollinating, thus the assessment of arable land as a feature is not appropriate. Instead the FA and NS values for crops have been used for the parameter 'Crop on adjacent arable land' which is used for all features. Thus those features that have a high scoring crop adjacent, will have higher FA and NS values.

As shown in Tables S3 and S4, the value for FA and NS can be derived from multiple qualitative parameters. Each parameter class has a score attached to it, so this needed to be combined to derive a single value for FA and NS to feed into Equation 3. The technique for combining the values is the same as that used in the existing EFA Calculator (Tzilivakis *et al.*, 2015). When a user enters data in the EFA Calculator that describes a feature, this selects parameter classes, which can then be used to 'look up' the factor values for those parameters. These values are combined into a single factor value using a weighted average. Each parameter identified for an equation factor can be given a weight. Typically they are all weighted equally, but there is scope within the system to set weightings as needed. Equation 5 is then used to derive the overall factor that is then used in the calculations.

$$Factor = \sum\left(class\ score_n \times \left(\frac{Parameter\ weight_n}{\sum(Parameter\ weights)}\right)\right)$$

Equation 5: Deriving equation factors from two or more parameters

A further function allows users to input the distance between 'very high quality' and 'high quality' habitat (HQH) patches, in order to derive a weighting for habitat connectivity. Connectivity is accounted for using the 'shortest' or 'least-cost path' solution. The ratio of estimated distance (user input) between each HQH patch and the average distance for the nearest neighbouring HQH patch relative to the pollinator forage range or maximum dispersal distance (default value with the option for the user to modify) adjusts the overall farm or field quality score. The forage range assumes the ability of the pollinator to traverse unsuitable forage habitat and locate suitable habitat providing the habitat is present within this maximum range. The index is calculated to a maximum value of 1 i.e. the HQH are within forage range of one another. The closer the distance between habitats, the greater the likelihood they will be located by the pollinator, and the higher the connectivity index. An index below 1 indicates that the forage range is either exceeded or the weighted area score for habitat size and proportion present within the overall area is low, in combination with a greater distance between patches. A lower farm quality score will result where habitat patches comprise a small area of the overall farm area and are isolated with respect to distance relative to one another.

2.2.3. Pest control

Pest control is also a critical ecosystem service that has been estimated to be worth $4.5 billion in the USA (Losey and Vaughan, 2006) and over $400 billion globally per year (Costanza *et al*. 1997). Similarly to pollination, pest control is also difficult to directly quantify and tends to be assessed using proxy measures (Crossman *et al*., 2013). Pest control has been one of the more complex ecosystem service categories to implement due to the considerable variability in the behaviour of different guilds of beneficial insects that may also differ in their use of crop and non-crop habitats. As such it has been split into three sub-categories:

- Pest control (aerial-boundary): benefits of pest control provided by aerial (flying) beneficial insects moving from boundary features.
- Pest control (ground-boundary): benefits of pest control provided by ground dwelling beneficial insects moving from boundary features.
- Pest control (ground-crop): benefits of pest control provided by ground dwelling beneficial insects present within the cropped area.

Pest control (aerial-boundary)

Equation 6 is used for pest control (aerial-boundary) and has been adapted from the Functional Plant Cover Index (FPCI) proposed by QuESSA partners (Rega *et al*., 2018) and the method used by the EFA calculator. It results in an indicator (e.g. a score of 0 – 100) of floral plant composition suitable for aerial predators ($FPCI_{pest}$).

$$FPCI_{pest} = \left(((FA * 100) * CW) * \left(\frac{(E1 * (FRA - D1))}{A1} \right) \right) + \left(\left(((FA * 100) * CW) * \left(\frac{(E2 * (FRA - D2))}{A1} \right) \right) * B \right)$$

Equation 6: Pest control (aerial-boundary)

Where:

FA = Floral availability
E1 = Length of feature edge that is adjacent or parallel to arable land with no barriers
FRA = Forage range of aerial insects (set to a default of 500m)
D1 = Distance to arable land with no barriers
A1 = Arable area of the farm
E2 = Length of feature edge that is adjacent or parallel to arable land with barriers
D2 = Distance to arable land with barriers
B = Barriers (1 = no barriers; 0 = vertical barriers)
CW = Connectivity weight - determined using Equation 7:

$$CW = \frac{FRA}{DTSNH}$$

Equation 7: Connectivity weight: pest control (aerial-boundary)

Where:

FRA = Forage range of aerial insects (set to a default of 500m)

DTSNH = Distance (metres) to the nearest high quality semi-natural habitat

The distance from the arable crop is used, in combination with the foraging range and the length of the feature edge, to determine the potential coverage provided by the feature. Additionally, there is scope to describe when vertical barriers are present that may prevent benefits from being realised (for example, when one side of hedge is adjacent to an arable field, and the other side has a vertical barrier, such as a building, between the hedge and a field).

The floral availability factor is adapted using the same parameters used for pollination (see Table 2.1).

Pest control (ground-boundary)

Equation 8 is used for pest control (ground-boundary). This is identical to the pest control aerial calculation (adapted from Rega *et al*., 2018) except carabid suitability (CS) replaces FA; the forage range is now for ground dwelling insects; and the barriers factor now included horizontal barriers (such as watercourses) as well as vertical barriers.

$$FPCI_{pest} = \left(((CS * 100) * CW) * \left(\frac{(E1 * (FRG - D1))}{A1} \right) \right) + \left(\left(((CS * 100) * CW) * \left(\frac{(E2 * (FRG - D2))}{A1} \right) \right) * B \right)$$

Equation 8: Pest control (ground-boundary)

Where:

CS = Carabid suitability
E1 = Length of feature edge that is adjacent or parallel to arable land with no barriers
FRG = Forage range of ground dwelling insects (set to a default of 60m)
D1 = Distance to arable land with no barriers
A1 = Arable area of the farm
E2 = Length of feature edge that is adjacent or parallel to arable land with barriers
D2 = Distance to arable land with barriers
B = Barriers (1 = no barriers; 0 = vertical or horizontal barriers)
CW = Connectivity weight - determined using Equation 9:

$$CW = \frac{FRG}{DTSNH}$$

Equation 9: Connectivity weight: pest control (ground-boundary)

Where:

FRG = Forage range of ground dwelling insects (set to a default of 60m)
DTSNH = Distance (metres) to the nearest high quality semi-natural habitat

Table 2.1 list the EFA features that have been assessed for carabid suitability and Table S5 lists each of the parameters that are used for each feature to adapt the carabid suitability factor.

Pest control (ground-crop)

Equation 10 is used for pest control (ground-boundary). This is a simpler calculation (adapted from Rega *et al*., 2018) as it only relates to the carabid suitability within the cropped area.

$$FPCI_{pest} = \frac{((CS * 100) * A2)}{A1}$$

Equation 10: Pest control (ground-crop)

Where:

CS = Carabid suitability
A1 = Arable area

A2 = Feature area

Table 2.1 list the EFA features that have been assessed for carabid suitability and Table S6 lists each of the parameters that are used for each feature to adapt the carabid suitability factor.

2.2.4. Aesthetics

The aesthetic value of farmland features is a cultural ecosystem service and is inherently subjective, making quantification more difficult (van Berkel and Verburg, 2014). Approaches tend to be based on economic valuation techniques, involving surveys of local stakeholders, and/or use factors that influence landscape attractiveness such as naturalness or skyline disturbance (Crossman *et al*., 2013). The latter is used for the approach adopted here.

The aesthetic value has been determined following the same scoring system that was used in QuESSA. Equation 11 consists of 3 positive factors and 3 negative factors. The positive factors are summed and the negative factors are summed and the latter is subtracted from the former.

$$A = (N + HD + R) + (U + SD + NL)$$

Equation 11: Aesthetics

Where:

N = Naturalness
HD = Historical distinctiveness
R = Relief
U = Urbanity
SD = Skyline disturbance
NL = Noise level

Table 2.2 lists the negative factors and scores. These do not vary with feature type and are derived by the location of the feature in landscape in relation to buildings, roads, structures and urban areas.

Table 2.2: Urbanity, skyline disturbance and noise level factors

Urbanity	Skyline disturbance[1]	Noise level	Score
<1% urban in surrounding 500m	None within 2.5km	Quiet (<35 dB)	0
1-5% urban in surrounding 500m	Visible within 2.5km	Not noisy (36-45 dB)	-1
6-10% urban in surrounding 500m	Visible within 1 to 2.5km	Rather noisy (46-55 dB)	-2
11-20% urban in surrounding 500m	Visible <1km	Noisy (56-65 dB)	-3
>20% urban in surrounding 500m	Visible <1km and higher than 35m	Very noisy (>65 dB)	-4

Notes:

1. Skyline disturbance is the presence of high-rise man made features in the surrounding landscape, for example buildings, wind turbines and pylons. It includes options shown in Table 2.2 in order of increasing disturbance

Table 2.3 shows which EFA features the naturalness, historical distinctiveness and relief factors are applied to for the aesthetic calculation, i.e. those are deemed to potentially have a 'natural' and 'historically distinct' character. Tables S7 to S9 show the parameters used to derive a value for each factor, with the classes used to determine low and high values (note: other classes exist, these are just the worst and best classes in a range). Each parameter is scored 0 to 4 and average across all the parameters is calculated to determine the over score for naturalness, historical distinctiveness and relief, which is then combined with the values for urbanity, skyline disturbance and noise level to generate an overall aesthetic score as shown in Equation 11.

It is acknowledged that the assessment of aesthetics is still very subjective. For example, in Table 2.2, increasing the amount of urban landscape results in a greater negative score for aesthetics. However, it could be argued that being close to urban areas and thus larger human populations may result in a feature having greater aesthetic value (i.e. in contrast to the urban setting). The alternate view is that a feature would be more aesthetically appealing in a rural landscape. Such subjectivity is unavoidable as is comes down to value judgements rather than objective scientific assessment. The approach presented here attempts to be objective by accounting for multiple criteria, but nevertheless it is still subjective.

Table 2.3: EFA features assessed for naturalness, historical distinctiveness and relief factors

EFA feature	Naturalness	Historical distinctiveness	Relief factors
Agroforestry (Af)	-	✓	✓
Ancient monuments (AM)	-	✓	✓
Ancient stones (An)	-	✓	✓
Arable land (AL)	-	-	✓
Archaeological sites (Ar)	-	✓	✓
Catch crops or green cover (C)	-	-	✓
Ditches (D)	✓	✓	✓
Fallow land (F)	-	-	✓
Garrigue (Ga)	✓	✓	✓
Grassland (Gr)	✓	✓	✓
Hedges or wooded strips (H)	✓	✓	✓
Isolated trees (I)	✓	✓	✓
Land strips (L)	✓	-	✓
Natural monuments (NM)	✓	✓	✓
Nitrogen fixing crops (NFC)	-	-	✓
Ponds (P)	✓	✓	✓
Short rotation coppice (SRC)	-	-	✓
Terraces (Te)	-	✓	✓
Traditional stone walls (SW)	-	✓	✓
Trees in a line (TL)	✓	✓	✓
Woodland (W)	✓	✓	✓

2.2.5. Carbon sequestration

Carbon sequestration is an ecosystem process that falls into the category of 'global climate regulation by reduction of greenhouse gas concentrations' under the regulation and maintenance services in the CICES classification. Quantifying the benefits of carbon sequestration in terms of global climate regulation is difficult, but estimates have been attempted. For example, Canu *et al*. (2015) estimated the benefit of carbon sequestration from biological processes in the Mediterranean region to be between €100 and 1500 million per annum.

Carbon sequestration is usually quantified as an annual sequestration rate, i.e. the amount of carbon sequestered into soil or biomass each year. When land use changes (or there is a change in management) there is potential for carbon to be either lost or sequestered. This process occurs until a balance (equilibrium) between losses and sequestration is reached for the new land use. However, in this instance, a change in land use is not being assessed, but rather the services provided by existing features. Consequently it is only possible to assess the carbon stock, and not the rate of sequestration or loss.

The carbon stock is calculated using the IPCC (2006) methodology described in AERU (2013). There are two sub-categories: biomass and soil organic carbon, which are described below.

Carbon stock (biomass)

The carbon stock for biomass is not calculated using an equation. Instead a combination of one or more parameters are used to look up carbon stock values for the feature. The values have been derived from the IPCC (2006) are shown in Table 2.4.

