Multifunctional Role of Field Margins in Arable Farming

Cambridge Environmental Assessments

European Crop Protection

Contents

Preface

The enclosed report was commissioned by the European Crop Protection Association (ECPA) and prepared by Cambridge Environmental Assessments (CEA), part of ADAS UK Ltd. CEA is an environmental and agricultural consultancy that specialises in regulatory environmental risk assessments for chemicals in Europe, as well as assessing chemical use in the wider agricultural landscape context.

Why did ECPA commission this report?

ECPA commissioned the report as part of the crop protection industry's commitment to promoting Best Management Practices (BMPs) for biodiversity and their integration with crop production practices in European agro-ecosystem landscapes, including the sustainable use of pesticides.

Why the focus on field margins?

Field margins are increasingly being considered as vital habitat for biodiversity in agricultural landscapes. They have the potential to provide semi-natural habitat for feeding, shelter and breeding of wild plants and nesting for small animals and birds, as well as providing corridors that connect such habitats. Also buffers can help prevent soil erosion and the transfer of agricultural pollutants from cropped areas to non-cropped areas, particularly aquatic habitats.
Under the rules established for direct payments to farmers under support schemes – within the framework of the Common Agricultural Policy (CAP) – field margins with a width between 1 and 20 metres on which there is no agricultural production are considered Ecological Focus Areas (EFA)*.

What are the key findings and implications of the report?

The report shows that field margins can be multi-functional in character, not only providing semi-natural habitat for biodiversity, including pollinators for crops and the predators or agricultural pests, but also reducing the effects of runoff and soil erosion. The report also shows that there are many different types of multifunctional margins across Europe that can be adapted to the wide variety of soil-landscape-climate combinations. Since some of these provide benefits to cropped fields, in terms of pollination services or pest control, the implications are that they can be part of a more integrated approach to agricultural production, which integrates the innovations of agronomy and pest management in cropped fields.

How should the report be used?

The intention of this report is to provide a summary of up-to-date information and descriptions of different types of field margins. This report was not produced to prescribe that field margins be implemented around all cropped fields or to insist on the 'best' or 'only way' that they should be implemented. This report offers some outline guidance on how the multifunctional benefits of field margins might be optimised.

* COMMISSION DELEGATED REGULATION (EU) No …/.. of 11.3.2014 supplementing Regulation (EU) No 1307/2013 of the European Parliament and of the Council establishing rules for direct payments to farmers under support schemes within the framework of the common agricultural policy and amending Annex X to that Regulation http://ec.europa.eu/agriculture/cap-post-2013/implementation/pdf/1476/c-2014-1476_en.pdf

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Report for European Crop Protection Association
by Cambridge Environmental Assessments – ADAS UK Ltd

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Executive Summary

This review aims to identify field margin types which have multiple benefits for the environment.

The environmental benefits of field margins depend upon how they are implemented and managed and where they are located within the landscape. Arable field margin management is an important tool used in agri-environment schemes throughout the EU. Field margins are primarily used to promote biodiversity and prevent the transfer of pollutants to off-crop areas. Their potential function in reducing transfer of pesticides is recognised in the use of field margin features such as vegetated buffer strips as mitigation measures in EU risk assessment of pesticides, primarily relating to aquatic risk assessment.

This project reviewed European literature relating to field margin management. Field margins were categorised according to management options available as part of the UK Entry Level Stewardship agri-environment scheme. The environmental benefits of field margins, and the magnitude of these benefits, are discussed in relation to the influence of size, on-going management, location within the landscape, and the landscape scale at which field margins are introduced. Each field margin type was assessed individually with regards to a range of potential environmental benefits. For each field margin type, the most consistent of a range of environmental benefits are presented. A broad comparison of all field margin types is also presented.

The impact of the relative dimensions and area of a field margin varies for different environment benefits. For runoff, width of field margins can be the most important factor in determining the magnitude of reduction for some types of pollutants. For spray drift, the width of a margin can also be the most important factor. For biodiversity, the importance of margin width varies with taxon. This may depend upon the mobility of the species and whether the feature is used as a single habitat within the landscape or as a connecting feature. For each of these environmental benefits, the composition and structure of vegetation in field margins is also important.

The management of field margins will also impact the magnitude and type of environmental benefit produced. Mowing, cultivation and pesticide application can all be used to alter or maintain the composition and structure of field margin vegetation. Mowing is favoured in most situations due to practicality and relative low cost.

Type, timing and frequency of management measures can have different impacts on individual environmental benefits.

Location of field margins is particularly important in relation to reduction of runoff and spray drift. A wildflower sown field margin placed at the boundary of sensitive features, such as watercourses or hedgerows, will provide additional benefit relating to spray drift reduction compared to a field margin which simply separates two fields. For runoff, reduced width buffer strips at the downslope edge of all fields may be more suitable than wide buffer strips adjacent to watercourses. This is because reducing channelization and volumes of runoff in the wider landscape and as close as possible to the source of runoff can be more effective than more localised measures. This also highlights that landscape scale targeting of field margin placement can help to maximise the environmental benefit produced. Landscape scale targeting can be used to increase habitat connectivity as well as heterogeneity of habitat features in the landscape, both of which may be particularly important for birds and mammals.

For each field margin type a table is presented which summarises the specific benefits highlighted in the literature. Broad reviews which assessed numerous studies were favoured in this assessment where possible. The benefits highlighted for each field margin type were then combined in order to provide a final summary of the overall findings of this review, presented below. A scoring system was used to allow comparison of the magnitude of environmental benefits offered by the different field margin types. The magnitude of environmental benefit offered by each field margin type is scored on a scale of -1 to 3. This scoring scale represents:

-1 = Negative impact for the environmental benefit
0 = No positive impact for the environmental benefit
1 = Some benefits for the environmental benefit
2 = Major benefits for the environmental benefit
3 = Most beneficial of all field margin types for the environmental benefit

Evaluation and ranking of multiple benefits of different field margin types

(NR = Natural regeneration, GR = Grass sown, WF = Wildflower sown, P&N = Pollen and Nectar mix, WBS = Wild bird seed mix, AC = Annual Cultivation, CH = Conservation headland)

Environmental Benefit	Attribute	NR	GR	WF	P&N	WBS	AC	CH
Management	Value (AES or crop) vs costs	1	1	2	1	1	1	3
	Practicality	3	3	2	1	1	3	3
Birds	Overall	2	2	2	1	3	3	1
	Summer - Seed & plant food	2	2	3	1	3	3	2
	Winter - Seed & plant food	1	1	1	1	3	3	2
	Invertebrate food	3	2	3	2	2	3	2
Mammals	Diversity	2	3	2	2	2	3	1
	Abundance	2	3	2	2	2	3	1
Pollinators	Food sources	2	2	3	3	1	2	2
	Species richness	2	2	3	3	2	2	1
	Abundance	2	2	3	3	2	2	1
	Hibernation sites	3	3	2	1	0	0	0
Non-target arthropods	Spiders	3	3	2	1	2	2	1
	Beetles	2	3	2	2	2	2	1
	Parasitic Wasps	2	2	3	2	1	1	1
	Soil invertebrates	3	3	2	2	1	1	1
Plants	Overall	2	1	2	1	1	3	3
	Annual arable weeds	1	-1	-1	1	2	3	3
	Perennial wildflowers	3	2	3	1	1	1	1
Aquatic	Aquatic Invertebrates	3	3	2	1	1	1	1
	Plants	3	3	2	1	1	1	1
Pest Management	Weeds	1	3	2	1	1	1	1
	Invertebrate	2	3	3	2	1	1	1
Runoff	Pesticides	3	3	2	2	1	1	0
	Sediment	3	3	2	2	1	1	0
	Phosphorus	3	3	2	2	1	1	0
	Nitrogen	3	3	2	1	1	2	2
Spray Drift	Pesticides	3	3	3	2	2	2	2
Soil	Soil erosion	3	3	3	2	2	1	1

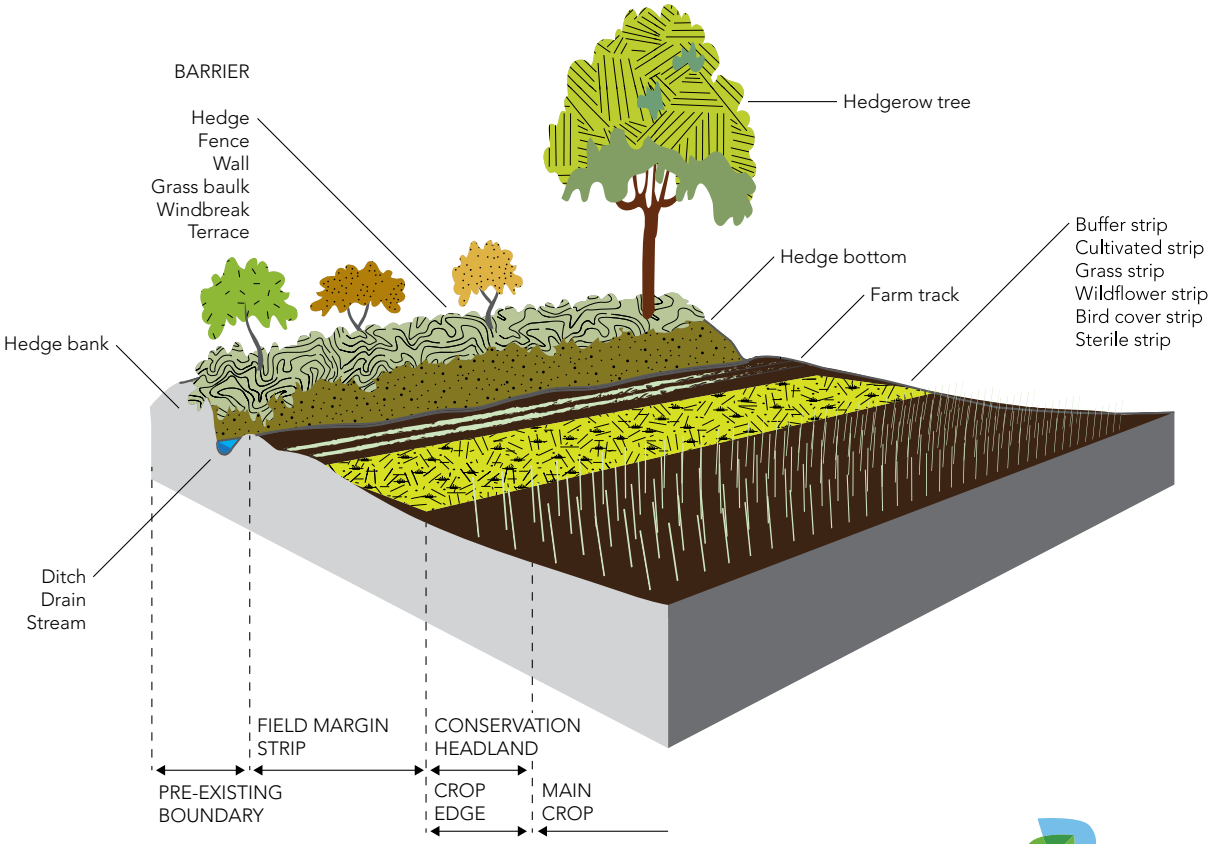
Based on this review it is clear that all field margin types offer multiple benefits. However, all field margin types are identified as having at least one environmental benefit topic for which they provide little or no benefit. In addition, some specific benefits, such as provision of winter seed for birds, are offered only by a few field margin types.

Overall, however, longer term and less disturbed field margins, such as natural regeneration, grass sown or wildflower sown field margins, appear to provide the most consistent environmental benefit across a range of measures.