Table 2.4: Biomass carbon stocks

Feature	t C ha^{-1}
Agroforestry	15
Arable land	2.2
Catch crops or green cover	2.2
Ditches	1.6
Fallow land (varies with ground cover)	0.1 to 2.4
Grassland	1.6
Hedges or wooded strips	15
Isolated trees (varies with ground cover ecological zone, woodland type and management)	0 to 110
Land strips	0.1 to 2.4
Nitrogen fixing crops	2.2
Ponds	0
Short rotation coppice	15
Terraces	2.2
Trees in line	15
Woodland (varies with ground cover ecological zone, woodland type and management)	0 to 110

As shown in Table 2.4, for some features the carbon stock values have a range which will vary based on the attributes of the feature (the attributes are listed in the brackets). For example, a coniferous woodland, with natural management in a temperate oceanic forest ecological zone, has a value of 110.2 t C ha^{-1}, whereas a broadleaved intensively managed even-aged woodland in a temperate steppe ecological zone has a value of 64.1 t C ha^{-1}.

Carbon stock (soil)

The carbon stock for soil is determined in a similar way to biomass. The values have been derived from the IPCC (2006) are shown in Table 2.5.

Table 2.5: Soil carbon stocks

Feature	t C ha^{-1}
Agroforestry	102
Arable land	77
Catch crops or green cover	77
Ditches	96
Fallow land (varies with ground cover)	77-96
Grassland	94
Hedges or wooded strips	102
Isolated trees	107
Land strips (varies with ground cover)	77-96
Nitrogen fixing crops	77
Ponds	0
Short rotation coppice	102
Terraces	77
Trees in line	102
Woodland	107

2.3. Case studies

The techniques described above have been applied to four case study farms, two in the UK (from the EFA Calculator project), and one in Germany and Hungary (from the QuESSA project), using the EFA

Calculator software. Each farm has numerous features including hedges, woodland, grassland, land strips, etc. The ideal approach would be to visit each farm to collect the data and thus base the assessment on ground observations, this would allow the tool to make assessments with the greatest accuracy. However, for this study it was not possible to directly collect/measure the data on the ground for these farms and their features. Therefore, aerial photographs were used to identify features and their qualitative attributes and GIS tools were used to generate dimension data. This results in less detail and accuracy, but the software is designed to handle gaps and a value range (best to worst case) can be calculated.

It is not possible to present the details of all features for all the farms within this paper, so the following have been undertaken:

1. Comparison of similar features on different farms. Example features for each farm have been selected to reveal the range of outputs that are generated from the techniques described above. Four blocks or woodland (Figures 2.1) and four hedgerows (Figures 2.2) (roughly the same size) are used as examples.
2. Comparison of all features on one farm. All the features for one farm (UK2) to highlight the variability of ecosystem service provision within a single farmed landscape (Figure 2.3). The UK2 example consists of 31 features: 9 arable fields (F1-9); 5 grassland areas (G1-5); 1 hedgerow (H1); 6 land strips (L1-6) and 10 woodland areas (W1-10). The ecosystem benefits and burdens for each feature have been calculated and then expressed as a fraction of the best performing feature on the farm (on a scale of 0 to 1, with 1 being the best). This then allows the services to summed up and allow the identification of the best performing features in the landscape on a total and a per hectare basis.

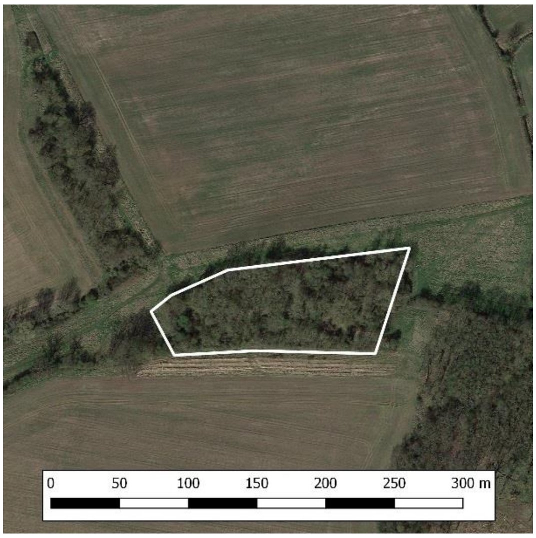
The data derived from the aerial photographs are shown in Tables S10 and S11. These data were entered into the EFA Calculator and the impact calculation routines were run to generate output data.

As mentioned above, ideally data from ground observations should be used and entered into the software to make the most accurate assessment. However, this was not possible in this study and consequently data for some qualitative parameters could not be derived from the aerial photographs (so these were left as blank). The EFA Calculator has functionality to calculate worst, average and best case values when data are missing. Therefore the software was run twice, once using worst case data and secondly using best case data. Consequently, for the comparison of similar features on different farms, a value range is presented for some outputs, which reflects the range from worst to best case. For the comparison of all features on one farm, the average case data has been used.

To compare the outputs of the quantified approach to the existing qualitative approach in the EFA software, the ecosystem services need to be mapped as the classifications are not identical. Table 2.6 shows the mapping that has been used between the existing qualitative approach (which uses the CICES classification - Haines-Young and Potschin, 2013) and new quantitative approach. It should be noted that 'Pest control (ground-crop)' is not included as no relevant features were included in the case studies. Also, pest control is included within the CICES classification (Regulation and Maintenance > Maintenance of physical, chemical, biological conditions > Pest and disease control) and is used in the existing qualitative approach, but the assessment made was very different. For example, for hedgerows the assessment examined their performance serving as a filtration trap for pests rather than as a habitat for beneficial organisms. However, features have been qualitatively assessed for their performance with respect to providing a habitat for a number of different species (under the biodiversity element of the EFA Calculator) including invertebrates, which is closer to the quantitative approach for pest control, so this has been used in this instance. It should also be noted that some features were not assessed for all ecosystem services using the qualitative approach, e.g. hedgerows were not assessed for soil erosion; and land strips were not assessed for aesthetics or soil erosion (only land strips adjacent to water were assessed for soil erosion), so these cannot be compared to the quantified approach. Also, arable and grassland are not EFAs so were not assessed using the qualitative approach.

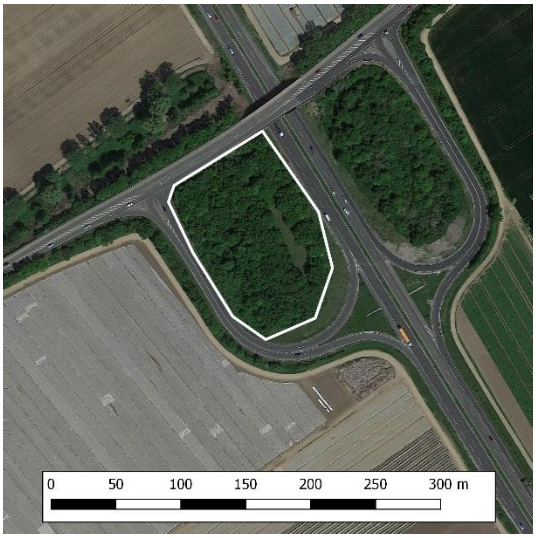
Table 2.6: Ecosystem service classification mapping

Existing qualitative approach	New quantitative approach
Cultural > Physical and intellectual interactions with biota, ecosystems, and land-/seascapes [environmental settings] > Intellectual and representative interactions > Aesthetic	Aesthetics
Regulation and Maintenance > Maintenance of physical, chemical, biological conditions > Atmospheric composition and climate regulation > Global climate regulation by reduction of greenhouse gas concentrations	Carbon stock (biomass) (actual)
	Carbon stock (soil) (actual)
Biodiversity > Invertebrates	Pest control (aerial-boundary)
	Pest control (ground-boundary)
Regulation and Maintenance > Maintenance of physical, chemical, biological conditions > Lifecycle maintenance, habitat and gene pool protection > Pollination and seed dispersal	Pollination
Regulation and Maintenance > Mediation of flows > Mass flows > Mass stabilisation and control of erosion rates	Soil erosion



(a) UK1 – W1

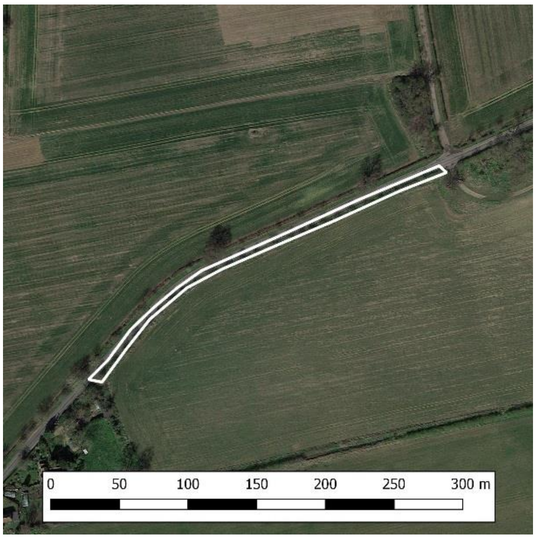
(b) UK2 – W2



(c) Germany – W4

(d) Hungary – W15

Figure 2.1: Woodland features



(a) UK1 – H4

(b) UK2 – H1

(c) Germany – H3

(d) Hungary – H4

Figure 2.2: Hedgerow features

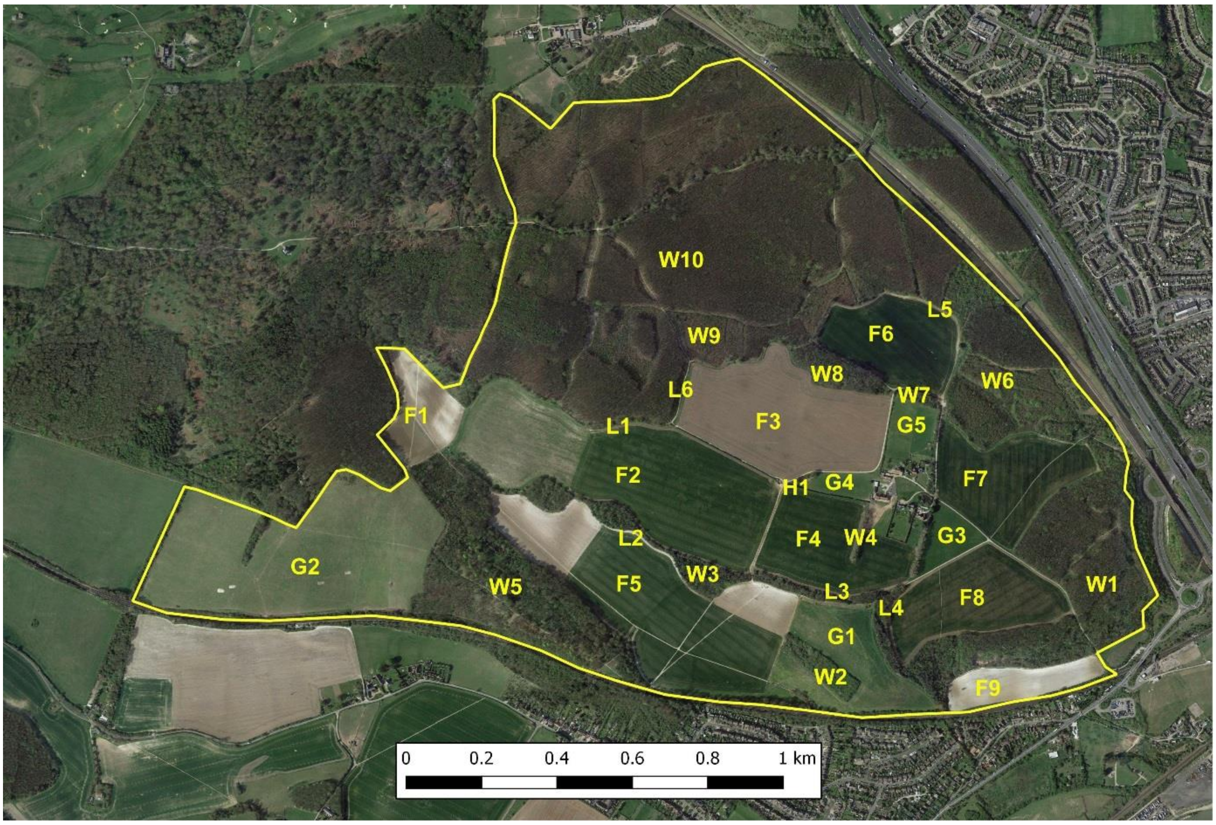


Figure 2.3: UK2 farm and features

3.0. Results

3.1. Comparison of similar features on different farms

Tables 3.1 and 3.2 present the results for the selected features from the case studies using the quantitative and qualitative approaches respectively. The units of the quantitative values (Table 3.1) are those outlined in the methods described in Section 2.2. The units for the qualitative values (Table 3.2) are a relative performance score (see Tzilivakis et al., 2016) and are unitless.

Table 3.1: Results: quantitative

	Aesthetics	Carbon stock (biomass) (actual)	Carbon stock (soil) (actual)	Pest control (aerial-boundary)	Pest control (ground-boundary)	Pollination	Soil erosion (actual)
UK1 – W1	4.63 to 5.25	106.46	111.28	18.22 to 24.01	1.71 to 2.48	42.13 to 63.51	0.0371
UK2 – W2	2.47 to 2.86	133.08	139.1	1.76 to 2.13	0.09 to 0.137	4.51 to 5.44	0.0315
Germany – W4	-9.61 to -8.87	126.94	132.68	0	0	0	0.00112
Hungary – W15	2.19 to 2.97	84.88	138.03	1.28 to 1.41	0.093 to 0.153	1.58 to 2.1	0.00139
UK1 – H4	0.177 to 0.275	1.87	12.69	28.47 to 33.49	1.37 to 2.29	78.7 to 97.68	0.00191
UK2 – H1	0.214 to 0.266	1.65	11.22	16.95 to 19.98	0.189 to 0.316	41.68 to 53.14	0.0603
Germany – H3	-0.687 to -0.611	1.44	9.79	2.4 to 2.82	0.113 to 0.213	6.33 to 8.07	0.00148
Hungary – H4	0.139 to 0.202	1.2	8.16	0.554 to 0.657	0.023 to 0.043	1.45 to 1.89	0.00147

Table 3.2: Results: qualitative

	Aesthetic	Climate regulation	Invertebrates	Pollination	Control of erosion
UK1 – W1	387111 to 572000	882196 to 1015433	261238 to 749048	312000 to 780000	-624000 to 0
UK2 – W2	585000 to 700556	1102745 to 1102745	295595 to 821786	975000	-585000 to -390000
Germany – W4	564889 to 785333	1051849 to 1210709	329190 to 910810	372000 to 930000	-744000 to 0
Hungary – W15	394167 to 623500	810677 to 975942	204250 to 809321	387000 to 967500	-580500 to 0
UK1 – H4	70493	23885 to 36822	50826 to 79854	11483 to 78468	-
UK2 – H1	44000	21120 to 32560	18752 to 44420	10154 to 69385	-
Germany – H3	67200	18432 to 28416	28800 to 76800	7385 to 88615	-
Hungary – H4	29333	15360 to 23680	12571 to 52571	6154 to 73846	-

Aesthetics: The results show that the features in the German case study have the lowest aesthetic value. This is due to the farm being in a predominantly urban area with little elevation. The farm in Hungary is more rural but is largely flat and the features have attributes with low landscape values. The UK2 farm is also on the edge of an urban area and surrounded by major transport infrastructure, and the features are isolated, so have relatively low aesthetic value. The UK1 farm is in a more rural area and features are more connected, consequently the features have the highest values.

Carbon stock: The carbon stock values for woodland are largely a reflection of the size of the features. Hungary has a lower stock per ha, as the woodland type, management and ecological zone are different. The carbon stock values for hedgerows all vary based the size of the features.

Pest control (aerial-boundary & ground-boundary): The two UK woodland features have a similar benefit per metre adjacent to arable land, with UK1-W1 having a larger value overall due to a significant greater length adjacent to arable land. The Hungarian woodland has the largest length adjacent to arable land, but its value as a habitat for beneficial organisms is much lower. The German woodland has horizontal and vertical barriers (a road and hedges) between it and the adjacent arable land, thus scores zero for pest control and pollination.

The two UK hedgerow features have the highest benefit overall and per metre adjacent to arable land for aerial-boundary. For ground-boundary the UK and German hedgerows have a lower benefit per m, but a greater total due their longer length adjacent to arable land. The German hedgerow has a lower benefit per metre and overall. The Hungarian hedgerow has a low benefit per metre and in total, partly because there is a 12m gap between the hedge and the arable land it is adjacent to.

Pollination: The two UK woodland features have a similar benefit for pollination per metre adjacent to arable land, with the UK1 woodland being marginally the highest. The Hungarian woodland has a significantly lower benefit as it is a coniferous woodland, thus has lower floral availability and nest suitability values.

The UK1 hedgerow has the highest value for pollination per metre and in total, following by the UK2 hedge. The German hedge has half the benefit per metre of the UK1 hedge, but us still significantly higher than the Hungarian hedge, which has the lowest value per metre and in total. The Hungarian hedgerow has a significantly lower benefit, due to it being quite isolated and of lower value for floral availability.

Soil erosion: The UK2 woodland and hedgerow features have the greatest soil erosion. This is due to the combination of a medium soil texture and a moderate slope, as the other farms are flat. The medium fine texture of UK1 results in these features having the second highest erosion value. The Hungarian features have a much higher rainfall erosivity value, but the farm is flat and has a very fine soil texture.

3.2. Comparison of all features on one farm

The stacked bar charts shown in Figures 3.1 and 3.2 shows the cumulative benefit/burden on each feature on the UK2 farm. The cumulative total index (benefits minus any burdens) is also presented graphically on a map of the farm in Figures 3.3 and 3.4.

The arable fields, not unexpectedly, have the lowest performance, with some fields (Field 2 (in total) and Field 9 (per ha)) having a slight overall burden due to negative values for soil erosion and aesthetics. The woodland features have the greatest benefits, with Woodland 10 clearly providing the greatest benefits in total and Woodland 3 clearly being the highest performer per ha for five of the eight services. The land strips (field margins) have notable benefits for pest control, especially L1 which second only to Woodland 3.

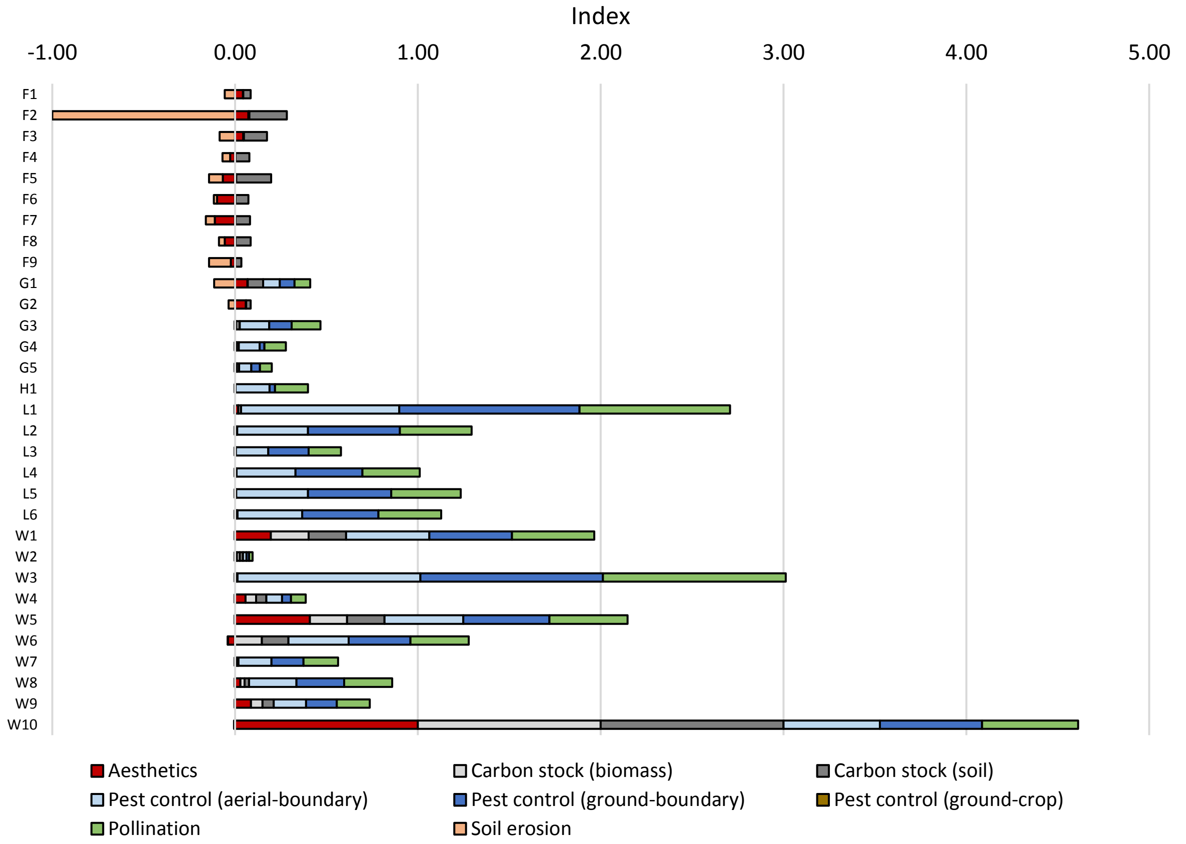


Figure 3.1: Breakdown of performance of UK2 farm features (total)

(F = arable field; G = grassland; H = hedgerow; L = land strip; and W = woodland – also see Figure 2.3)

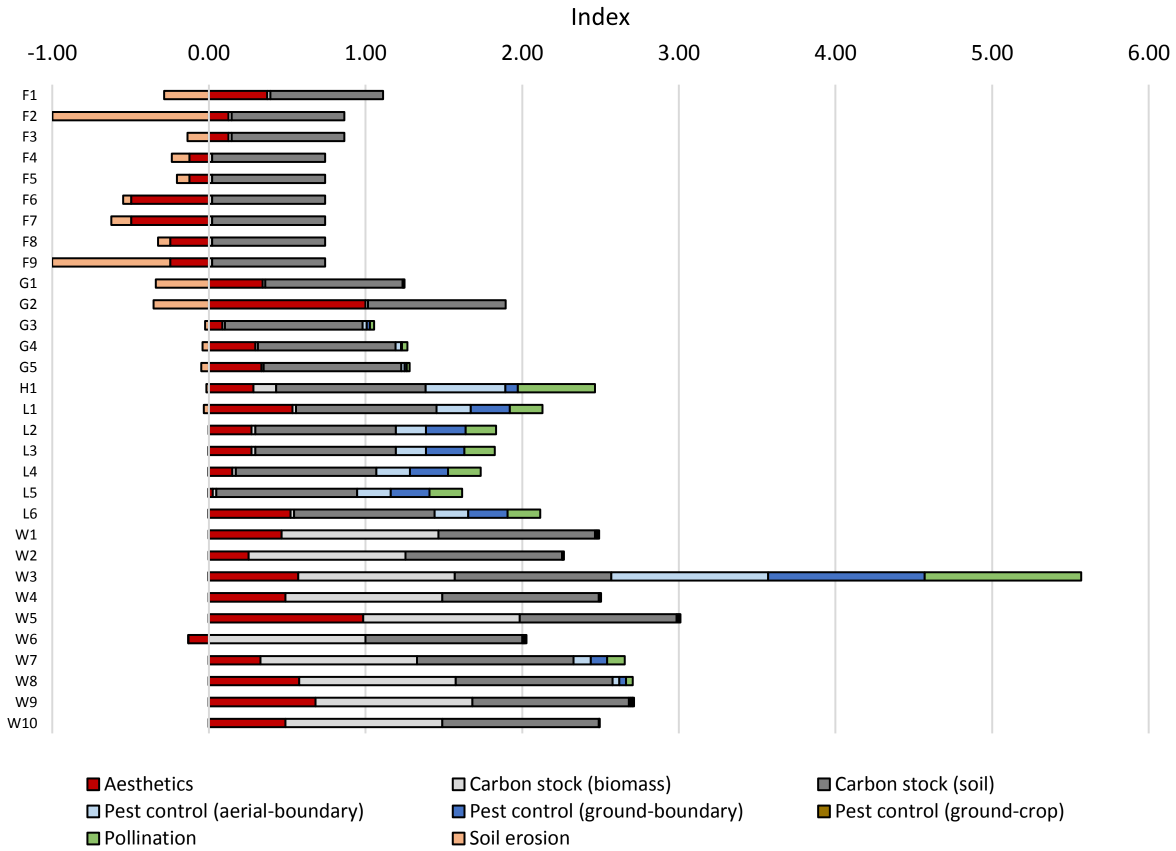


Figure 3.2: Breakdown of performance of UK2 farm features (per hectare)