1. Introduction

Field margins occur at the connection between the arable crop and boundary structures, such as other crops, grassland, hedgerows, woodland and surface water. Below is a general schematic to describe the position of a field margin relative to crop and field boundary structures:

Figure 1: The principal components of an arable field margin
(After Greaves and Marshall, 1987 and Marshall and Moonen, 2002*)



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* Marshall EJP, Moonen AC. 2002. Field margins in northern Europe: Their functions and interactions with agriculture. *Agriculture, Ecosystems and Environment* 89:5-21.

Negative impacts of intensive arable farming on soil, water, biodiversity and landscape[1] have been highlighted. Transfer of pollutants, including silt and sediment, plant nutrients and pesticides, to water and other off crop areas results in impacts on terrestrial and aquatic biodiversity as well as water quality. In the case of plant nutrients and pesticides, this generally occurs as a result of run-off, leaching to ground and drainage. Spray drift to off-crop terrestrial and aquatic environments is also relevant for spray applications of pesticides. Intensification of arable systems has also led to a large decline in biodiversity on arable farmland[2]. This is considered to be the result of loss of non-crop habitat, simplification of cropping systems as well as disruption of food chains[1]. This is particularly well researched and documented for birds[2] which are seen as a sentinel for wider declines in biodiversity.

Ecosystem services, of direct benefit to agricultural production (e.g. pollination, pest and weed control), or of benefit to the wider environment (e.g. biodiversity, water quality), are viewed as an increasingly important part of modern agriculture. There is increasing pressure for ecosystem services to be provided in addition to food and other direct production outputs of agriculture. The provision of ecosystem services in agriculture relies to a large extent upon the diversity of plants and other organisms within and around cropped fields. Field margin management is an important tool in reducing the negative external impacts of arable farming as well as providing positive benefits for crop production and the wider landscape.

Field margins are identified as a key component of agricultural landscapes[3]. This is particularly highlighted for their role in maintaining and promoting wildlife within the cropped area, thus contributing to maintain and promote biodiversity in the wider landscape[3]. Agri-environment schemes (AES) are a central component of Pillar II of the current European Union (EU) Common Agricultural Policy (CAP)[4]. The importance of field margin management is reflected in their inclusion in AES throughout the EU[5]. The Entry Level Stewardship scheme (ELS) in the UK is an example of such AES[6]. Within ELS there are multiple options for field margin management[6]. Different options are designed to produce specific benefits for the environment and the implementation of each option is rewarded with a specific number of "points" (which equate to economic return). Some field margin options are specifically designed to provide particular benefits (e.g. winter seed producing mixtures for birds or pollen and nectar producing flower mixtures for bees and other pollinators). Other field margin options are designed to provide multiple benefits.

As an area of non-cropped habitat within a largely cropped landscape, field margins may provide multiple benefits for biodiversity. Field margins are used for foraging, nesting, feeding, as shelter or for migration and movement by various species. As suitable habitat for invertebrates, field margins also have the potential to provide additional agronomic benefits for the crops which they surround by providing ecosystem services in the form of pollination or pest control. Field margins can also function to reduce and mitigate the negative impacts of intensive arable farming which have been highlighted for soil, water, biodiversity and landscape[1] by reducing the transfer of pesticides and fertilizers via runoff[7] and spray drift[8], and reducing soil erosion[9]. This may in turn benefit biodiversity in off-crop areas and improve water quality.

It is often difficult to quantify whether environmental benefits observed in a study, (e.g. increased species richness) exist within the field margin or the wider farming landscape, and whether benefits occur due to the provision of additional habitat provided by the margin itself, or the increase in quality of adjacent (off-field) habitats due to reduced input as a result of attenuation by the margin. A study which identifies benefits at the local scale may not indicate if benefits are also applicable to the wider landscape as the effects may not transfer beyond the local area. At the most basic level, a field margin provides an additional area of alternative habitat within the farm which can attract and sustain species from the surrounding landscape. Once a species is attracted their numbers will respond to the available refugia and resources provided by the field margin.

If the habitat allows the species to survive from year to year this may act as a new population for that species and individuals from this new population will potentially colonise the surrounding farmland. Field margins can also act as a component of the wider farmland and provide a habitat feature required for a specific stage of a species life cycle or a part of its daily requirements (e.g. nesting site for birds or bumblebees).

Field margins can also separate the cropped area from hedgerows or other off-crop features (including other cropped areas) thus reducing levels of spray drift of pesticides. However, to reduce spray drift to a hedgerow the field margin intercepts the pesticide and may be impacted. The level of impact caused by spray drift will then depend on whether a species occupies the field margin or hedgerow alone. However, as an additional area of non-crop habitat, the field margin can provide suitable habitat for off-field species not affected by spray drift to colonise.

Large variation occurs in the size, location, implementation method and on-going management strategy (both in-year and between year) of field margins. The management strategy used for a field margin influences its potential to provide benefits for the crop, the biodiversity and soil within the field margin and the wider environment of the field boundary and beyond. Multiple options for implementation, management and design of field margins have been investigated in the literature. This is an area which is well researched throughout the EU as field margin management options are regularly used in AES and other schemes designed to promote biodiversity and reduce water pollution.

2. Review methodology

2.1 Purpose of the review

The objective of this review is to identify and categorize arable farmland field margin types with regard to benefits for the environment on the basis of a review of existing developments and projects. The aim of this review is to identify field margins which have the potential to provide multiple benefits for the environment.

2.2 Information sources

2.2.1 Initial list of papers

Various research papers and journal article details were provided at the outset of the project by the project sponsor. Literature searches were also conducted to obtain details of similar research and highlight relevant authors in this field.

2.2.2 Contact with relevant authors

To obtain details of any on-going or current research relating to field margins, selected relevant authors and organisations were contacted by email. Authors and organisation were identified through published work provided by the sponsor and initial literature searches. Details of research and journal citations were provided by several authors.

2.2.3 Open literature review

A search of the open literature using the SCOPUS database was conducted.

Search terms used

A review of results from initial searches identified that different terms were used throughout the literature to refer to field margins. Therefore, a wide variety of terms were combined as one search term. The combined terms used to refer to field margins are listed in Appendix A.

Different searches were conducted for separate environmental benefits. This was required due to the large variety of potential environmental benefits discussed in the literature. The search terms relating to field margins were combined using the AND function with a list of search terms relating to different environmental benefits. The search terms used for each of the environmental benefits, and the number of results produced, are also included in Appendix A.

Filtering of results

Relevant studies were selected according to the following criteria: subject of study, location, agricultural system (conventional) and agricultural landscape.

The most detailed and consistent information was found to relate to conventional European arable agriculture, which was chosen as the focus of the review. However, a brief discussion of projects outside the Europe is included. Organic farming was not the focus of the review.

2.3 Assessment of multiple benefits of field margins

2.3.1 Field Margin Types

Various field margin types were identified in the literature[4-6,10-12], and may be grouped broadly by implementation method. Some field margin types are broadly similar in the benefits which they provide and also the method by which they are introduced and managed. Therefore, it was possible to combine field margin types for the review. By combining similar field margin types the following groups were identified:

- Natural regeneration (NR), sown grass seed mix (GR) & sown wildflower seed mix
- Sown pollen and nectar seed mix (P&N)
- Sown wild bird seed mix (WBS)
- Annual cultivation (AC) & conservation headland (CH)

To introduce the different field margin types, an outline of each is presented in Section 4, followed by a review, in tabulated form, of its environmental benefits.

2.3.2 Assessment of environmental benefits of field margin types

Format of assessment

The environmental benefits of different field margin types are presented in tabulated form to allow ease of interpretation. The tabulated format concisely presents the clear and important benefits for each field margin type. Each field margin grouping is presented in a separate table.

To allow comparison of the different field margin types, a summary of each of the environmental benefits provided is presented. The magnitude of

environmental benefit offered by each field margin type is scored on a scale of -1 to 3. This scoring scale represents:

-1 = Negative impact
0 = No positive impact
1 = Some benefits
2 = Major benefits
3 = Most beneficial of all field margin types

A similar scoring system has been used, by HGCA, to compare field margin types[13] based on large scale projects involving reviews and field studies[14,15]. The HGCA review uses more generalised environmental benefit categories compared to this review; however, the HGCA review scores were considered as evidence during selection of rankings in this review. Broad reviews of field margins[9-12,14-19] were relied upon as evidence for selection of rankings where possible. Broad reviews were favoured as they provided the most consistent assessment of environmental benefits offered by field margins.

To illustrate how the scoring was performed in this review, an example is presented below for the category Management: Value (AES or crop) vs. costs. The ranking for this category is primarily based on the Farm4Bio project[18]. The UK based Farm4Bio project calculated mean gross margins over a 5 year period, based on income from AES payments or sale of crops, for each type of field margin assessed as part of the project.

Gross margins were calculated in the Farm4Bio project based on assumptions and available data on income (value of crop or AES option) and costs (purchase of seed, removal) per ha associated with different field margin types. The calculations do not account for maintenance costs such as diesel or labour required for mowing. AES incomes were based on the UK Entry Level Scheme income/ha generated by each field margin option. In Farm4Bio, gross margins for winter wheat and winter oilseed rape crops were based on data available from other studies for the years 2006 to 2009. Herbicide (glyphosate) use prior to establishment of the field margin and for its removal is assigned a cost of £8/ha. Seed costs from the Farm4Bio project were assigned at £200/ha for FEG (Floristically Enhanced Grassland) and £70/ha for grass margins, WBS (Wild Bird Seed) and IRC (Insect Rich Cover). It was assumed that P&N would have similar seed costs to FEG. P&N gross margin was calculated based on replacement every 4 years (3-5 years recommended in ELS guidance) as this represents mean length for the option. Based on the approach used in Farm4Bio it was possible to calculate mean gross margin for additional field margin types covered in this review (P&N and NR). The gross margins/ha and mean gross margin over a 5 year period for each field margin category from Farm4Bio and this review are presented below in Table 1. Gross margins for all categories have been recalculated for this review, as presented

Table 1: Environmental Scheme (ES) funding/ha and Gross Margins/ha for natural regeneration, sown covers, winter wheat and oilseed rape; 2006-2010. Floristically enhanced grass (FEG), wild bird seed (WBS) and insect rich cover (IRC), natural regeneration (NR) for rare arable plants, Environmental Stewardship (ES) (After Holland *et al.* 2013[18] Farm4bio). Mean gross margins for all categories have been recalculated for this review based on the annual gross margins presented below.

Farm4Bio/**Current** field margin category	ES funding £/ha	Gross margin £/ha					Mean gross margin
		2006	2007	2008	2009	2010	
FEG	485	277	485	485	485	477	442
WBS/ IRC	*450*	364	364	364	364	364	364
WBS biennial	450	364	450	364	450	-	407[b]
Annual NR	400	384	384	384	384	384	384
Grass margin 4m	400	322	400	400	400	392	383
Winter wheat	-	810	788	679	477	-	689[c]
Winter oilseed rape	-	444	445	606	475	-	493[c]
NR[a]	*400*	392	400	400	400	392	397
P&N[a]	450	277	450	450	442	-	405[b]

a The additional categories NR and P&N covered in this review were calculated using the methodology and costs available from Farm4Bio.
b Based upon 4 year field margin cycle
c Based upon 4 years data

in Table 1 – it was not possible to recreate all the calculated financial margins presented in the Farm4Bio project, due either to unreported costs or inconsistencies.

Using the mean gross margin/ha values, re-calculated here for the field margin types in Farm4Bio and this review, it was possible to score the different field margin types as illustrated below in Table 2. This forms a ranking system for the field margins types in this review assigning a score of 3 to CH as the highest gross margin, 2 to WF as the next highest gross margin and because the remaining field margin types are similar they were all assigned a score of 1. A similar approach was used to assign scores for all other environmental benefit categories based on the available information.