(F = arable field; G = grassland; H = hedgerow; L = land strip; and W = woodland – also see Figure 2.3)

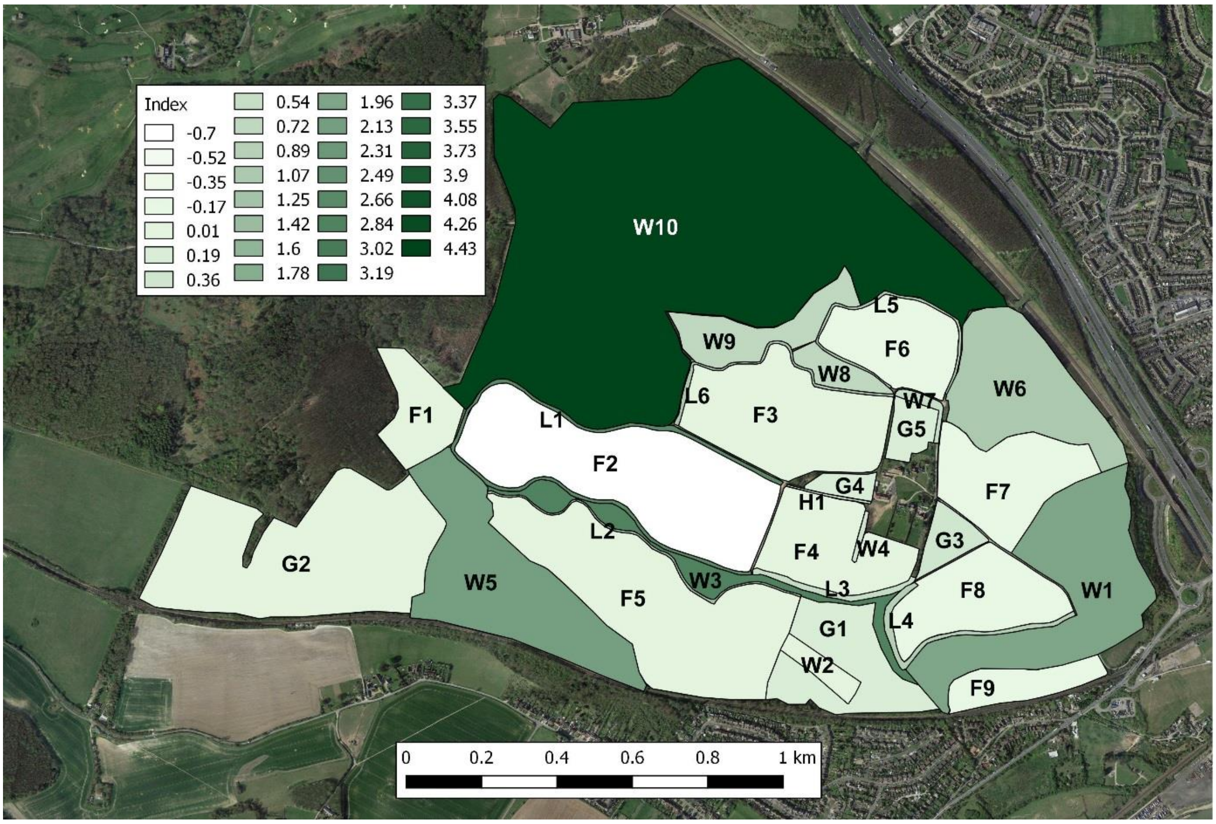


Figure 3.3: Map showing the overall cumulative performance of UK2 farm features (total)

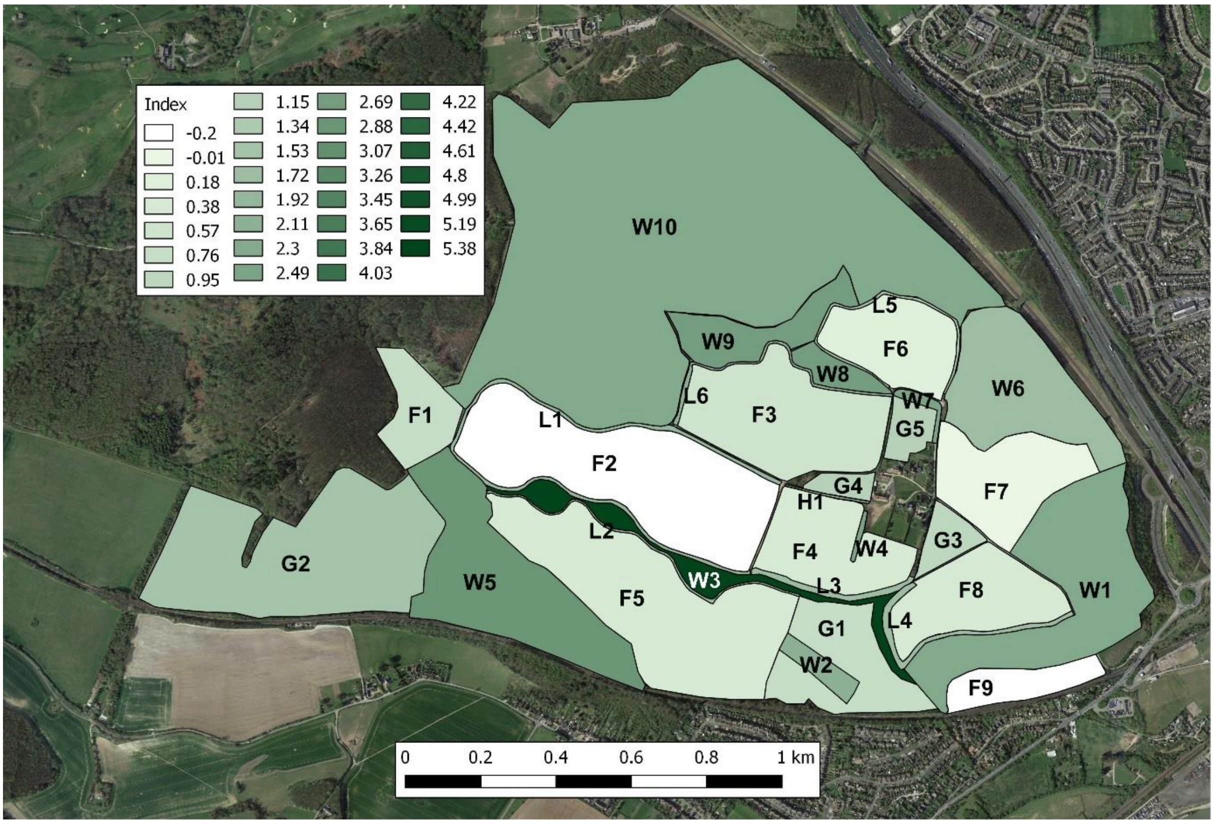


Figure 3.4: Map showing the overall cumulative performance of UK2 farm features (per hectare)

3.3. Comparison of approaches

Figures 3.5 to 3.9 show X-Y plots of the outputs from the qualitative and quantitative approaches available within the EFA calculator for aesthetics, climate regulation, pest control, pollination and soil erosion, using data from applicable features in all the case studies where applicable. The outputs from the qualitative assessment are expressed using a performance index on the Y axis and the outputs from the quantitative assessment are expressed using the units outlined in Section 2.2 on the X axis. A trend line has been added and the R^2 value displayed to indicate how well correlated the data from the two approaches is. A second R^2 value has also been calculated with the outliers removed to eliminate the effect of any extreme values on the correlation.

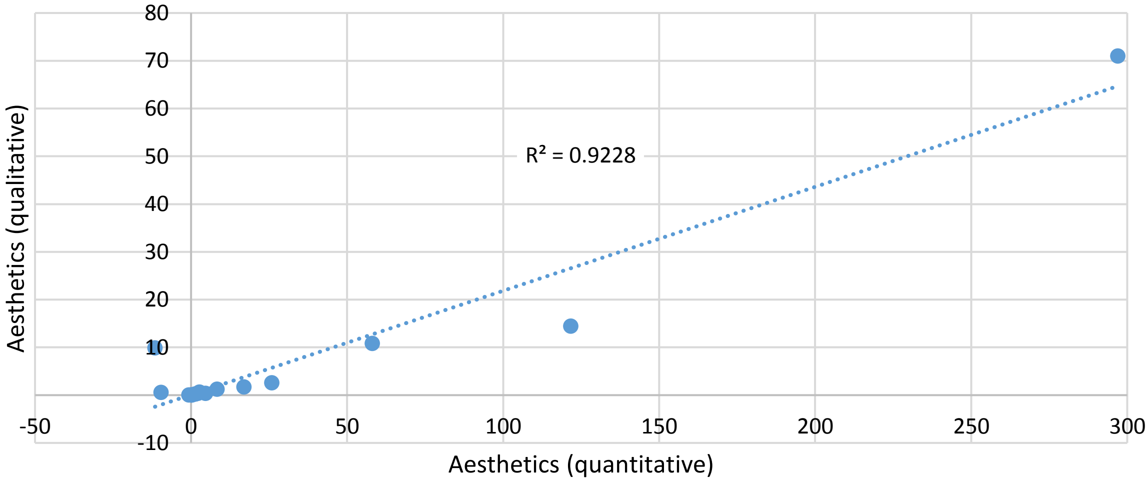


Figure 3.5: Comparison of approaches: Aesthetics

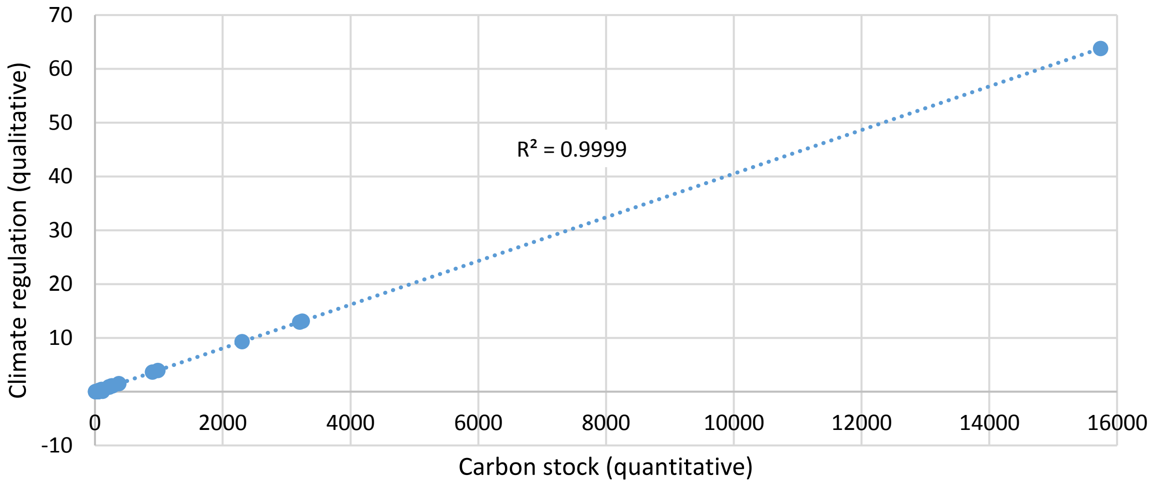


Figure 3.6: Comparison of approaches: Climate regulation

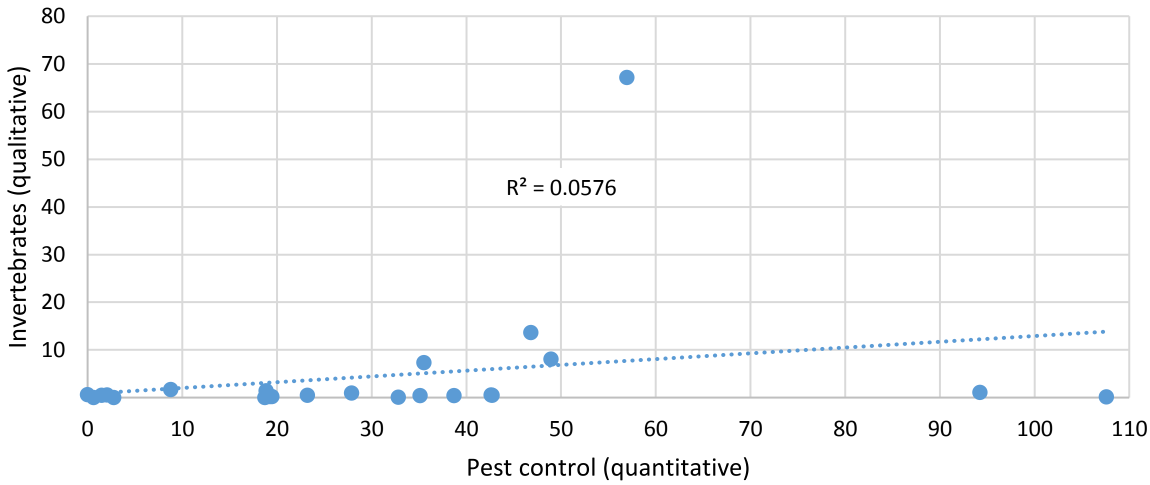


Figure 3.7: Comparison of approaches: Pest control

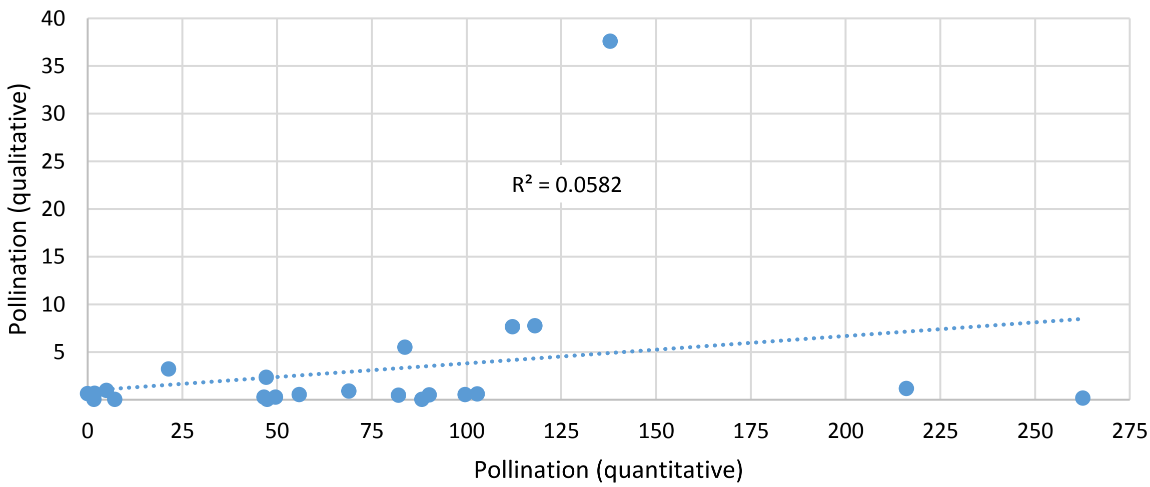


Figure 3.8: Comparison of approaches: Pollination

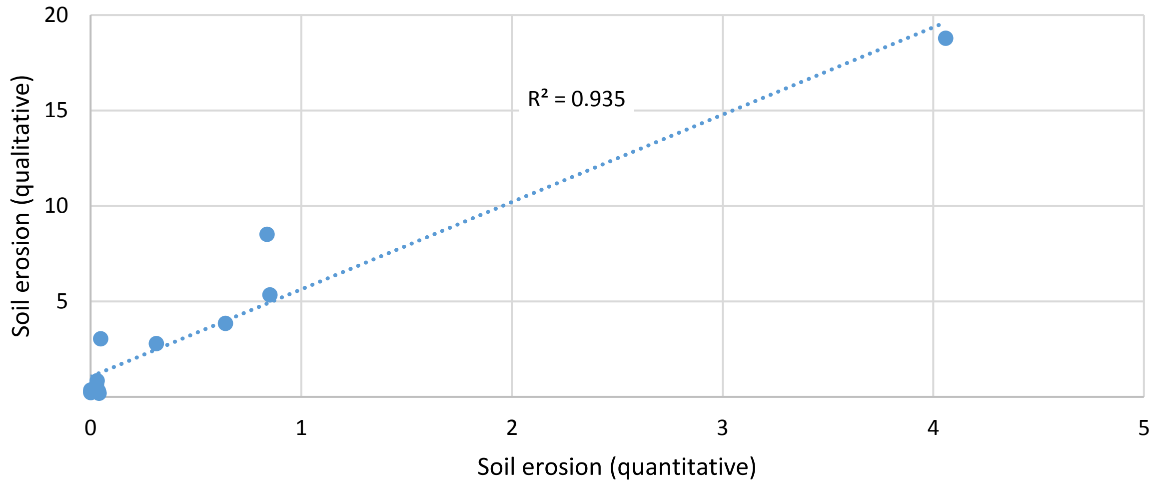


Figure 3.9: Comparison of approaches: Soil erosion

For aesthetics there is a strong correlation in the outputs (R^2 = 0.923, 0.877 with outliers removed). There are some instances where the quantitative assessment results in a negative value, whereas the qualitative assessment results in a positive value, albeit this value is relatively low. For climate regulation there is also a strong correlation between the outputs of the two approaches (R^2 = 0.999, 0.993 with outliers removed). For pest control and pollination there is little correlation between the outputs of the two approaches (R^2 = 0.0576 and R^2 = 0.0582 respectively, 0.058 and 0.022 with outliers removed). This is due to the quantitative approach accounting for the length of the feature adjacent to arable land and the foraging range of beneficial insects, whereas the qualitative approach accounts for the attributes of the feature and its area. Consequently large area features with only small lengths adjacent to arable land tend to score higher than perhaps they should. Finally, for soil erosion there is a moderate correlation in the outputs (R^2 = 0.935, 0.816 with outliers removed), with some variation where erosion is either under or overestimated by the qualitative approach compared to the quantitative approach.

4.0. Discussion

4.1. Introduction

When seeking to manage land to meet multiple objectives, there is an increasing need for tools and techniques that can be used to aid decision making that will reliably deliver the desired outcomes. This includes decision making at the policy level (including agri-environment scheme administrators) and at the farm and field level (including farmers, land managers and their advisors). Many different methods, tools and techniques for measuring and assessing ecosystem services have been developed, with different degrees of complexity and sophistication (ARIES, 2019; Farley and Costanza, 2010; Ingwall-King *et al.*, 2016; InVEST, 2019; Holland *et al.*, 2014; Moore *et al.*, 2017; OpenNESS, 2019; OPERAs, 2019; Scheufele and Bennett, 2017; Swinton *et al.*, 2007; Tallis and Polasky, 2009; Tzilivakis *et al.*, 2016; Van Dijk *et al.*, 2018; Villa *et al.*, 2014). However, a common approach is yet to be established, especially with respect to approaches that are practical use within the context of environmental management on farms. With respect to practicality, it is important to determine the reliability of simpler more practical approaches compared to more complex approaches in order identify whether they are fit for purpose.

Many different indicators and measures have been developed, but they all tend to have their own specific purpose and/or context of operation. On a broad basis, the purpose can be split into appraising current and planning future services, and context can be broken down by spatial scale ranging from individual landscape features and fields, whole farms, landscapes, catchments, regions, nations, continents and global. Potential users of the tools and techniques will also vary with purpose and context. Farmers, land managers and consultants may operate at the field and farm level; regulators may operate at the field, farm, landscape and catchment level; and policy makers may operate at the regional, national, continental or global scale. The inclination, skill and time to use these tools will also vary with different purposes and contexts, thus this may need to be taken into account when considering the practicality of the tool (e.g. farmers are unlikely to have the inclination, skill and/or time to use complex time consuming tools).

Direct measurement of ecosystem services is the ultimate endpoint in terms of assessing the performance of land management. Such measures are desired by regulators and policy makers to ensure the outcomes society desires are being achieved and delivered. However, the delivery of outcomes is often reliant on the decision making and performance of those working at the field, farm or landscape level, where direct measurement of ecosystem services is not feasible. In the absence of direct measurements on the ground, alternative approaches are needed based on data that can be practically collected within the constraints of the time and resources available. Hence techniques, such as those presented in this study, have been developed.

The discussion below reflects on the techniques that have been developed and explored in this study. It explores how they might be used in the context of appraising current ecosystem services and planning changes/improvements to increase or enhance ecosystem services, for new and/or existing features. The two approaches (qualitative and quantitative) explored in this study are compared and their limitations are examined.

4.2. Appraisal of ecosystem services

One of the first steps in any approach to environmental management is to assess current environmental performance to determine strengths and weaknesses and thus areas for improvement. As mentioned above, in ideal world ecosystem services and natural capital would be directly measured, but this is not practical in a commercial context, thus alternative approaches are needed to appraise performance. Typically such approaches consist of a range of indicators, algorithms, expert judgement and multi-criteria assessment techniques and this is reflected in many of the existing tools such as the Cool Farm suite of tools or the New Zealand Sustainability Dashboard project (Alrøe *et al*., 2016; Dicks *et al*., 2016; Hillier *et al*., 2011; Shackelford *et al*., 2018).

Two approaches have been explored within this study. The qualitative approach expresses the performance of features as a percentage of the maximum that might be achieved. This is useful for assessing relative performance, i.e. how well that feature is performing with respect to achieving its maximum potential, thus highlighting areas where there is scope for improvement. However, the qualitative approach does not easily facilitate comparisons between different types of features (for most ecosystem services) as it is not quantifying the service. The quantitative approach overcomes this issue by providing a common scale that allows quantities to be compared for different types of features. However, it does not provide an indication of the relative performance in relation to the maximum value for a service that could be achieved. Thus both approaches have advantages and disadvantages. The latter issue could potentially be overcome by calculating (quantifying) a maximum value for ecosystem services for a given area of land. This could be done by 'fixing' all the parameters that would not vary (e.g. soil type, slope, climate, etc.) and then systematically calculating ecosystem service values for all combinations of variable parameters for each type of feature. This would determine a maximum theoretical value, which could then be used to place the value for the existing feature into context and thus provide a point of reference to judge its performance. It would however, require a significant number of calculations to be undertaken to determine the maximum value, which could make the EFA Calculator software slower and less practical to use (albeit there may be solutions to overcome such technical issues, such as pre-processing multiple combinations of data to generate lookup tables and thus avoid the need for multiple calculations when the software is used).

4.3. Planning ecosystem service enhancements

One of the purposes for undertaking an assessment of the ecosystem services provided by a feature and/or a landscape could be identify where improvements could be made to increase benefits or decrease burdens. This could be via changes to management or the creation of new features. For example, with respect to the later, the EFA Calculator can be used to explore the potential impact of new features, both in terms of the feature itself and the impact on other existing features. For example, Figure 4.1 shows where 3 new hedgerows could be created on the UK2 farm. H2 and H3 would connect Woodland 2 to other habitats and H4 would link Woodlands 10 and 3. The new hedgerows have been created in the EFA calculator software to assess their potential impact. Table 4.1 shows the results expressed as a percent increase for the farm. For woodland 2 (W2) Table 4.1 shows the existing and revised values for the woodland, and the percent increase for the feature and the farm.