Where specific data or information for each field margin type was unavailable for a specific environmental benefit, scores were assigned based on a judgement of similarity to other field margin types for the attributes which primarily affect the environmental benefit category. For example with spray drift, vegetation structure and margin width are the primary relevant variables. As width is not controlled by field margin type, vegetation structure is the most important variable. Therefore, as NR, GR and WF are longer term features with year round vegetation cover, these margin types are considered most beneficial. Assuming no pesticides are applied within the field margins, each of the remaining types can provide similar benefit unless specific vegetation structure is designed for in WBS and P&N seed mixtures or spray applications occur early in the season before vegetation has developed in a particular margin type. Margin width could be more crucial in controlling spray drift than the use of any particular margin type. However, this does not vary between margin types so does not get considered in the scoring system used here.

Caveats to note when considering this review

This review discusses the benefits of different field margin types as they have been identified in Section 2.3.1. However, within each of the different field margin types there are multiple alternative options for management which can affect the benefit which is achieved. The alternative management options will therefore also be discussed in Section 3 to highlight this prior to the analysis of the benefits of alternative margin types.

Table 2: Gross Margins/ha calculated for Farm4Bio[18] and current review field margin categories and their corresponding type and scoring in this review

Farm4Bio/Current field margin category	Mean gross margin £/ha	Applicable field margin type in current review	Review scoring
FEG	442	WF	2
WBS/IRC[a]	364	WBS	1
WBS biennial[a]	407	–	–
Annual NR	384	AC	1
Grass margin 4m	383	GR	1
Winter Wheat	689	CH	3
Winter oilseed rape	493	CH	3
NR[b]	397	NR	1
P&N[b]	405	P&N	1

a Annual WBS option from Farm4Bio was used as this represents worst case.
b NR and P&N categories were not covered in Farm4Bio project. Mean gross margin for both was calculated based on the methodology used in the Farm4Bio project as present above in Table 1.

3. Field margin management options

Apart from the establishment method used to produce a particular field margin type, a wide variety of other management options have been described relating to field margins. Generally, the most important factors which affect field margins relate to the width and size, on-going management method, on-going management frequency and timing, the location within the landscape where the field margin is placed and the landscape scale at which the field margins are introduced.

Each of these management options can be varied to maximise a particular environmental benefit, but other benefits may be compromised in the process. For example, mowing of a grass field margin may promote foraging for birds but this may also damage and kill invertebrate species. Mowing a field margin later to delay the production of flowers and provide late nectar sources for pollinators may not be beneficial for small mammal species which rely on the field margin for cover and protection from predators at that time of year.

Therefore, prior to assessing the various field margin types, aspects of management and establishment which are common to all are discussed below. This provides a discussion of the general themes affecting the level of environment benefit produced for all types of field margin and is based on a review of the literature. A more structured review of the benefits of different field margin types is provided in Section 4.

3.1 Size

The width and length of a margin can influence the magnitude of environmental benefits which can be achieved and different margin widths are specified for different purposes e.g. spray drift vs. runoff of pesticides. For example, assuming that the rate of sediment removal from runoff is proportional to the length of vegetated margin through which it travels, the wider the margin the greater the environmental benefit. However, the size of a field margin feature will also affect the amount of agricultural land which must be removed from production increasing the loss of income to the farmer and level of financial support which may be required. If it was assumed the rate of sediment removal from runoff did not increase beyond 1 m then a wider field margin would not provide additional benefit and it would require removal of additional land from production. For runoff related transfer of pollutants, field margin width varies depending on the substance, with wider margins required for water soluble substances, such as nitrogen, compared to sediment or sediment associated pollutants[9].

If we consider field margins as an area of habitat, another consideration of size is whether that area should be spread out evenly throughout the landscape or concentrated into larger continuous sections. If it is assumed that an increased supply of winter seed for birds results in increased winter survival then a larger area dedicated to its provision is favourable. However, the location within the landscape in which the seed source is placed may be also relevant in this case. Assuming that the presence of winter sources of seeds at the landscape scale is most relevant then a large area in one out of every ten fields, for example, may be most useful. This would also increase efficiency in terms of implementation and on-going management and reduce the number of farms which need to be targeted for this measure in the landscape. Conversely, if the number of sources of winter seed at the farm scale was more important, then planting 1 m strips of grain at all field margins may be more beneficial than large blocks of seed. Similarly, the same overall area devoted to field margins implemented in different ways can potentially influence the benefits provided (i.e. either a 2 m width at the full perimeter of multiple fields vs. a 10 m width implemented within only one field). Therefore, the smallest margin width required to achieve a specified benefit should be favoured. For sown wild bird seed margins, which are designed to provide a stable supply of seed throughout winter, the ELS handbook[6] identifies wild bird seed mixtures as requiring a minimum width of 6 m. This will mainly be required in winter as a food supply for birds when territorial restrictions on movement (e.g. nest site location) are reduced[12]. During summer, field margins which provide high insect food sources for birds may be more beneficial if distributed widely next to hedgerow features as many species nest in or at the base of hedgerows and will preferentially forage nearby[12].

3.2 On-going management method

The on-going management methods used to maintain a favourable vegetation community within a field margin is also an important consideration.

Again this will depend on the vegetation community which is targeted. In the case of promoting the availability of pollen and nectar, the aim is to reduce the competitive advantage of grass and unfavourable weeds. This can be achieved by mowing to provide light and space for flowers to compete with grass species which tend to dominate margins. Alternative management methods for establishment of seed, such as scarification of soil, to increase germination sites for flowering seeds, or application of graminicide, to stunt grass growth, have also been tested[20-23] and can produce different vegetation communities which may provide additional benefits for beneficial arthropods (spiders)[22] and pollinators (butterflies)[20]. Scarification of the soil surface provides conditions similar to standard cultivation methods, while not fully cultivating the soil, which encourage an early successional plant community[23] by increasing the area of bare soil. Neither graminicide nor scarification are currently included as management options under the UK ELS[6,22]. Spot treatment of problem weed species is also relevant and permitted under some AES. Mowing is favoured in most situations due to practicality and relative low cost. Additional on-going management options include removal of cuttings or leaving cuttings in place following mowing. Compared to leaving cuttings in place, removal of cuttings has been shown to promote growth of existing flora and increase species richness in a long-term study[24]. Removal of cuttings can also help to reduce the nutrient balance of the margin[25]. However, due to strong interaction and connection between the crop and the field margin, high nutrient status is likely to be inevitable[25]. Leaving cuttings in place will generally favour dominant, competitive species and reduce plant and animal diversity[12]. Conversely, however, cuttings left in place could also be assumed to promote soil organisms as a source of detritus and organic matter and by increasing the litter layer. The litter layer also provides overwintering habitat for foliar insects[12].

Different taxonomic groups may have different requirements relating to field margins, and margins established to benefit one taxonomic group may not benefit another. Pollinators, including bees and butterflies, require a source of nectar and pollen from spring to autumn. This can be provided by sowing flower seed mixtures which are mown to help establish the community. Equally, pollinators require refugia for hibernation, which may consist of undisturbed areas of soil and vegetation.

Soil organisms are promoted through reduction in disturbance of soil, benefitting from methods with limited requirements for re-cultivation. Soil as a component of biodiversity itself also is promoted through minimal disturbance. Reduction in the transfer of pollutants via runoff and spray drift to aquatic areas adjacent to fields would also be achieved by minimum disturbance of soil and promotion of dense (and tall in the case of spray drift) vegetation growth. Rare arable weeds may not benefit in any option discussed above as they rely on low-intensity arable cropping systems and suffer as a result of modern control techniques and changes in cultivation timing[26]. Cultivation methods which match the in-field crop can also promote economically relevant weed species and implementation methods which inhibit this growth will generally be favoured by farmers.

The timing of on-going management is also important. Different management may be required in the first year following implementation compared to subsequent years. For example, for sown wild flower mixtures repeat cutting in the first year may be required but in subsequent years less cutting may be required. Wild flowers may be promoted by mowing early in the growing season to reduce the competitive advantage of grasses. Alternatively, early cutting may not favour ground nesting bird species which rely on thick vegetation early during the breeding season. Similarly, late cutting will not favour bird species if the margin is to be used as a source of seed in winter.

Reducing transfer of pollutants to surface water via runoff would require thick vegetation cover to be present at times when runoff volumes or runoff pollutant concentration is highest. However, as runoff reduction does not depend on height of vegetation and may be impeded by it, this would likely be favoured by repeated cutting. However, minimal vehicular activity within field margins is recommended to prevent formation of preferential flow paths caused by tractor tramlines[9,27,28]. Also for runoff generally, ideal timing of management depends on rainfall events as well as application timing for pesticides and fertilizers[9]. Separation distance and vegetation structure are the most relevant attributes relating to spray drift which can be controlled through management of field margins[8].

The vegetation component of field margins may also vary with age as a result of natural succession of vegetation communities. This can affect the quality of the field margins for the targeted environmental benefit. For example, subsequent to sowing of wild flower, pollen and nectar and/or wild bird seed mixtures, the vegetation will vary to favour the plant

species which respond most favourably to mowing. This can result in a decrease in the benefit that each particular margin provides for target groups such as pollinators or birds. To re-establish favourable field margin vegetation communities and maximise the resources provided, repeated cultivation and reseeding may be required. Cultivation and reseeding may have knock-on effects for other aspects such as reduction in the potential of the field margin to intercept run-off, removal of any source of cover or refuge sites at an important time of the year and disturbance of soil biodiversity. It also involves additional cost which would make this method less favourable. The ideal situation would maximise functionality, with minimal management requirements and no requirement for repeated cultivation.

3.3 Location and landscape scale of field margin introduction

The location and landscape scale at which field margins are introduced is also important. Promotion of biodiversity, for example, can be treated as a local scale or landscape scale issue. The same can be said for runoff to surface water. Field margins can be targeted to regional areas to take account of locally important arable plant species and target management to promote these species. Alternatively, it is possible to consider a landscape as a whole and to favour methods of management which provide maximum benefit for the majority of species so that plant species richness is increased throughout the landscape. Both options would require different targeting of resources. If considering all species it may be more beneficial to ensure that the margins of all fields within the landscape are managed to promote growth of diverse plant communities in some way. This would require a restricted area of land and reduced management cost within each field to achieve landscape scale coverage. Targeted approaches at local scales within the landscape are likely to incur higher additional costs. However, targeted approaches could be used for particularly rare or threatened groups. For different groups of species the scale of introduction of a particular type of field margin may also be important, as discussed in Section 3.1 for birds. This can vary between species in the same taxonomic group (e.g. mammals[29]). The location of field margins within the landscape is also an important point if landscape connectivity is to be considered. To maximise landscape connectivity using field margins, the location of existing semi-natural habitats[29-34] and features[35,36] within the landscape may need to be considered.

Measures required for compliance with some EU legislation, such as the Nitrates Directive and Water Framework Directive (and in some situations the Birds Directive and Habitats Directive), act on large scales and can be strictly controlled through regulation. For example, no-spray buffer zones restricting fertilizer and manure application within certain distances of water bodies and domestic water sources are required in catchments designated as "nitrate vulnerable zones" (NVZ) under the Nitrates Directive. As part of cross-compliance, single farm payment penalties can be incurred for failure to adhere with NVZ buffers. Birds and Habitats Directive designations often require famers to comply with mandatory management requirements. It has been highlighted that a third of important farmland bird, mammal, reptile, amphibian and bumblebee species operate at scales greater than the typical English farm (146 ha)[37]. In this paper McKenzie *et al.* also considered the potential benefits for biodiversity and other ecosystem services and challenges of implementing AES at the landscape scale in the form of collaboration between farmers (cAES)[37]. Based on face-to-face interviews and online consultation, more than 75% of farmers indicated willingness to participate in collaborative schemes. Such schemes would be unlikely to negatively impact species operating at smaller scales while being more beneficial for species which operate at larger scales than current farm-scale schemes.

Benton *et al.* (2003)[38], highlighted that heterogeneity at the farm and landscape scale is very important for biodiversity (particularly birds) and that field margin habitats are a very practical and favourable way of establishing this heterogeneity at local and landscape level. For field margins, variation in management methods used and their location with respect to boundary and other habitat features within a farm can increase floral diversity at the farm scale[39]. Similarly, variation between farms can increase diversity at the landscape scale[39]. It is also recognised that effective conservation of farmland mammals should rely on landscape scale measures, addressing such issues as habitat connectivity between farms[33]. Other authors have also suggested that agri-environment scheme administrators may need to address landscape structure and average field size to achieve significant enhancement of populations of declining farmland species[40]. Landscape scale initiatives for field margin introduction are particularly important when considering aquatic features such as rivers (e.g. CORPEN[9]) and also with regards to improving landscape connectivity.

4. Specific benefits of different field margins types

Field margins have the potential to provide multiple benefits for the environment. However, as discussed above, the effectiveness of field margins depends on their design, management and placement at local and landscape scales. The importance of the different aspects of field margin management vary depending on the environmental benefit being considered. Therefore, this review will consider each environmental benefit separately for each field margin type.

For each field margin type a table is also presented which highlights the environmental benefits which are consistently identified in the literature. Field margins assessed in the literature were categorised based on their similarity to field margin types available as options under UK ELS. Methods sections of studies do not always include the level of detail relating to management actions covered by ELS guidance. Therefore, it was difficult to fully assess similarity to ELS in some cases. Deviation may occur in the specific management applied to field margins in different studies and all margins may not fully comply with the requirements of ELS. However, variation is also possible for management of each ELS option. Therefore, potential variation outside of ELS prescriptions is not expected to affect the overall conclusions of this review. Broad reviews which assessed numerous studies were favoured in this assessment where possible, in an effort to reduce the effect of variations in field margin management between studies.

In Section 5, the results are combined with the findings other reviews to rank field margin types in terms of their importance for different environmental benefit categories. This is presented in tabulated form as a final summary of the overall findings of this review.

European research and AES covering different field margin types

Reviews covering the different types of measures used as part of European AES are available for pollinators[41], insects[16] and environmental benefits generally[4]. A database of European biodiversity research related to AES is available[42] and a review of studies assessing the effects of all farmland conservation measures is also available[10]. Each of these studies highlights the UK as a detailed source of background information and abundant research on field margins and AES measures in general. There is also a greater variety of AES options available in the UK, compared to other countries[41]. However, as with this review, English language searching conducted as part of many of these reviews is likely to be relevant as a source of bias. Other major countries for research relating to AES measures include Germany, Switzerland, the Netherlands and France[42].

Field margins are also highlighted as the most researched farmland conservation measure category[42].

Buffer strips are an important tool used in mitigation of runoff and spray drift in Europe and beyond and are included as AES options in the majority of EU countries (e.g. Poland, Czech Republic, Greece, Belgium, Estonia, Denmark (regulatory), Sweden, Finland)[4]. Buffer strips are not available as options under AES in some countries (e.g. Cyprus, Hungary, Slovenia, Austria, Germany, Spain, France, Italy, the Netherlands)[4]. This may be due to the use of alternative measures which are better suited to regional conditions[4]. Buffers may already be a requirement of agricultural good practice standards[4] or are a requirement of legislation or part of cross compliance for single farm payments, as is the case for watercourses in the UK (2 m), Italy (5 m) and Denmark (10 m).

A review of the use of sown wildflower strips and areas (sometimes as set aside) for insect conservation in Europe presents details of a selection of countries which include this measure as part of AES[16]. This is presented below in Table 3. As can be seen in Table 3, the composition of seed mixtures sown varies between countries. In the UK, wildflowers can be sown with grasses, using hay meadows as a model. In the UK and also in other countries different mixes are used without the inclusion of grasses which produce very different sward compositions requiring different management[16]. The UK pollen and nectar seed mix AES option performs best in terms of flower production when it is reseeded after the margin has matured after several years[6]. Other wildflower sown margins will improve with increasing age and are more suited to long term implementation[6,16]. However, the general purpose in each case is to produce a species rich sward which provides resources for pollinators and contributes to biological pest control by favouring insect predators[16].

Table 3: Selection of countries that have schemes for sown wildflower strips, wildflower areas or set aside sown with flower mixtures in their 'Rural development programme, 2007–2013'.

(After Haaland *et al.* 2011[16])

State	Sown wildflow-er strips	Wild flower areas (sometimes as set side)	Term	Seed mixtures	Size	Management
Austria	x	x	Flowering strips (Blühstreifen) Flowering areas (Blühflächen; Biodi-versitätsflächen)	At least two flowering species, for example clover, Phacelia, or sunflower. Can additionally contain grasses	Strips 2.5–12 m wide	Cutting after 1 August, once per year
Finland		x	Landscape set aside	For example Phacelia, cornflowers, poppies		
Germany*, Niedersachen	x	x	Flowering strips (Blühstreifen) 'Colourful fallow' (Buntbrache)	30 species recommended including legumes, the mixture must contain several of these species and not more than 10% legumes	3–24 m wide	Cutting if necessary, but not between 1 April and 15 July
UK	x	x	Sown wildflower strips/pollen & nectar flower mixture	Mixture of wildflowers and grasses or pollen & nectar flower mixture (legumes)	2–6 m wide, pollen strips at least 6 m wide	After the first year recommended to cut once per year after mid-September pollen and nectar strips can be grazed in winter
Switzerland	x	x	Colourful fallow' (Buntbrache) Improved field margins (Säume)	Usually 24–37 wildflower species, no grasses	Variable, often at least 3–4 m wide	Cutting once per year is recommended but often not carried out
Sweden**		x	Biodiversity fallow (Mångfaldsträda or bioträda)	Recommended species include clover, meliot, black medic, bird's-foot-trefoil, vetch and chicory	At least 10 m wide	Occasional cutting is recommended, but not allowed before August

* Each Land has its own Rural development programme, several Länder offer schemes for wildflower strips.
** Schemes on set aside sown with seed mixtures in several län (counties).

AES measures to benefit pollinators and the level of uptake of these measures throughout the EU has also been reviewed[41].

Creation of flower strips and fallows are included as a measure in AES in Belgium, Czech Republic, Estonia, Finland, Germany, Greece, Ireland, the Netherlands, Sweden, Switzerland and the UK[41].

Wild bird focussed options, involving the sowing of seed mixtures to produce abundant seed resources, are less well researched compared to pollinator and insect focussed field margin measures[10,42]. The UK is highlighted as a major source of research with some research also available from France[10,42]. Options specific to birds are also available in other countries which can include measures for sowing of seed mixtures.

Conservation headlands, crop edges without herbicide or insecticide application, are a normal part of agricultural practice in many countries and can be used as a mitigation measure to reduce pesticides spray drift to off-crop areas. Their value and use has been evaluated in various countries in the EU (e.g. Finland, Germany, the Netherlands, Sweden, the UK)[10] with the UK highlighted as a major source of research[42].

Annual cultivation without sowing of crop (also referred to as fallow plots[41], uncropped wildlife strips[12,43] or rotational set-aside[12]) is an historically common whole field agricultural practice for soil fertility and weed management and reduction of production outputs. It is now less common due to modern crop rotations, use of cover crops and removal of CAP set-aside requirements. However, it is retained as AES option in many European countries[41]. As a field margin feature the majority of research has been focussed on the UK with some research also available from Finland, Sweden, Germany and Austria.

Field margin research from outside the EU

A large volume of research on field margins has been conducted in the United States (US) relating to the use of field margins to supply environmental benefits. The use of field margins as buffer and filter strips to reduce transfer of pollutants in runoff[44-47] and spray drift[48] is particularly well researched. Research which considers the potential for field margins to provide multiple benefits is also available[49-51].

As part of guidance on the establishment of vegetated buffers strips, a United States Department of Agriculture (USDA)[52] review concluded that buffer features are an effective method of reducing pesticide transfer to water. A maximum width of approximately 15 m and a minimum width of approximately 10 m are considered adequate for most pesticides in this review. This is broadly similar to the conclusions of the CORPEN[9] review, and the guidance produced, which recommends buffer width of between 10 m to 20 m for 70 to 80 % reduction efficiency of pesticides. The USDA guidance also concludes on the additional importance of using buffers as one tool within a variety of measures which are implemented to match the local conditions and runoff risks. The importance of the location within the landscape for placement of buffers as well as the importance of management of vegetation and restriction of vehicle traffic within the margins is also highlighted which are in general agreement with the conclusions and recommendations of CORPEN[9].

One US study considered the potential for different landscape scale targeting options for buffer features to produce multiple benefits (water quality improvement, erosion control, wildlife habitat improvement, and stormwater mitigation)[49]. This study concluded that the location of buffers within the landscape has an important impact on their cost in terms of resources as well as the range of benefits produced[49]. Soil survey-based and topography-based buffer targeting strategies were more cost-effective than riparian focused options. This is in agreement with current European conclusions[9,53] that placement of buffers within the wider catchment can be more effective for mitigation of runoff compared to riparian margins.
A review highlights the importance of field margins as a tool for the enhancement of pollinators and other insects as a source of food resources as well as shelter and refuge[50]. A US and European focussed review of the potential benefit of pollinator habitat enhancement measures[51] (including field margins) highlights the importance of these features, in addition to expected benefits for pollinators and other insects, for ecosystem services such as wider biodiversity, pest population reduction, protection of soil and water quality by mitigating runoff and protecting against soil erosion, and enhancement of rural aesthetics[51].

4.1 Natural regeneration (NR), sown grass seed mix (GR) & sown wildflower seed mixture

For each field margin type the management strategy as used under the UK ELS is used to illustrate the standard establishment and management methods used[6]. The ELS field margin types referenced in this review also reflect AES options available in other EU countries.

4.1.1 Natural regeneration (NR) and sown grass seed mix (GR)

Establishment and Management

Based on the UK ELS handbook[6], the establishment and management guidance for the option which applies to GR and NR is as follows:

EE1 (2 m), EE2 (4 m), EE3 (6 m) Buffer strips on cultivated land
For these options, you must comply with the following:

- Establish or maintain a grassy strip during the first 12 months of your agreement, either by sowing or, ideally, by natural regeneration. Remove any compaction in the topsoil if you need to prepare a seedbed, except on archaeological features.
- Regular cutting in the first 12–24 months may be needed to control annual weeds and encourage grasses to tiller. Avoid cutting when the soil is moist, to prevent further compaction. Do not apply any fertilisers or manures.
- Only apply herbicides to spot-treat or weed-wipe for the control of injurious weeds (i.e. creeping and spear thistles, curled and broad-leaved docks or common ragwort) or invasive non-native species (e.g. Himalayan balsam, rhododendron or Japanese knotweed).
- After the first 12–24 months of your agreement, cut buffer strips only to control woody growth, and no more than once in every 2 years.
- Do not use buffer strips for regular vehicular access, turning or storage. There should be no tracks, compacted areas or poaching.

Placement of buffer adjacent to watercourse
In-field and edge of field buffers, rather than riparian buffers, which break up the flow of runoff or alternative buffer features, which match the flow path of runoff, are more effective and efficient when concentrated flow is an issue. Edge-of-field buffers which are separated from the water feature are generally more efficient for reducing runoff transfer than riparian buffers.

Positioning buffer strips nearest to vulnerable fields is usually the most effective strategy for mitigation, as flowing run-off water tends to form channels of concentrated flow within the field, as rivers and streams already do within the landscape, as it passes downhill. This would suggest that in-field and non-riparian edge-of-field buffer strips may be most efficient use of land area.