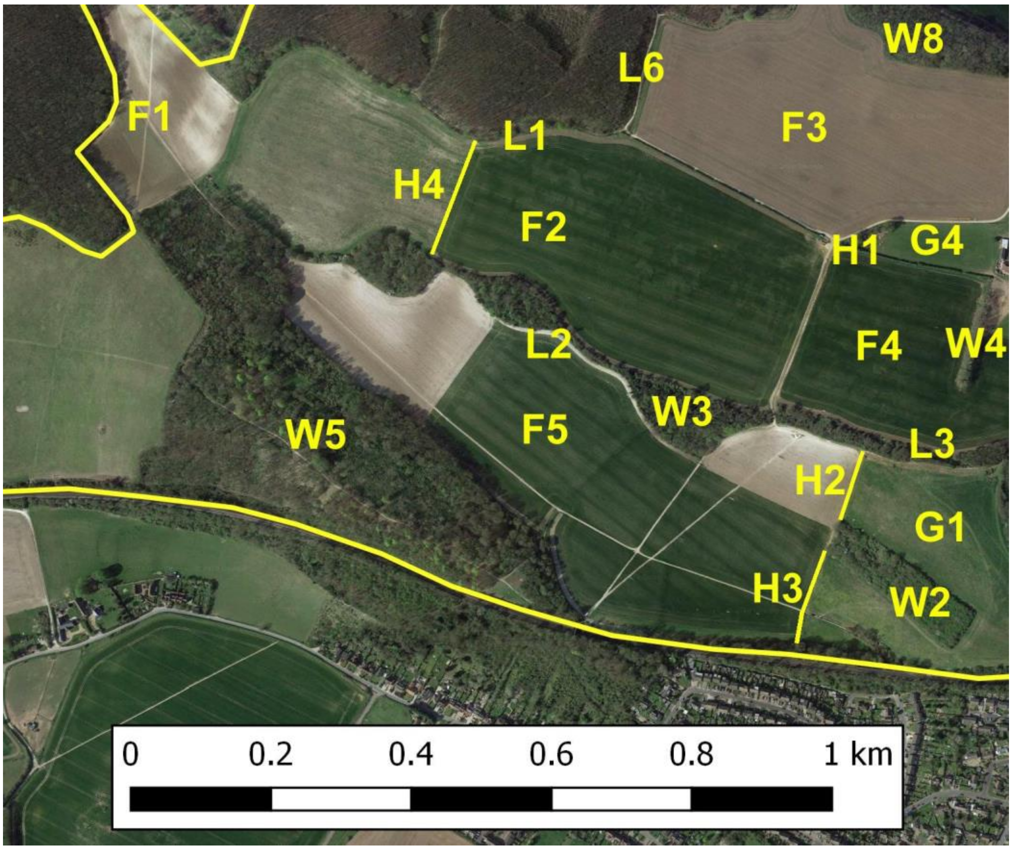


Figure 4.1: Map showing potential new hedgerows (H2, 3 & 4)

Table 4.1: Impact of new features on ecosystem services (% of farm total)

	Aesthetics	Carbon stock (biomass) (actual)	Carbon stock (soil) (actual)	Pest control (aerial-boundary)	Pest control (ground-boundary)	Pollination	Soil erosion (actual)
H2	0.003	0.006	0.02	0.66	0.44	0.66	0.0006
H3	0.004	0.008	0.03	0.9	0.61	0.91	0.0004
H4	0.05	0.01	0.04	2.52	1.64	2.51	0.003
W2 existing	0.78	0.98	0.61	0.29	0.2	0.29	0.003
W2 revised	0.89	0.98	0.61	0.29	0.29	0.29	0.003
W2 Farm % increase	0.12	0	0	0	0.09	0	0

	Aesthetics	Carbon stock (biomass) (actual)	Carbon stock (soil) (actual)	Pest control (aerial-boundary)	Pest control (ground-boundary)	Pollination	Soil erosion (actual)
W2 Feature % increase	14.9	0	0	0	48.3	0	0

The results in Table 4.1 show that, firstly, the new hedges only have minor contributions towards carbon sequestration, aesthetics, pollination and soil erosion. However, there are some notable benefits for pest control from Hedges 2, 3 and 4, with a total increase for the whole farm of 4.1% and 2.7% in Pest control (aerial-boundary) and Pest control (ground-boundary) respectively. Secondly, there are some beneficial effects of Hedges 2 and 3 on Woodland 2. Although the hedges themselves do not add significantly to aesthetics, they increase the individual aesthetic value of Woodland 2 by 14.9%, and there is also a 48% increase in Pest control (ground-boundary). These are small increases for the whole farm (as Woodland 2 is relatively small), but they are significant for the individual feature. The hedges add connectivity which improves aesthetic value and also improves the connectivity weighting for Pest control (ground-boundary) due to the limited foraging range (60m) for ground dwelling beneficial insects. The new hedges do not improve connectivity for Pest control (aerial-boundary) or Pollination as the existing Woodland 2 is 89m from other habitats which is within the range of aerial (500m) and pollinating (1500m) insects.

It is important to acknowledge that when planning interventions other factors may need to be taken into account. This may include, for example, the financial cost of the intervention and/or the practicalities with respect to the commercial management of the farm. For example, the location of proposed new hedge (H4) was probably a hedge previously (dividing two arable fields) which was removed to accommodate larger machinery, therefore this practical issue may need some consideration should the hedge be re-established. However, importantly, the approach outlined herein provides some indication of the potential benefits of different interventions, thus helping to judge the relative cost-benefit of different options.

In terms of planning, more sophisticated tools could potentially be more useful. At the moment, the EFA Calculator calculates the ecosystem service benefits and burdens based on quantitative (dimensions) data and a qualitative description of the feature. The results can then be exported from the software and the data displayed spatially on a map using GIS tools (as shown in Figures 3.3 and 3.4). However, it would perhaps be more practical if new features were 'drawn' directly onto a map (e.g. using GIS) and the resulting benefits and burdens automatically calculated. It is of course not quite that simple because new features can influence the services from other features (as shown in Table 4.1); there may need to be optimisation routines to determine what type of features offer the greatest potential benefits for a specific area (as highlighted in Section 4.2); and there could be trade-offs between different ecosystem services to consider. Nevertheless, if such complexities could be encompassed within an application, then planning ecosystem service enhancements within a sophisticated GIS tool may be the more valuable approach. However, to date, the uptake of sophisticated decision support and GIS tools by land managers and farmers has been limited and with respect to GIS this is largely confined to precision farming applications rather than bespoke environmental planning and management (Aubert *et al*., 2012; Fountas *et al*., 2015; Jeppesen *et al*., 2018; Kaloxylos *et al*., 2012; Rose *et al*., 2016; Sørensen *et al*., 2010).

4.4. Comparison of the results from the quantitative and qualitative approaches

When there are two or more approaches to assessing ecosystem services, although they may have different purposes and contexts it is important to have some understanding of any differences between them with respect to the results they provide. Two types of approach have been explored in the case studies, a qualitative approach (Tzilivakis *et al*., 2016) and the new quantitative approach (and associated techniques) outlined in this paper. The case studies have shown that in some instances there is agreement between the results of the two approaches and other instances they disagree.

For assessing aesthetic services, although the quantitative approach attempts to spatially account for aspects that impact upon aesthetic value, it is still in essence a largely qualitative approach. Thus the two approaches are just two different indexes for assessing the aesthetic value of landscape features. They do draw upon some similar data, but there are also some differences. One of the major differences appears to be that the new 'quantitative' approach attempts to account for the presence of factors that may negatively impact the aesthetic value of landscape features, such as urban infrastructure. This is why there is notable difference in the outputs for the aesthetic value of woodland and hedges in Germany, as the farm is located in an urban area.

For carbon stocks and climate regulation, the two approaches seem to concur. This is not unexpected as although the quantitative approach generates output in terms of the biomass and soil carbon, the qualitative approach draws upon similar parameters to derive its performance index.

For pollination and pest control, there is a notable difference in the outputs. As explained in the methodology, the qualitative assessment for invertebrates were used as a surrogate to compare to the quantitative assessment of pest control, thus this generic assessment may account for some of the difference. However, an element that accounts for a greater degree of the difference is that the qualitative assessment calculates the pollination and pest control benefits based on the area of the whole feature and it does not account for how much of the feature is adjacent to arable land. Whereas the quantitative approach does account for the length of edge adjacent to arable land. The case studies where the qualitative approach suggests significantly higher benefits, are those where actually only a small fraction of the feature is adjacent to arable land. Thus the new quantitative approach appears to provide a clear step forward in accounting for pollination and pest control benefits compared to the qualitative approach.

For soil erosion there is a moderate correlation between the two approaches, which is not unexpected as the qualitative approach draws upon some of the parameters that are used in the quantitative approach (i.e. slope, soil texture, annual rainfall and ground cover). There is some variation which is probably due to the quantitative approach accounting for slope and gradient in a more quantitative manner compared to the qualitative approach (which only accounts for slope using three bands: flat, moderate and steep). It would appear that the qualitative approach, which takes account of the main risk factors for soil erosion, is a reasonable surrogate, but it is not accurate enough to determine more subtle differences between features, which is where perhaps the quantitative approach has the advantage (by quantifying the risk factors, differences in potential soil loss can be determined more accurately).

The development of quantitative approaches is a step in the right direction. However, such approaches do not exist for all ecosystem services, thus for a more holistic perspective the qualitative approach is still required. In the EFA Calculator software users can choose between using the either the qualitative or quantitative approach with different outputs for each. In theory, these could be merged into a single approach with quantitative replacing qualitative techniques where available, but this would result in mixture of outputs which has the potential to be confusing and/or misleading, hence two separate approaches is preferable. However, as knowledge improves in the future, there may be scope to extend quantitative techniques to other ecosystem services allowing a quantitative holistic perspective to be taken, and thus the evolution of a single approach. Additionally, more generally, there may be scope to draw upon broader sources of data and/or incorporate outputs from meta-analyses to refine and improve the existing quantitative and qualitative techniques presented herein.

4.5. Reflections, limitations and wider perspectives

The aim of this study was to integrate the outputs of the QuESSA project into the EFA Calculator software to provide quantitative outputs alongside the existing qualitative performance assessment.

This has been achieved but there a number of aspects and limitations that need to be considered in order to place the advances made in context.

Firstly, it is important to understand what is meant by quantified. For carbon sequestration and soil erosion, there are clear quantified values with established units. For aesthetics, the techniques developed are simply a means of quantifying subjective elements. It is a unitless measurement, but it does provide a numerical scale from low to high aesthetic value. For pollination and pest control, the techniques developed account for factors that influence these services and then a quantified benefit is calculated. This benefit also used a unitless measurement, so the meaningfulness of this value needs some discussion. For example, The UK1-H4 hedgerow has almost twice the benefit for pest control compared to the UK2-H1 hedgerow. Does this mean that UK1-H4 has double the pest control of UK2-H1? The answer to this question is unknown without undertaking actual measurements of pest and predator populations using techniques such as those used by Schmidt *et al*. (2003) and Holland *et al*. (2012). Additionally, the benefits for pollination and pest control are expressed in relation to the arable area of the farm (thus, for example if the pest control benefits are maximised, they would score 100 for the farm as the entire arable area would be covered with the highest benefit). Thus it is not specifying or quantifying actual pest control, just potential. However, although these approaches are not fully quantifying an ecosystem service, they are providing a common scale for all types of feature, which is a clear advantage over the more qualitative approach. Additionally, as discussed by Rega *et al*. (2018), the process of attempting to quantify services (even when considering the limitations of the techniques) has benefits in terms of raising awareness of land managers and policy makers on the value of different landscape features and that there is scope to make improvements.

Secondly, there are limitations of what can be defined and characterised using just basic dimensions and qualitative attributes. When defining large features (e.g. see Woodland 10, Figures 2.3 and 3.3), if they are homogeneous in terms their qualitative attributes, then the benefits or burden they provide are likely to be equal throughout the feature. However, when there is heterogeneity within the feature then the benefits and burdens are likely to be variable. For example, soil erosion from a feature could be variable if the parameters that go into the USLE vary within the feature (e.g. if one end of a woodland happened to be on a steep slope). Similarly, for Woodland 10, the attributes that affect pollination and pest control benefits might vary with differences where the woodland is adjacent to Fields 1, 2, 3 and 6. This can be overcome by defining individual features based on their properties. Thus using the example above, the woodland would perhaps be defined as two blocks of woodland, with the steeply sloping woodland being a separate feature; or as separate blocks in relation to Fields 1, 2, 3 and 6; or accounting for woodland edge as a separate feature (from the whole woodland) to account for the benefits for pollination and pest control, as done by Rega *et al*. (2018). However, accounting for all the services and associated attributes, this could start to make the process less practical to undertake as the definition of multiple features could become a laborious process in the absence of more sophisticated tools such as GIS. Therefore, ultimately a pragmatic approach needs to be taken and the features defined based on clear differences that are likely to give rise to significantly different benefits and burdens.