EE1 (2 m), EE2 (4 m), EE3 (6 m) can also be used adjacent to watercourse features with the following additional requirements from the ELS handbook[6]:

EE9 6 m buffer strips on cultivated land next to a watercourse
EE9 should always be used when a 6m buffer on cultivated land is placed alongside a watercourse.

For this option, you must follow the management for options EE1/EE2 and in addition comply with the following:

- After the first 12–24 months of your agreement, cut the 3 m next to the crop edge annually after mid-July. Only cut the other 3 m to control woody growth, and no more than once every 2 years.

EJ9 12 m buffer strips for watercourses on cultivated land
This option aims to reduce the risk of transport of potential pollutants, such as sediment, nutrients (principally phosphate) and pesticides, to watercourses.

This option is intended for land adjacent to ditches, rivers or streams where it can intercept and remove sediment, organic material, nutrients and chemicals carried in run-off water. These buffer strips must not overlap with the cross compliance requirement not to cultivate land within 2 m of the centre of a hedgerow or watercourse (and within 1 m of the top of the bank of a watercourse). This option is only available on arable or rotational land that has been identified as at risk of soil erosion or run-off.

For this option, you must comply with the following in addition to the requirements of EE1, EE2 or EE3:

- The width of the strip may vary between 12 and 24 m along its length but must not be less than 12 m wide at any point.
- Do not apply any fertilisers or manures.
- After the first 12–24 months, cut the 6 m next to the crop edge annually after mid-July. Only cut the remainder to control woody growth, and no more than once every 2 years.
- Do not graze the buffer strip.

Factors affecting uptake of NR and GS options

NR is favourable over GS due to the lower initial cost of establishment. Natural regeneration can also produce a diverse fauna on lighter (non-clay) soils where there is a diverse local seed bank[43]. However, if there are existing issues with weeds in field boundaries this will affect uptake and long term management of margins[43].

Sowing with grass seed mixtures is recommended where weeds are already an issue[43]. However, sowing grass seed is not favourable in situations where rare or locally important annual species are present. As perennial options NR and GS require reduced input and management once established. They may require intensive mowing in first two years to reduce weed pressure. However, beyond this management requirements can be minimal.
The ease of management and extended life of these margins are likely to promote uptake.

4.1.2 Sown Wildflower seed mixture (WF)

Wildflower seed can be incorporated as an additional component of buffer options relevant to NR and GS, including 6 m buffers adjacent to watercourses (EE1-EE3, EE9).

Establishment and Management

Based on the UK ELS handbook[6], the establishment and management guidance for the option which applies to WF is as follows:

EE12 Supplement to add wildflowers to field corners and buffer strips on cultivated land
The aim of this supplement is to create flower-rich areas on cultivated land that will provide valuable sources of food for invertebrates and birds, and a greater diversity and structure of vegetation compared to grass only areas.

This supplement can be used with field margin options for sown grass seed mixture and natural regeneration (EE1-EE3, EE9). It must not be used to sow wild flowers into established buffer strips, field corners and in-field grass areas unless the areas are present at the start of the agreement and will be managed to ensure successful flower establishment in the first year.

You must follow the management for the base option except the sowing and cutting requirements and in addition comply with the following:

- By the end of the first 12 months of the agreement, establish a mix or maintain existing areas containing fine-leaved grasses (such as crested dog's tail, chewings fescue, slender red fescue, smooth-stalked meadow grass and common bent) and flowers (such as knapweed, bird's-foot trefoil, self-heal, oxeye daisy, yarrow, wild red clover and wild carrot).
- Where sown, the flower component must be included at a minimum seed rate of 1.0 kg/ha.
- Do not sow tussock-forming grasses such as cocksfoot, meadow foxtail and meadow fescue, as these can swamp the wild flowers.
- By the beginning of year three, there must be at least five flower species (excluding injurious weeds) and three fine-leaved grass species present frequently across the flower-rich area. Maintain this floristic area for the duration of your agreement.
- Regular cutting and removal of cuttings in the first 12 months after sowing may be needed to ensure successful establishment of sown species.
- After establishment, cut the whole area to 10 cm between 1 August and 30 September, removing cuttings to avoid patches of dead material developing. If excess vegetation threatens to suppress the flowers, cut again the following March or April providing no birds are nesting in the flower-rich area.

Factors affecting uptake of WF options

WF margins allow for additional income to be generated from NG and GS options under UK AES options based on similar management. The WF supplement also ensures that a wildflower component is incorporated which can benefit a wider variety of biodiversity. This may be particularly important where GS is required to help control weeds. The additional supplement provided when WF is established under ELS[6] ensures that additional costs (higher seed prices and more intensive initial and ongoing management), compared to NR and GS, are rewarded. In an assessment of the economic value of AES field margin options studied as part of the Farm4Bio project, WF, as Floristically Enhanced Grass mix, was calculated as the most valuable option based on gross margin earned over a five year AES period[18].

Table 4: Benefits of field margin type - Natural regeneration, sown grass seed mixture EE1 (2 m), EE2 (4 m), EE3 (6 m) and sown wildflower seed mixture (EE9)

Category	Specific benefit	Details
Birds	**General**	Nine studies from the UK found that planting floristically-enhanced grass buffer strips (some grass-only) benefits birds, resulting in increased numbers, densities, species richness and foraging time[10]. Four replicated, controlled studies from Switzerland and the UK and one review of European studies found evidence that plots sown with a **wildflower** or legume seed mix had a positive influence on birds[10]. **Flower strips** attracted more birds or bird species compared to other farmland habitats and the number of birds using flower strips increased over time[10].
	Summer seed and plant food resources	Sown wildflower strips provide abundant annual weed and perennial herb seeds and some biennial seeds[12]. Comparing several treatment types, the most diverse and abundant plant food resources will be derived from naturally regenerated margins (e.g. set-aside) and **wildflower strips**[12].
	Invertebrate food resources	Comparing several treatment types, the most diverse and abundant invertebrate food resources will be derived from naturally regenerated margins (e.g. set-aside) and **wildflower strips**[12].
	Mammal food resources for birds of prey	Field margin management treatments that benefit small mammals e.g. voles, mice and shrews will also benefit the birds that feed on them—such as barn owl *Tyto alba* and kestrel *Falco tinnunculus*. Experimentally established **grass margins** supported more small mammal prey for raptors such as kestrels and nocturnal hunters such as barn owls than permanent set-aside[12,54]. The abundance of small mammals such as bank voles *Clethrionomys glareolus* and common shrews *Sorex araneus* has been shown to be enhanced in grassy field margins compared with conventionally managed field edges[12,55].
Mammals	**General**	Five studies investigating the effects of wildflower strips on small mammals (four replicated studies from Switzerland and one review of studies from northwestern Europe) found evidence that small mammals benefit from strips **sown with wild flowers** or flowers rich in pollen and nectar, with increases in abundance, density and species richness[10].
	Density / activity	Five studies from Finland and the UK, found that planting grass buffer strips benefits small mammals: including increased activity and numbers[10]. In March the density of small mammals was significantly higher in **wild-flower** (mainly due to common vole) and **herbaceous strips** than in the other habitat types[56].
	Biomass	Total small mammal biomass increased between spring and autumn on the 3 and 6 m-wide grassy margins and decreased on the conventionally managed field margins (intensively cultivated to field edge)[55].
	Diversity	**Herbaceous strips** supported the highest diversity of small mammal species, with six species caught, compared to autumn-sown wheat, high and low-intensity grassland and **wild-flower strips**[56].
	Shelter / refuge	Habitats that were not mown each year supported the highest densities of small mammals. Wild-flower and herbaceous strips, make up an important refuge for small mammals. This can also promote **predator species** that depend on small mammals, particularly if a mosaic with mown surfaces is created[56].
	Voles	In a study which compared small mammal abundance and biomass in spring and autumn on 3 and 6 m wide **grass sown field margins** with that on conventionally managed field margins bank vole and common shrew numbers were higher on the grassy margins in autumn than on conventional field margins (intensively cultivated to field edge)[55]. Margin width was positively associated with bank vole abundance[55]. Overall **sown wildflower field margins** were high-quality habitats for voles and sustained high population densities without increased risk of voles dispersing into adjacent fields[57]. One replicated study from Switzerland reported that most common vole home ranges and core regions of their territories were found within a wildflower strip[10].

Category	Specific benefit	Details
Pollinators	Species richness	**Wildflower sown field margins**, when compared to intensive crop management resulted, in a stable, perennial vegetation community with both legumes and regulating hemi-parasitic plants that supported significantly more pollinator species [58].
	Bumblebees	A review found grass margins benefited bumblebees and some other invertebrates but did not distinguish between the effects of several different margin types[10].
	Bees	Positive impacts on diversity or abundance for bees for **6 m grass sown field margin**. Bee numbers were significantly lower in field centres where there were no **grass sown 6 m field margins**[40].
	Butterflies	**Wildflower sown field margin** seed mixtures introduced using scarification of soil, to create germination niches for sown wildflower seeds, and managed using graminicide treatment, to reduce the dominance of competitive grasses, produced the greatest cover and species richness of sown wildflowers. Butterfly abundance, species richness and diversity were positively correlated with sown wildflower species richness, with the highest values in the combined scarification and graminicide treatment[20].
	Early & late food source	**Grass and wildflower mixture sown field margins** had the highest bumblebee abundance, and provided a consistent supply of forage species, with different components of the seed mixture flowering in each year[59].
Non-target arthropods	General	Forty-one studies from eight European countries found evidence that flower strips had a positive influence on invertebrate numbers with increased species abundance, diversity, or both diversity and abundance[10]. Nineteen studies from Finland, the Netherlands, Sweden and the UK, found that planting grass buffer strips (some margins floristically-enhanced) increased arthropod abundance species richness and diversity[10]. Introduction of **botanically diverse field margins** is an important method of increasing the arthropod diversity of semi-natural habitat in farmland[60].
	Species richness	Arthropod diversity was greater in **wildflower sown field margins**, compared to grass sown field margins, crop edge and crop[60].
	Hibernation & reproduction	Over-wintering arthropod diversity from soil samples was greater in **grass and wildflower mixture sown field margins**, compared to grass sown field margins, crop edge and crop[60]
	Movement and habitat corridors – Beetles	Beetles use field margins as corridors to recolonise suitable habitat[61]
	Beneficial arthropod predators	**Wildflower sown field margins**, when compared to intensive crop management, resulted in a stable, perennial vegetation community with both legumes and regulating hemi-parasitic plants that supported significantly more pollinator and herbivore species, as well as higher abundances of beneficial arthropod predators[58].
	Spiders	Lycosid spiders were consistently more abundant in boundaries of small fields with 6 m margin strips[40].
	Beetles	One replicated controlled study showed that ground beetles were more active or had enhanced feeding/reproductive conditions in **sown wildflower strips**. A review found **sown wildflower strips** supported ground beetle species that were rarely found in crops[10].
	Boundary species - Orthoptera	Positive impacts on diversity or abundance for Orthoptera for 6 m grass sown field margin. Orthoptera which were only found in field boundaries were more abundant where 6 m field margins were present[40]. Require tall vegetation and mixed grass sward. Mowing in August causes adult mortality and dispersal[62].

Category	Specific benefit	Details
Plants	General	**Grass and wildflower sown field** margins maintained significantly higher species rich than naturally regenerated margins even after 13 years[24]. Seven studies from the Netherlands and the UK, found that planting grass buffer strips (some margins floristically-enhanced) increased the cover and species richness of plants[10]. Regularly disturbed crop areas support only a small number of species, compared with field margin[61]. With the exception of rare arable weed species, **grass sown field margins** are a positive influence on boundary flora diversity and reduce boundary or margin weeds in arable landscapes[63]. **Removal of cuttings** - Leaving cuttings in place after mowing produced species-poor swards in **naturally regenerated** as well as **grass** and **wildflower** mixture sown field margins[24].
	Perennial wildflowers	Most perennial species of field margins are not adapted to successful establishment in arable crops in lowland Britain[61]. Non-disturbance encourages perennial species, which can become crop weeds, and limit annuals [61].
	Hedgerow / Woodland plants	Perennial plants of field margin are normally associated with hedgerows61. Field margins can act as habitat corridors by allowing colonisation and dispersal of species from woodland habitats[61]. Higher species richness in hedgerow boundaries adjacent to 6 m g**rass sown field margin** [40,63].
Aquatic organisms	Reduced spray drift	Highly reduced levels of spray drift can promote all aquatic biota potentially impacted by different pesticide types.
	In-stream Nutrient cycling	Inclusion of woody vegetation such as bushes and trees at watercourse margins can increase woody debris which can promote in-stream microbial nutrient cycling[25,64].
	Aquatic plants	Large riparian buffer width or increased buffering in the landscape can reduce eutrophication and pesticide transfer, and can promote high value riparian habitats[65].
	Aquatic invertebrates	Addition of taller vegetation, such as trees and bushes, may provide additional organic matter and alternative shading conditions within watercourse which can benefit aquatic invertebrates[25,65].
Pest Management	Plant weeds – General	Sowing grass is preferable with respect to weed control[66]. Little relationship between the margin and the field weed flora[61]. Rapid establishment of tall, competitive grasses was effective in excluding undesirable weed species[67]. **Field margins swards established with a wildflower seed mixture effectively excluded perennial as well as annual weeds in the establishment years but not in the longer term over a 13 year experiment**[24].
	Plant weeds – Annuals	Reduced disturbance reduces annual arable weed species in field margins[61]. Exclusion of annuals was achieved more rapidly by grass and wildflower mixture sown field margins than by any specific mowing regime (included combinations of two cuts, one cut or no cut and summer, spring or autumn timing)[24].
	Plant weeds – Hedgerow	**Grass sown and wildflower sown field margins** adjacent to hedgerows reduce the abundance in these boundaries of *Anisantha sterilis*, *Galium aparine*, *Poa trivialis* and *Urtica dioica*, four pernicious weed species[39]. **Grass sown 6 m field margins** had a small influence on the weed flora of the crop edge, possibly reducing weed cover, but had no influence on floras of field centres. **Grass sown field margins** reduce boundary or margin weeds in arable landscapes[63]. **For wildflower sown field margins** little relationship between the margin and the field weed flora[61].
	Insect pests	Field margins containing wild flower/grass mixtures can help to reduce aphid densities in adjacent cereal crops. **Flower-rich field margins** may increase the impact of aphid parasitoids on aphid populations in field brassicas[15]. A dual margin consisting of a narrow strip of grassy uncut vegetation against the field boundary (around 1m), with a broader (at least 2m) flower-rich strip, cut in late summer, would probably benefit the greatest range of beneficial invertebrates[15].

Category	Specific benefit	Details	
Runoff	**Pesticides**	Width of 10 m to 20 m for 70 to 80 % reduction efficiency depending on pesticide properties (water soluble pesticides require greater widths)[9].	
	Sediment	Width of 5 m (coarse particles) or 10 - 20 m (fine particles) required for 70 to 80% reduction efficiency[9].	
	Phosphorus	Width of 10 m (particulate phosphorus) to 15 m (dissolved) required for 70 to 80 % reduction efficiency[9].	
	Nitrogen	Width of 10 m required for 70 to 80 % reduction efficiency. Waterlogged areas can improve nitrogen cycle functioning[9]. Legume species not favourable in case of nitrogen[9].	
	Ideal management	**Location**	Lower continuous width is required and improved performance is achieved if field margin buffers are located throughout the landscape to prevent concentration and channelling of runoff flows[9].
		Vegetation	Grass vegetation most favourable in majority of cases with dense compact growth and good root growth favoured (pesticides, sediment, and phosphorus) [9].
		Maintenance	Frequent mowing is beneficial for buffering of pesticides, sediment, and phosphorus[9].
		Restrict vehicles	Restriction of vehicle traffic required in all cases to reduce channelling of runoff and bypass of pollutants[9].
Spray Drift	**Hedgerow**	Tall, competitive species of grass can provide dense, screening vegetation which is an effective physical barrier against pesticide into any adjacent wildlife habitats[10]. Fertiliser drift can also be reduced.	
	Watercourse	Width of 6 m (+ depending on pesticide ecotoxicity) required for 70 - 80 % reduction efficiency when placed adjacent to watercourse[9].	
	Ideal management	**Vegetation height**	Tall vegetation increases the screen effect thus increasing efficiency[10]. Alternative management with half of margin adjacent to watercourse or hedgerow managed to promote taller vegetation can achieve this screen effect.
		Trees	Addition of taller vegetation, such as trees and bushes, may improve screening effect[9].
		Width	6 m width likely to provide efficient protection for most pesticide types[9].
Soil	**Soil erosion**	Measures designed to reduce sediment and phosphorus runoff transfer will also reduce soil erosion. Most benefit provided by placing at downslope field margins within landscape to reduce distance of transfer from source field.	

4.2 Sown pollen and nectar seed mix (P&N)

Establishment and Management

Based on the UK ELS handbook[6], the establishment and management guidance for the option which applies to P&N is as follows:

EF4 Nectar flower mixture

This option is available on arable land or temporary grassland (sown to grass for less than five years).

Sowing an area of flowering plants into the farmed landscape will boost the availability of essential food sources for a range of nectar-feeding insects, including butterflies and bumblebees.
This option provides valuable benefits to wildlife at a landscape scale and is ideally suited to larger blocks and small fields.

This option is a 'rotational option'. This means that it can move around the farm within the normal rotation, but the same total hectarage must be maintained each year. Relocating these blocks or strips will help to avoid the build-up of weeds or soil borne disease and can be rotated with EF2 Wild bird seed mixture to utilise any residual fertility left behind.

For this option, you must comply with the following:

- Remove any compaction in the topsoil if you need to prepare a seedbed, except on archaeological features.
- Sow a mixture of at least four nectar-rich plants (e.g. red clover, alsike clover, bird's-foot-trefoil, sainfoin, musk mallow, common knapweed), with no single species making up more than 50 % of the mix by weight.
- Sow in blocks and/or strips at least 6 m wide in early spring or late summer.
- Re-establish the mix as necessary, to maintain a sustained nectar supply (this is typically after three years).
- Regular cutting and removal of cuttings in the first 12 months after sowing may be needed to ensure successful establishment of sown species.
- Only apply herbicides to spot-treat or weed-wipe for the control of injurious weeds (i.e. creeping and spear thistles, curled and broad-leaved docks or common ragwort) or invasive non-native species (Himalayan balsam, rhododendron or Japanese knotweed). Non-residual, non-selective herbicides may be applied prior to sowing, to help re-establishment.
- Do not apply any other pesticides, fertilisers, manures or lime.
- To stimulate valuable late flowering to meet the peak demand from bees, cut half the area to 20 cm between mid-June and the end of the first week of July. Do not cut if ground-nesting birds are present.
- Cut the whole area to 10 cm between 15 September and 31 October, removing or shredding cuttings to avoid patches of dead material developing.
- Do not graze in the spring or summer. Late autumn/early winter grazing of areas is allowed and will benefit legumes, but take care to avoid poaching damage and compaction, particularly when conditions are wet.
- Do not use the area for access, turning or storage.

Factors affecting uptake of P&N options

P&N margins generally require greater ongoing management and repeated cultivation compared to more perennial and robust margins such as WF, GS and NR. Similar non-grass flower mixes are available under Swiss and German AES[16]. Greater than 30 species can be included in these seed mixes[16]. P&N are designed to produce a period of highly abundant pollen and nectar supply based primarily on clovers and other legumes common to agriculture. The value of P&N as a pollen and nectar source options generally declines with age[6]. From research, P&N margins are observed to decline in flower abundance over time due to short life span of mixture species and competition from grasses[68-70]. Consequently their value as a source of pollen and nectar may be reduced over time and, generally, this margin type must be re-established after 3 years. The short life-span of P&N margins is a trade-off for to their high value benefit as nectar and pollen sources. Therefore, P&N must be reestablished every few years thus reducing its economic value compared to more permanent options[6]. As a rotational option it is possible to rotate this with other more short term options.

Table 5: Benefits of field margin type - Pollen and nectar mix (EF4)

Category	Specific benefit	Details
Birds	**General - Abundance**	Four replicated, controlled studies from Switzerland and the UK and one review of European studies found evidence that plots sown with a wildflower or legume seed mix had a positive influence on birds[10]. Flower strips attracted more birds or bird species compared to other farmland habitats and the number of birds using the strips increased over time[10].
	Invertebrate food resources	Pollen and nectar mixes support a rich variety of insect food for birds in summer[12].
Mammals	**General - Small Mammals**	Five studies investigating the effects of wildflower strips on small mammals (four replicated studies from Switzerland and one review of studies from northwestern Europe) found evidence that small mammals benefit from strips sown with wild flowers or flowers rich in pollen and nectar, with increases in abundance, density and species richness[10].
	Species diversity	**Herbaceous strips** supported the highest diversity of small mammal species, with six species caught, compared to autumn-sown wheat, high and low-intensity grassland and **wild-flower strips**[56].
	Density	In March the density of small mammals was significantly higher in **wild-flower** (mainly due to common vole) and **herbaceous strips** than in the other habitat types.
Pollinators	**Species richness**	**Wildflower sown field margins**, when compared to intensive crop management resulted, in a stable, perennial vegetation community with both legumes and regulating hemi-parasitic plants that supported significantly more pollinator species [58].
	Abundance	Pollen and nectar-rich mixtures attract the highest number of bumblebees and honey bees[71,72]. Bumblebees and butterflies were most common in pollen and nectar mixtures compared to sown wildflower and other field margins [68].
	Bumblebees	Results suggest that the legume-based **'pollen and nectar flower mix'**, as prescribed under Entry Level Stewardship in England, can quickly provide a highly attractive forage resource for bumble bees, but that issues of **seasonal flowering phenology and longevity of the mixture need to be addressed**[71]. Abundance of bumblebees was highest in the sown pollen and nectar mix compared to sown wildflower and other field margins[72].
	Butterflies	**Wildflower sown field margin** seed mixtures introduced using scarification of soil, to create germination niches for sown wildflower seeds, and managed using graminicide treatment, to reduce the dominance of competitive grasses, produced the greatest cover and species richness of sown wildflowers. Butterfly abundance, species richness and diversity were positively correlated with sown wildflower species richness, with the highest values in the combined scarification and graminicide treatment[20].
Non-target arthropods	**General**	Introduction of **botanically diverse field margins** is an important method of increasing the arthropod diversity of semi-natural habitat in farmland[60]. Insect abundance and diversity tends to be greater in wildflower strips than in sown grass margins and natural regeneration, but greater still in pollen and nectar mixes[16].

4.3 Sown wild bird seed mix (WBS)

Establishment and Management

Based on the UK ELS handbook[6], the establishment and management guidance for the option which applies to WBS is as follows:

EF2 Wild bird seed mixture

This option is available on arable land or temporary grassland (sown to grass for less than five years). This option will provide important food resources for farmland birds, especially in winter and early spring, on arable and mixed farms. The aim is to maximise the production of small seeds suitable as bird food in either annual or annual/biennial mixtures, while also providing a source of invertebrates for birds.