Finally, with respect to developing techniques that are practical to use, it is important recognise that 'practical' can only be defined in the context of the end user and understanding their decision support needs (Rose and Bruce, 2018; Rose *et al*., 2018). A tool that is practical to use for policy makers and agri-environment scheme administrators may not be practical to use for land managers. Additionally, the effort required to gather the data, use the techniques, use any software and interpret the outputs, needs to be commensurate with the value of the outputs that the process provides. The current EFA Calculator requires a relatively high level of data input to gain the most accurate results, thus can take a reasonable amount of time to complete (e.g. a farm with 30 features could entail an hour of data entry, which does not include the time required for data collection). However, this is a prototype tool and there is always scope to improve it. For example, if the ecosystem service calculations could be combined within a simple to use GIS tool (as mentioned above), then this has the potential to be a valuable and practical tool, i.e. minimal inputs with valuable outputs, that could ensure wider adoption beyond those using the tool for administrative purposes. This could significantly raise the awareness of farmers of the ecosystem services their land provides. However, it also needs to be acknowledged that in the context of current commercial farms, the need to appraise or plan the provision of ecosystem services is limited and likely to be confined to those that have a strong personal interest in the topic. As yet, there is no regulatory requirement to undertake such activities and little demand from the market to take such an approach. However, there is there is a growing consensus that, with respect to subsidies and stewardship schemes, that performance should be assessed based on environmental outcomes, taking the perspective of 'public goods for public money' (Defra, 2018; Hart *et al*., 2018; Keenleyside *et al*. 2014). Additionally, the concept of payments for ecosystem services (PES) is also gathering momentum (Bouwma *et al*., 2018; Defra, 2013; Herzon *et al*., 2018; Viszlai *et al*., 2016). There are pilot Results-Based Agri-environment Payment Schemes (RBAPS) ongoing in England, Ireland, Romania and Spain (EC, 2017) and a pilot Payment by Results (PBR) scheme was recently announced as the first agri-environment scheme to be directly funded by the UK after it leaves the EU (Yates, 2018). Consequently, in the future, the provision of ecosystem services may be coupled with financial drivers and returns, at which point the demand for techniques and tools to manage and enhance ecosystem service provision is likely to increase.

5.0. Conclusions

Understanding how different landscapes, and the features within them, contribute towards ecosystem services is a complex and evolving topic. Consequently, developing interventions to enhance ecosystem services is also inherently complex. However, in a world where the demand for ecosystem services, such as climate regulation or pollination, is becoming parallel to food, fibre and fuel production, there is a need for tools to support decision making to deliver these, and the demand for such tools is likely to increase when agri-environment schemes move towards a system of payment for results/ecosystem services (PBR/PES). These tools need to be as reliable and practical as those currently used for commercial crop production, for example, where decisions made that aim increase gross margins actually result in the anticipated benefits. Thus, tools to aid decisions to increase pollination, for example, need to be as practical to use and result in anticipated benefits with the same reliability.

The techniques presented in this study, and delivered via the EFA Calculator, are prototype tools that draw upon the latest scientific understanding whilst aiming to be as simple and practical as possible. There is of course an inherent trade-off between detailed scientific information and simple and practical tools (Tzilivakis *et al*., 2016). It is possible to develop sophisticated scientific tools, but these are not necessarily practical or simple to use. Consideration needs to be given the requirements and capabilities of different end users. In some instances sophisticated tools (e.g. complex GIS models) can be suitable and valuable and in other instances simpler tools are needed, but which are also reliable. Thus, with respect the hypothesis set out in the introduction, some simpler approaches can provide reliable metrics for some ecosystem services (e.g. climate regulation), but other ecosystem services (such as pest control) demand a more sophisticated approach. Additionally, the context will also affect the degree of sophistication required. For example, simple metrics are ideal for rapid appraisals and/or estimates; whereas GIS, combined with complex algorithms and models, can be valuable for advanced planning that needs to account for important spatial interactions.

Whether tools are sophisticated or simple, they need to be based on the latest evidence and understanding. As new science emerges, techniques need to evolve to reflect this. Further empirical research and results of meta-analyses should be used to update and develop the tools and techniques presented herein. Additionally, it is important to apply the techniques and undertake studies to ground truth them. Data from such studies can then be used to refine the tools and improve their reliability and usability.

The ultimate goal of this field of study is to develop common indicators, tools, techniques and frameworks. The work presented herein aims to contribute towards achieving this goal, alongside the efforts of many others in Europe and globally. However, with regard to the goal of attaining a common or standardised approach, there is still a long way to go. The scientific community is still at the stage of generating approaches for different ecosystem services rather than trying to reach consensus on a common approach. Similar to the evolution of impact characterisation factors used in Life Cycle Assessment (LCA) (JRC, 2011; Pennington *et al*., 2004), it is likely that consensus will emerge for some ecosystem services first, and then consensus on others will follow. At the same time, as intellectual, economic and technical capacity increases within the land management sector, the level of sophistication that may be deemed to be practical will also evolve. It is important to acknowledge the evolutionary dynamics of this arena and recognise that as scientific knowledge evolves the approach to the delivery and implementation of that knowledge also needs to evolve.

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Supplementary material

Table S1: Soil texture factors

Class	**Factor**
Coarse	0.012
Medium	0.031
Medium fine	0.044
Fine	0.034
Very fine	0.017

Table S2: Land cover factors

Feature	**C**
Arable crop (varies with crop)	0.2 to 0.5
Catch crops or green cover	0.2
Ditches	0.1
Fallow land (varies with ground cover)	0.045 to 0.5
Grassland	0.1
Hedges or wooded strips	0.0265
Isolated trees	0.00155
Land strips (varies with ground cover)	0.045 to 0.5
Nitrogen fixing crops	0.2
Short rotation coppice	0.0265
Trees in line	0.0265
Woodland	0.00155

Table S3: Parameters used to adapt the floral availability factor

Parameter	**EFAs**	**Low**	**High**
Age of wall (time since construction/repair)	SW	New (1-5 years)	Old (>15 years)
Agroforestry species & floral diversity at the base of the trees	Af	e.g. *Abies spp.* (Fir) and low floral diversity	e.g. *Salix spp.* (Willow) and high floral diversity
Aquatic vegetation cover	P	0 to 10%	90 to 100%
Bank vegetation cutting period	D	Before seed setting	After seed setting
Buffer strip adjacent	P	No	Yes
Condition of wall	SW	Poor (derelict)	Good
Crop on adjacent arable land	All	Bare ground	e.g. Sunflower, Orchards, Rapeseed, Vines
Density of hedgerow trees	H	None	High
Distribution density of adjacent water bodies	P	None	>1.3 per km²
Diversity of tree species	TL, W	Strict monoculture	Very diverse mixture
Floral diversity	Gr, H, I, L, P, W	Low	High
Floral diversity at the base of trees	TL	Low	High
General nutrient status	P	High	Low
Ground cover	L	None (bare soil)	Sown wildflower
Ground cover (fallow)	F	Bare soil	Sown wildflower
Ground cover (in woods)	W	Very sparse	Very good

Parameter	EFAs	Low	High
Age of wall (time since construction/repair)	SW	New (1-5 years)	Old (>15 years)
Ground cover at base of hedge	H	Low (bare)	High
Hedge height	H	Short	Tall
Hedgerow cutting frequency	H	Every year	Every 3 years (or more)
Hedgerow cutting season	H	Spring/Summer	Winter
Hedgerow is part of a green lane	H	No	Yes
Hedgerow vegetation structure	H	Limited structure	Diverse structure
Level of grazing	Gr, I, W	Very high	Low
Level of structural variability	W	Limited structural variability	Highly varied structure
Livestock access to ditch bank	D	0.2	No access/No livestock
Nitrogen fixing crop species	NFC	e.g. *Vicia spp.* (Vetch)	e.g. *Lotus spp.* (Birds foot-trefoil)
Number of ponds present	P	One	More than seven
Presence of pollen bearing plants	Af, C, Gr, H, I, L, P, SRC, TL, W	Low	High
Short rotation coppice species	SRC	e.g. *Eucalyptus spp*. (Eucalyptus)	e.g. *Salix spp*. (Willow)
Stonewall material	SW	Other	Limestone
Woodland age (years)	W	1 to 5	>26
Woodland edge profile	W	1 step edges	3 step edges
Woodland edge vegetation density	W	Sparse	Dense
Woodland type (used to amend other parameters)	W	Coniferous	Broadleaved

Table S4: Parameters used to adapt the nest suitability factor

Parameter	EFAs	Low	High
Age of wall (time since construction/repair)	SW	New (1-5 years)	Old (>15 years)
Bank vegetation cutting period	D	Before seed setting	After seed setting
Buffer strip adjacent	P	No	Yes
Condition of wall	SW	Poor (derelict)	Good
Crop on adjacent arable land	All	e.g. Flax and hemp; Tobacco	e.g. Bare ground; Olive trees
Deadwood present	H, W	No	Yes
Density of hedgerow trees	H	None	High
Distribution density of adjacent water bodies	P	None	>1.3 per km²
Floral diversity	I	Low	High
Form of the bank	P	Very shallow	Very steep
Ground cover	L	Arable crop	Natural regeneration
Ground cover (fallow)	F	Sown bird seed mix	Sown wildflower
Ground cover (in woods)	W	Very sparse with <25% facing south	Moderate with >75% facing south
Ground cover at base of hedge	H	Low (bare) with <25% facing south	Moderate (partial) with >75% facing south
Ground under canopy is cultivated	I	Yes	No

Parameter	EFAs	Low	High
Age of wall (time since construction/repair)	SW	New (1-5 years)	Old (>15 years)
Hedgerow vegetation structure	H	Limited structure	Diverse structure
Level of grazing	I	Very high	Low
Level of structural variability	W	Limited structural variability	Highly varied structure
Livestock access to ditch bank	D	Direct access	No access/No livestock
Mature trees with basal hollows	H, I, TL, W	No	Yes
Number of ponds present	P	One	More than seven
Pond substrate	P	Concrete or plastic	Natural
Presence of pollen bearing plants	All	Low	High
South aspect	SW	<25% faces south	>75% faces south
Stonewall material	SW	Other	Limestone
Veteran/ancient trees	H, I, TL, W	No	Yes
Woodland edge vegetation density	W	Sparse	Dense
Woodland type (used to amend other parameters)	W	Coniferous	Broadleaved

Table S5: Parameters used to adapt the carabid suitability factor for pest control (ground-boundary)

Parameter	EFAs	Low	High
Age of wall (time since construction/repair)	SW	New (1-5 years)	Old (>15 years)
Agroforestry species & floral diversity at the base of the trees	Af	e.g. *Abies spp.* (Fir) and low floral diversity	e.g. *Salix spp.* (Willow) and high floral diversity
Condition of wall	SW	Poor (derelict)	Good
Deadwood present	H, I, TL, W	No	Yes
Floral diversity	C, D, F, Gr, H, I, L, NFC, TL	Low	High
Floral diversity at the base of trees	SRC	Low	High
Ground cover	L	Arable crop	Sown grass mixtures
Ground cover (fallow)	F	None (bare soil)	Sown grass mixtures
Ground cover (in woods)	W	Very sparse	Very good
Ground cover at base of hedge	Hedges	Poor (bare)	High
Ground under canopy is cultivated	I	No	Yes
Herbaceous vegetation in woodland edge	W	Herbaceous vegetation limited	Considerable herbaceous vegetation
Level of grazing	Gr, I, W	Low	Very high
Level of structural variability	W	Limited structural variability	Highly varied structure
Livestock access to ditch bank	D	Direct access	No access/No livestock
Nitrogen fixing crop species	NFC	*Trigonella foenum-graecum* (Fenugreek)	*Lathyrus* (Vetchlings)
Number of connected terrestrial linear habitats	D	None	Six or more
Pesticides sprayed on adjacent field	D, F, Gr, H, I, TL, W	Yes	No
Presence of pollen bearing plants	All	Low	High

Parameter	EFAs	Low	High
South aspect	Af, C, D, F, Gr, H, I, L, NFC, SRC, TL, W	<25% faces south	25-75% faces south
Topography	Af , C, D, H, I, L, NFC, SRC, TL, W	Mostly uniform	Banks, ridges, hollows or hummocks
Veteran/ancient trees	Af, H, I, TL, W	No	Yes
Woodland edge profile & woodland floral diversity	W	1 step edges, conifer with low understory plant species diversity	3 step edges, deciduous with high understory plant species diversity
Woodland edge vegetation density	W	Sparse	Dense
Woodland floral diversity	W	Conifer with low understory plant species diversity	Deciduous with high understory plant species diversity
Woodland type	W	Coniferous	Broadleaved