This option is a 'rotational option'. This means that it can move around the farm within the normal rotation, but the same total hectarage must be maintained each year. Relocating these blocks or strips will help to avoid the build-up of weeds or soil-borne disease. Rotating them with EF4 Nectar flower mixtures makes use of any residual fertility from that option.

For this option, you must comply with the following:

- Sow a balanced combination of at least three small-seed bearing crops chosen from barley, triticale, kale, quinoa, linseed, millet, mustard, fodder radish and sunflower. No single species should make up more than 70 % by weight of the mix and the combination must cover a range of crop groups to minimise any pest and disease impacts. Large-seeded crops (maize) and game covers (giant sorghum or sweet clover) are not allowed.
- Sow in blocks and/or strips at least 6 m wide at the edges of fields. Both should be between 0.4 ha and 3 ha in size. Ensure that the strips or blocks are well distributed across your farm and that food is always available for seed-eating birds.
- In the first year, sow at the optimum time for the chosen species mixture, which may be autumn or spring, ensuring that any areas of soil compaction are removed prior to establishment, except on archaeological features. Avoid sowing too early in the spring, when seedbeds may be dry, cold and of poor quality.
- To help with weed and pest management, the seed can be sown in separate drill widths or blocks within the option area.
- On sandy soils, strips must be sown along contours.
- Retain the crop mixture until at least 1 March before re-establishment in spring, which could be annually or every other year (biennial crops), to maintain sufficient seed production to feed birds during the late autumn/early winter.
- Fertilisers or manures (but not within 10 m of watercourses) and seed treatments may also be used to aid establishment and ensure sufficient seed production during that period.
- Only apply herbicides to spot-treat or weed-wipe for the control of injurious weeds (i.e. creeping and spear thistles, curled and broad-leaved docks or common ragwort) or invasive non-native species (e.g. Himalayan balsam, rhododendron or Japanese knotweed).
- Non-residual, non-selective herbicides may be used prior to sowing to help re-establishment.
- Apply environmentally sympathetic insecticides during establishment where there is a strong risk of crop failure due to severe pest attack (identified through monitoring and use of thresholds). Advice must be taken from a British Agrochemical Standards Inspection Scheme (BASIS) professional before any insecticides are used.
- Do not use the area for access, turning or storage.
- Do not graze.

Factors affecting uptake of WBS option

Similar to P&N, WBS margins require repeated cultivation. WBS are essentially annual or biennial crops for which the cropping season is extended to provide a winter supply of seed for birds. A large variety of seed mix options are available and these can be targeted to promote particular species. Annual and biennial mixtures are available. This option is likely to be favourable to farmers, as similar management techniques employed in the main crop can be used to control weed and pest species if required[6].

Table 6: Benefits of field margin type - Wild bird seed mix (EF2)

Category	Specific benefit	Details
Birds	**General**	Fourteen studies from the UK found that fields **sown with wild bird cover mix** had higher abundance, density, species diversity and species richness of birds than other farmland habitats[10]. Six studies from the UK found that birds showed a preference for **wild bird cover** and used it significantly more than other habitats[10].
	Partridge	One review found the grey partridge population increased substantially on farms where conservation measures including **cover crops** were in place[10].
	Plant and seed food resource	Seed supplies for birds are provided by the sown crop and weeds within it and the creation of seed-rich winter stubble will provide an important food resource for gamebirds and passerines[12]. Six studies found that **wild bird seed mixtures** including kale or a mixture of kale and/or other species attracted the largest number of bird species or highest bird abundance[10]. Kale generally supports high densities of the widest range of bird species (insectivorous and seed-eating species)[12]. Quinoa can support large numbers of finches and sparrows[12]. Seeding cereals can support high densities of buntings[12]. Kale and quinoa seed mixes are highly valuable in late winter due to their high seed retention[12].
	Invertebrate food resource (crop arthropod pest)	Wild bird crops can support large numbers of pest insects e.g. aphids and caterpillars which are a valuable food source for some birds[12].
Mammals	**Density/activity**	One replicated trial from the UK found that small mammal activity was higher in wild bird cover than in the crop in winter but not in summer[10].
Pollinators	**Butterflies – Species richness & abundance**	Farmland habitats **sown with wild bird cover mix** were used more by butterflies, and had a higher abundance or species richness of butterflies and bees than other farmland habitats[10].
Non-target arthropods	**Species richness & abundance**	Seven studies from the UK found positive effects for **wild bird cover strips** on invertebrates[10].
Plants	**Annual Arable weeds Annual Wildflowers**	Eight studies from the UK looked at plants and wild bird cover[10]. Six UK studies found that planting **wild bird cover mix** was one of the three best options for conservation of annual herbaceous plant communities, benefited plants and resulted in increased plant diversity and species richness. However two replicated studies found mixed/negative effects for plant species richness[10].

4.4 Cereal conservation headland (CH) and uncropped annual cultivation (AC)

4.4.1 Cereal conservation headland (CH)

Establishment and Management

Based on the UK ELS handbook[6], the establishment and management guidance for the option which applies to CH are as follows:

EF9 Unfertilised cereal headland

This option provides an important food supply for birds, and habitat for arable plants and insects, within any arable field during the cropping year. It will deliver most benefit when sited next to a buffer strip, stubble or area planted for wild bird seed or nectar flower mixtures.

Unfertilised cereal headlands can be difficult to manage where grass weeds are a problem, particularly where herbicide resistance is present. If an unexpected weed infestation occurs and becomes unmanageable, select a less weedy location in following years.

This is a 'rotational option'. This means that the headlands can move around the farm within the normal arable rotation, but the same total hectarage must be maintained each year. The headlands can also remain in the same place in the field. This will be especially beneficial where scarce arable plants are present.

For this option, you must comply with the following:

- Do not apply fertilisers or manures to the headland between harvest of the previous crop and resuming normal management.
- Sow and manage a 3 m–24 m wide cereal headland along the edge of an arable crop.
- Do not apply insecticides between 15 March and the following harvest.
- Only the following herbicides can be applied to control problem grass and broad-leaved weeds: for broad-leaved weeds, only use amidosulfuron, and only between 1 February and 31 March; and for grass weeds, use the following active ingredients only – tri-allate, fenoxapropPethyl, tralkoxydim, clodinafop-propargyl or pinoxaden.
- Where weed growth threatens harvest, you may use a pre-harvest desiccant, unless you plan to use this area as overwintered stubble.
- Sow and manage a 3 m–24 m wide cereal headland along the edge of any arable crop, ensuring that any areas of soil compaction are removed prior to establishment, except on archaeological features.

An additional option (EF10) which allows leaving the crop unharvested through winter is also available for cereal headlands under ELS[6]. Leaving the crop unharvested can provide additional benefits for birds, annual weeds and invertebrates due to the extended undisturbed period and can potentially supply food resources in winter similar to WBS.

EF10 Unharvested cereal headlands for birds and rare arable plants
This option provides a year-round food supply for birds, and habitat for arable plants and insects, within any arable field over two cropping years. It will deliver most benefit when sited next to a buffer strip, stubble or area managed for wild bird seed or nectar flower mixtures.

Unharvested cereal headlands can be difficult to manage where grass weeds are a problem, particularly where herbicide resistance is present. If an unexpected weed infestation occurs and becomes unmanageable, select a less weedy location in following years.

This is a 'rotational option'. This means that the headlands can move around the farm within the normal arable rotation, but the same total hectarage must be maintained each year.

The headlands can also remain in the same place in the field. This will be especially beneficial where scarce arable plants are present.

For this option, you must comply with the following: Do not apply fertilisers or manures to the headland between harvest of the previous crop and resuming normal management.

You can sow the headland in either autumn or spring (do not leave as bare ground over the winter) and leave it unharvested until the following spring (1 March), before resuming normal management. Sow and manage a 3 m–24 m wide cereal headland along the edge of any arable crop, ensuring that any areas of soil compaction are removed prior to establishment, except on archaeological features.

Sow a cereal or cereal mixture at a reduced seed rate, to encourage a more open headland structure. On more difficult or weedy sites, conventional seed rates can be used.

Do not apply insecticides between 15 March and the following harvest.

Only the following herbicides can be applied to control problem grass and broad-leaved weeds: for broad-leaved weeds, only use amidosulfuron, and only between 1 February and 31 March; and for grass weeds, use the following active ingredients only – tri-allate, fenoxaprop-P-ethyl, tralkoxydim, clodinafop-propargyl or pinoxaden.

Factors affecting uptake of CH options

Conservation headlands involve limiting or complete restriction of insecticide and herbicide as well as manure and fertilizer inputs to a specified width of crop edge. This is generally used to allow broad leaved weeds and associated insects to survive in cereal crop edges[43]. As an option this is favourable as it does not fully remove the land from production and direct income from the crop can still be earned. For unharvested headlands (EF10) this advantage does not apply, however, this option can greatly enhance the benefit of a conservation headland option for biodiversity. It is a highly favourable option for rare annual arable plants which may not be promoted under long term margins[43]. Use of conservation headlands in combination with other field margin features is likely to enhance both features as buffering of off-field areas is increased. This also results in greater diversity of management methods being used.

4.4.2 Uncropped annual cultivation (AC)

Establishment and Management

Based on the UK ELS handbook[6], the establishment and management guidance for the option which applies to AC is as follows:

EF11 Uncropped cultivated margins for rare plants
These margins will provide beneficial management for rare arable plants, insects and foraging sites for seed-eating birds. It is better to avoid locating these margins where you have a grass weed problem. Where run-off is a problem, a grass buffer should be considered. The option will provide greatest benefits on sandy, shallow, chalky or stony soils. For this option, you must comply with the following:

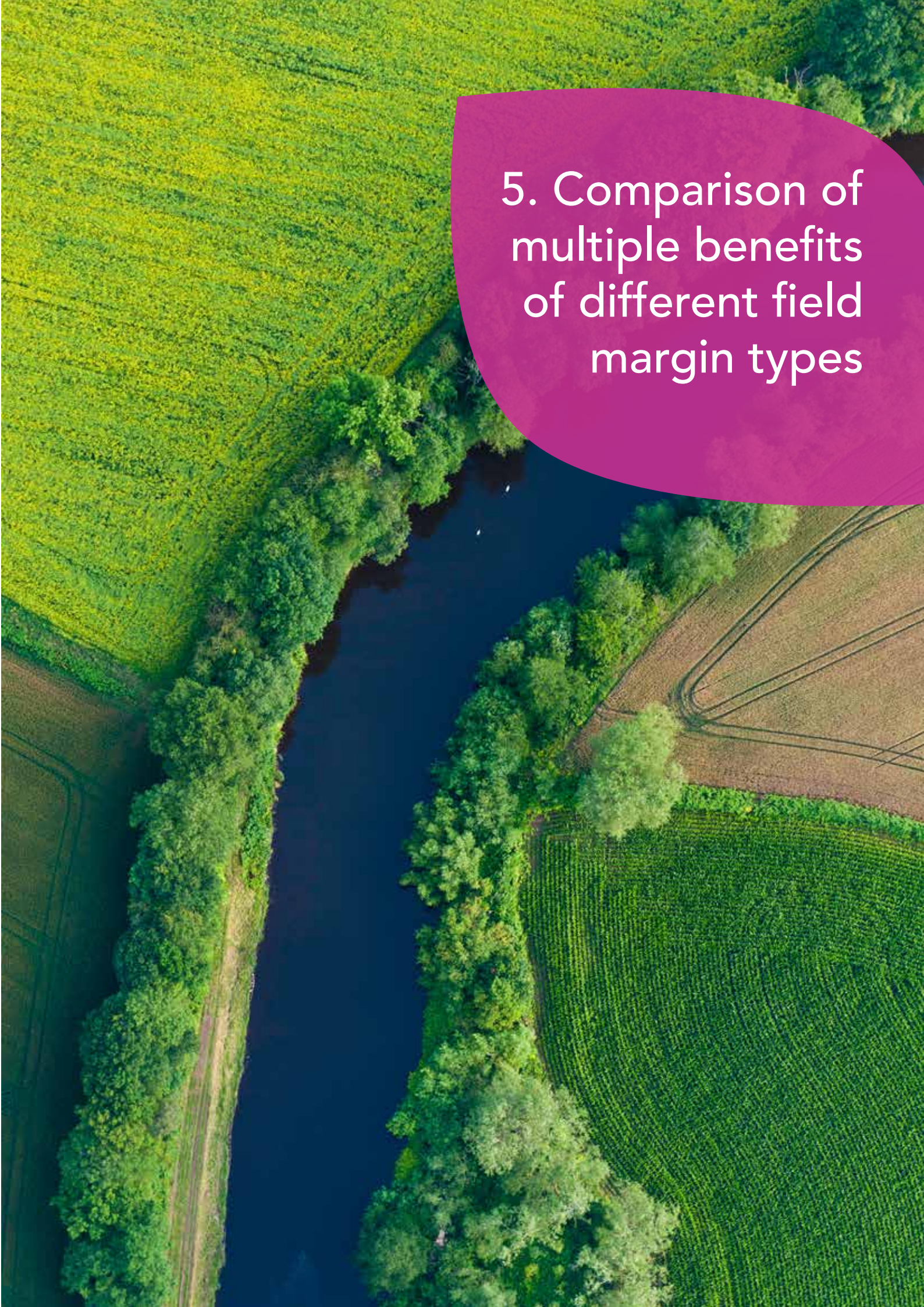
- Cultivate an arable field margin annually in either spring or autumn to a depth of about 15 cm.
- Varying the depth and time of cultivation may help prevent the build-up of undesirable weeds, but should always be managed according to the requirements of the target species.
- Margins should be 3–6 m wide. They can be relocated within the same field to avoid the build-up of pernicious weeds.