Table S6: Parameters used to adapt the carabid suitability factor for pest control (ground- crop)

Parameter	EFAs	Low	High
Agroforestry species & floral diversity at the base of the trees	Af	e.g. *Abies spp.* (Fir) and low floral diversity	e.g. *Salix spp.* (Willow) and high floral diversity
Floral diversity	C, NFC	Low	High
Floral diversity at the base of trees	SRC	Low	High
Nitrogen fixing crop species	NFC	*Trigonella foenum-graecum* (Fenugreek)	*Lathyrus* (Vetchlings)
Presence of pollen bearing plants	Af	Low	High
South aspect	C, NFC, SRC	<25% faces south	>75% faces south
South aspect & floral diversity at the base of the trees	Af	<25% faces south and low floral diversity	>75% faces south and high floral diversity
Topography	C, NFC, SRC	Mostly uniform	Banks, ridges, hollows or hummocks
Topography & floral diversity at the base of the trees	Af	Mostly uniform and low floral diversity	Banks, ridges, hollows or hummocks and high floral diversity
Veteran/ancient trees & floral diversity at the base of the trees	Af	No and low floral diversity	Yes and high floral diversity

Table S7: Parameters used to adapt the naturalness factor for aesthetics

Parameter	EFAs	Low	High
Adjacent trees and woodland	D, Ga, Gr, H, L, NM, P, TL	None	Lots of trees and woodland
Adjacent vegetation structure	All	Large areas of bare ground	Large area (>1ha) of rough grassland, scrub, hedges or woodland

Parameter	EFAs	Low	High
Adjacent water bodies quality	All	No adjacent water bodies or Very poor (Discoloured/green, negligible organisms)	Good (clear water abundant organisms)
Adjacent wildlife corridors	All	No linear features	Diverse and complete linear features
Aquatic vegetation cover	P	70 to 100%	30 to 40%
Density of hedgerow trees	H	None	High
Distribution density of adjacent water bodies	All	None	>1.3 per km^2
Floral diversity	All	Low	High
Ground cover	L	None (bare soil)	Natural regeneration or Sown wildflower
Ground cover (in woods)	W	Very sparse	Very good
Ground cover at base of hedge	H	Poor (bare)	High
Hedge height	H	Short	Tall
Hedgerow adjacent	W	No	Yes
Hedgerow cutting frequency	H	Every year	Every 3 years (or more)
Hedgerow cutting season	H	Any other time	Winter
Hedgerow is part of a green lane	H	No	Yes
Hedges are a traditional feature of local area	H & TL	No	Yes
Level of grazing	Gr, I & W	Very high	Low
Level of structural variability	W	Limited structural variability	Highly varied structure
Local area context (forests)	I & W	Other	Local area largely forested
Number of connected aquatic habitats	All	None	Six or more
Number of connected terrestrial linear habitats	All	None	Six or more
Number of ponds present	P	One	More than seven
Pesticides sprayed on adjacent field	H & TL	Yes	No
Pond shape	P	Very regular	Very irregular
Pond substrate	P	Concrete or plastic	Natural
Pond water source	P	Surface flow (intensive agriculture)	Groundwater, river or stream
Presence of pollen bearing plants	All	Low	High
Proximity to other woodland/forest areas	W	Low	High
Shelterbelt height	TL	Short	Tall
Variety of neighbouring ponds	P	No neighbouring ponds or all similar	Very varied
Veteran/ancient trees	H, TL, I & W	No	Yes
Woodland age (years)	W	1 to 5	>26
Woodland commercially harvested	W	Yes	No
Woodland edge shape	W	Straight and uniform	Curvy and variable

Parameter	EFAs	Low	High
Woodland edge vegetation density	W	Sparse	Dense
Woodland edge width	W	None	Wide (>10m)

Table S8: Parameters used to adapt the historical distinctiveness factor for aesthetics

Parameter	EFAs	Low	High
Age of wall (time since construction/repair)	SW	New (1-5 years)	Old (>15 years)
Condition of wall	SW	Poor (derelict)	Good
Feature has infrastructure for visitors	AM, An, Ar, Gr, NM, W	No	Yes
Feature is a significant component in the local landscape	All	No	Yes
Form of the bank	D	Very shallow	Very steep
Hedges are a traditional feature of local area	H, TL	No	Yes
Lichens present	SW	No	Yes
Number of visitors	AM, An, Ar, Gr, NM, W	None	High
Old trees or buildings present within 1 km²	Af, H, I, SW, TL, W	No	Yes
Stonewall material	SW	Other	Limestone
Stonewalls are a traditional feature of local area	SW	No	Yes
Terraces are a traditional feature of local area	Te	No	Yes
Terraces are regularly maintained	Te	No	Yes
Veteran/ancient trees	Af, H, I, TL, W	No	Yes

Table S9: Parameters used to adapt the relief factor for aesthetics

Parameter	EFAs	Low	High
Slope	All	Flat	Steep
Topography	All	Mostly uniform	Banks, ridges, hollows or hummocks

Table S10: Input data for woodland

Parameter	UK1 – W1	UK2 – W2	Germany – W4	Hungary – W15
Quantitative (dimensions)				
Area (m²)	10400	13000	12400	12900
Distance to arable land (no barriers) (m)	0	0	-	0
Distance to arable land (with barriers) (m)	-	-	30	-
Distance to SNH (m)	35	89	35	140
Farm area (ha)	288	266	310	707
Arable area of the farm (ha)	80.6	94.4	155.4	614.8
Gradient	6.8	7.5	0	0
Length of edge adjacent/parallel to arable land (no barriers) (m)	460	51	-	638

Parameter	UK1 – W1	UK2 – W2	Germany – W4	Hungary – W15
Length of edge adjacent/parallel to arable land (with barriers) (m)	-	-	175	-
Rainfall erosivity	340	340	375	815
Slope length	191	81	0	0
Qualitative				
Adjacent vegetation structure	Large area (>1ha) of rough grassland, scrub, hedges or woodland	Short closely grazed grassland or arable crops	Large areas of bare ground	Small area (<1ha) of rough grassland, scrub, hedges or woodland
Adjacent water bodies quality	No adjacent water bodies	No adjacent water bodies	No adjacent water bodies	No adjacent water bodies
Adjacent wildlife corridors	Diverse and complete linear features	No linear features	No linear features	Uniform linear features with gaps
Barriers between feature and arable land	None	None	Vertical and horizontal	None
Crop on adjacent arable land	Cereals	Cereals	Other vegetables	Other industrial crops
Deadwood present	?	?	?	?
Distribution density of adjacent water bodies	0.5 per km²	0.1 per km²	None	0.5 per km²
Diversity of tree species	?	?	?	?
Ecological zone	Temperate oceanic forest	Temperate oceanic forest	Temperate oceanic forest	Temperate continental forest
Feature has infrastructure for visitors	No	Yes	No	No
Feature is a significant component in the local landscape	No	No	No	No
Floral diversity	?	?	?	?
Ground cover (in woods)	?	?	?	?
Hedgerow adjacent	Yes	No	No	Yes
Herbaceous vegetation in woodland edge	?	?	?	?
Level of grazing	Low	Low	Low	Low
Level of structural variability	Moderately varied structure	Some structural variability	Moderate to highly varied structure	Limited structural variability
Local area context (forests)	Local area largely forested	Local area largely forested	Local area largely unforested	Local area largely unforested
Local area context (urban)	<1% urban in surrounding 500m	6-10% urban in surrounding 500m	>20% urban in surrounding 500m	<1% urban in surrounding 500m
Mature trees with basal hollows	?	?	?	?
Noise level	Quiet (<35 dB)	Rather noisy (46-55 dB)	Rather noisy (46-55 dB)	Quiet (<35 dB)
Number of connected aquatic habitats	None	None	None	None
Number of connected terrestrial linear habitats	Two	None	None	Two
Number of visitors	Low	Moderate	None	None
Old trees or buildings present within 1 km²	Yes	No	No	No
Pesticides sprayed on adjacent field	?	?	?	?
Presence of pollen bearing plants	?	?	?	?
Proximity to other woodland/forest areas	High	High	Moderate	Moderate
Skyline disturbance	None within 2.5km	None within 2.5km	Visible <1km	None within 2.5km
Slope	Flat	Moderate	Flat	Flat
Soil texture	Fine	Medium	Medium	Very fine
South aspect	<25% faces south	50-75% faces south	25-50% faces south	50-75% faces south
Topography	Mostly uniform	Banks, ridges, hollows or hummocks	Mostly uniform	Mostly uniform
Veteran/ancient trees	Yes	No	No	No
Woodland age (years)	>26	16 to 20	>26	21 to 25
Woodland edge profile	1 step edges	1 step edges	1 step edges	1 step edges
Woodland edge shape	Straight and uniform	Straight and uniform	Straight and variable	Straight and uniform
Woodland edge vegetation density	Intermediate	Sparse	Intermediate	Intermediate
Woodland edge width	Field edge	None	Narrow (<10m)	Narrow (<10m)
Woodland management	Close-to-nature managed woodland	Close-to-nature managed woodland	Close-to-nature managed woodland	Intensively managed even-aged woodland
Woodland type	Broadleaved	Broadleaved	Broadleaved	Coniferous

Table S11: Input data for hedgerows

Parameter	UK1 – H4	UK2 – H1	Germany – H3	Hungary – H4
Quantitative (dimensions)				
Area (m^2)	1244	1100	960	800
Distance to arable land (no barriers) (m)	0	0	0	12
Distance to arable land (with barriers) (m)	-	-	-	-
Distance to SNH (m)	5	260	8	10
Farm area (ha)	288	266	310	707
Gradient	0	6.4	0	0
Length of edge adjacent/parallel to arable land (no barriers) (m)	622	440	100	100
Length of edge adjacent/parallel to arable land (with barriers) (m)	-	-	-	-
Rainfall erosivity	340	340	375	815
Slope length	0	218	0	0
Qualitative				
Adjacent trees and woodland	Some trees and woodland	Some trees and woodland	None	None
Adjacent vegetation structure	Short closely grazed grassland or arable crops	Short closely grazed grassland or arable crops	Short closely grazed grassland or arable crops	Short closely grazed grassland or arable crops
Adjacent water bodies quality	No adjacent water bodies	No adjacent water bodies	No adjacent water bodies	No adjacent water bodies
Adjacent wildlife corridors	Uniform linear features with gaps	No linear features	No linear features	No linear features
Barriers between feature and arable land	None	None	None	None
Crop on adjacent arable land	Cereals	Cereals	Other vegetables	Bare ground
Deadwood present	No	No	?	?
Density of hedgerow trees	High	None	Moderate	None
Distribution density of adjacent water bodies	>1.3 per km^2	0.1 per km^2	None	0.5 per km^2
Feature is a significant component in the local landscape	No	No	No	No
Floral diversity	?	?	?	?
Ground cover at base of hedge	?	?	?	?
Hedge height	Moderate	Moderate	Moderate	Short
Hedgerow cutting frequency	?	?	?	?
Hedgerow cutting season	?	?	?	?
Hedgerow is part of a green lane	No	No	No	No
Hedges are a traditional feature of local area	Yes	Yes	Yes	Yes
Local area context (urban)	<1% urban in surrounding 500m	<1% urban in surrounding 500m	>20% urban in surrounding 500m	<1% urban in surrounding 500m
Mature trees with basal hollows	?	?	?	?
Noise level	Rather noisy (46-55 dB)	Not noisy (36-45 dB)	Rather noisy (46-55 dB)	Quiet (<35 dB)
Number of connected aquatic habitats	None	None	None	None
Number of connected terrestrial linear habitats	One	None	None	None
Old trees or buildings present within 1 km^2	Yes	Yes	No	No
Pesticides sprayed on adjacent field	Yes	Yes	Yes	Yes
Presence of pollen bearing plants	?	?	?	?
Skyline disturbance	None within 2.5km	None within 2.5km	Visible <1km	None within 2.5km
Slope	Flat	Flat	Flat	Flat
Soil texture	Fine	Medium	Medium	Very fine
South aspect	>75% faces south	25-50% faces south	25-50% faces south	<25% faces south
Topography	Mostly uniform	Mostly uniform	Mostly uniform	Mostly uniform
Veteran/ancient trees	No	No	No	No