Factors affecting uptake of AC options

Annual cultivation requires cultivation and field preparation similar to arable crops with the difference that no crop is sown and the area is left to naturally regenerate. This can be highly valuable for annual arable plants[6]. A locally diverse seed bank is required for this measure to be most effective[43]. Suitable colonisation and germination conditions are also provided where problem weeds already exist and highly fertile sites are unlikely to be favourable for this measure[43]. AC is likely to be favourable as an option due to low inputs required and ease with which these margins can be incorporated into existing field management operations. Uptake is likely to be lower where problem weeds are already present in existing boundaries and the field crop.

Table 7: Benefits of field margin type - Conservation headland (EF9) / annual cultivation (EF11)

Category	Specific benefit	Details
Birds	**Gamebirds**	Conservation headlands particularly benefit gamebirds as they can provide nesting and brood rearing areas as well as abundant cereal arthropods that are important in the diet of their young[12].
	Seed and plant food resources	**Conservation headlands** provide moderate levels of cereal and annual weed seed and some grass seed, while uncropped cultivated margins provide moderate or abundant seeds, annual weeds and grasses[12]. **Conservation headlands** can provide diverse and abundant plant food resources for birds but are less valuable than **regularly cultivated "uncropped wildlife strips"** margins (e.g. set-aside) and wildflower strips[12]. **Regularly cultivated "uncropped wildlife strip"** margins supply moderate or abundant seeds from cereals, as well as seeds from grasses and annual weeds[12]. They also provide food sources in winter through the creation of stubble strips[12]. Comparing several treatment types, **regularly cultivated "uncropped wildlife strips"** and wildflower strips provide the most diverse and abundant plant food resources[12].
	Invertebrate food resources	**Conservation headlands** can provide diverse and abundant invertebrate food resources for birds but are less valuable than **regularly cultivated "uncropped wildlife strips"** margins (e.g. set-aside) and wildflower strips[12]. Comparing several treatment types, **regularly cultivated "uncropped wildlife strips"** (e.g. set-aside) and wildflower strips provide the most diverse and abundant invertebrate food resources[12].
Mammals	**Small mammal abundance**	The abundance of small mammals is influenced by food availability and they are likely to benefit from conservation headlands with moderate cover but abundant weed and cereal seeds and invertebrates[12, 33].
Pollinators	**Pollen and nectar sources**	Disturbance of soil can promote flowering annuals which are beneficial for pollinators and other species[61].
Plants	**Annual Arable weeds Annual Wildflowers**	Disturbance of soil and absence of herbicide can promotes flowering annuals which can include rare species[61].
Aquatic organisms	**Reduced spray drift**	Restriction of pesticide spraying within the field margin and this separation from watercourse may reduce the spray drift volume.
Spray Drift	**Hedgerow Watercourse**	Restriction of pesticide spraying within the field margin and this separation from boundary features may reduce the spray drift volume.



5. Comparison of multiple benefits of different field margin types

To provide a summarised output from the above assessment in Section 4, a scoring scale was used to rank the benefit of different field margin types for the broad range of environmental benefit categories. This is presented below in Table 10. The methods used in this approach are discussed in Section 2.3 but are also presented below.

This scoring scale used in Table 10 represents the following:

-1 = Negative impact
0 = No positive impact
1 = Some benefits
2 = Major benefits
3 = Most beneficial of all field margin types

This approach is broadly in line with similar reviews[13] and analyses conducted for field margins[9-12,14-19] and the results of these reviews are considered in the rankings. No additional insight would be provided by summing the scores of each of field margin type. The values and scoring used are generally arbitrary and used as an indicative, rather than a direct, measure of environmental benefit.

To illustrate how the scoring was performed in this review, an example is presented below for the category Management: Value (AES or crop) vs. costs. The ranking for this category is primarily based on the Farm4Bio project[18]. The UK based Farm4Bio project calculated mean gross margins over a 5 year period, based on income from AES payments or sale of crops, for each type of field margin assessed as part of the project.

Gross margins were calculated in the Farm4Bio project based on assumptions and available data on income (value of crop or AES option) and costs (purchase of seed, removal) per ha associated with different field margin types. The calculations do not account for maintenance costs such as diesel or labour required for mowing. AES incomes were based on the UK Entry Level Scheme income/ha generated by each field margin option. In Farm4Bio, gross margins for winter wheat and winter oilseed rape crops were based on data available from other studies for the years 2006 to 2009. Herbicide (glyphosate) use prior to establishment of the field margin and for its removal is assigned a cost of £8/ha. Seed costs from the Farm4Bio project were assigned at £200/ha for FEG (Floristically Enhanced Grassland) and £70/ha for grass margins, WBS (Wild Bird Seed) and IRC (Insect Rich Cover).

Table 8: Environmental Scheme (ES) funding/ha and Gross Margins/ha for natural regeneration, sown covers, winter wheat and oilseed rape; 2006-2010. Floristically enhanced grass (FEG), wild bird seed (WBS) and insect rich cover (IRC), natural regeneration (NR) for rare arable plants, Environmental Stewardship (ES) (After Holland *et al.* 2013[18] Farm4bio). Mean gross margins for all categories have been recalculated for this review based on the annual gross margins presented below.

Farm4Bio/Current field margin category	ES funding £/ha	Gross margin £/ha					Mean gross margin
		2006	2007	2008	2009	2010	
FEG	485	277	485	485	485	477	442
WBS/ IRC	*450*	364	364	364	364	364	364
WBS biennial	450	364	450	364	450	-	407[b]
Annual NR	400	384	384	384	384	384	384
Grass margin 4m	400	322	400	400	400	392	383
Winter wheat	-	810	788	679	477	-	689[c]
Winter oilseed rape	-	444	445	606	475	-	493[c]
NR[a]	*400*	392	400	400	400	392	397
P&N[a]	450	277	450	450	442	-	405[b]

a The additional categories NR and P&N covered in this review were calculated using the methodology and costs available from Farm4Bio.
b Based upon 4 year field margin cycle
c Based upon 4 years data

It was assumed that P&N would have similar seed costs to FEG. P&N gross margin was calculated based on replacement every 4 years (3-5 years recommended in ELS guidance) as this represents mean length for the option. Based on the approach used in Farm4Bio it was possible to calculate mean gross margin for additional field margin types covered in this review (P&N and NR). The gross margins/ha and mean gross margin over a 5 year period for each field margin category from Farm4Bio and this review are presented above in Table 8. Gross margins for all categories have been recalculated for this review, as presented in Table 8 – it was not possible to recreate all the calculated financial margins presented in the Farm4Bio project, due either to unreported costs or inconsistencies.

Using the mean gross margin/ha values, re-calculated here for the field margin types in Farm4Bio and this review, it was possible to score the different field margin types as illustrated below in Table 9. This forms a ranking system for the field margins types in this review assigning a score of 3 to CH as the highest gross margin, 2 to WF as the next highest gross margin and because the remaining field margin types are similar they were all assigned a score of 1. A similar approach was used to assign scores for all other environmental benefit categories based on the available information.

Where specific data or information for each field margin type was unavailable for a specific environmental benefit type, scores were assigned based on a judgement of similarity to other field margin types for the attributes which primarily affect the environmental benefit category. For example with spray drift, vegetation structure and margin width are the primary relevant variables. As width is not controlled by field margin type, vegetation structure is the most important variable. Therefore, as NR, GR and WF are longer term features with year round vegetation cover, these margin types are considered most beneficial. Assuming no pesticides are applied within the field margins, each of the remaining types can provide similar benefit unless specific vegetation structure is designed for in WBS and P&N seed mixtures or spray applications occur early in the season before vegetation has developed in a particular margin type. Margin width could be more crucial in controlling spray drift than the use of any particular margin type. However, this does not vary between margin types so does not get considered in the scoring system used here.

Table 9: Gross Margins/ha calculated for Farm4Bio[18] and current review field margin categories and their corresponding type and scoring in this review

Farm4Bio/Current field margin category	Mean gross margin £/ha	Applicable field margin type in current review	Review scoring
FEG	442	WF	2
WBS/IRC[a]	364	WBS	1
WBS biennial[a]	407	–	–
Annual NR	384	AC	1
Grass margin 4m	383	GR	1
Winter Wheat	689	CH	3
Winter oilseed rape	493	CH	3
NR[b]	397	NR	1
P&N[b]	405	P&N	1

a Annual WBS option from Farm4Bio was used as this represents worst case.
b NR and P&N categories were not covered in Farm4Bio project. Mean gross margin for both was calculated based on the methodology used in the Farm4Bio project as present above in Table 8.

Table 10: Evaluation and ranking of multiple benefits of different field margin types

(RM = Riparian Margin, NR = Natural regeneration, GR = Grass sown, WF = Wildflower sown, P&N = Pollen and Nectar mix, WBS = Wild bird seed mix, AC = Annual Cultivation, CH = Conservation headland). This scoring system used and the scores attributed generally follows HGCA (2005)[13].

Environmental Benefit	Attribute	NR	GR	WF	P&N	WBS	AC	CH	Additional sources and references
Management	**Value (AES or crop) vs costs**	1	1	2	1	1	1	3	Holland *et al.* 2013[18]
	Practicality	3	3	2	1	1	3	3	ELS handbook[6], Holland *et al.* 2013[18]
Birds	**Overall**	2	2	2	1	3	3	1	Vickery *et al.* 2009[12], Dicks *et al.* 2013[10], Holland *et al.* 2013[18]
	Summer - Seed & plant food	2	2	3	1	3	3	2	Vickery *et al.* 2009[12], Dicks *et al.* 2013[10], Holland *et al.* 2013[18]
	Winter - Seed & plant food	1	1	1	1	3	3	2	Vickery *et al.* 2009[12], Dicks *et al.* 2013[10], Holland *et al.* 2013[18]
	Invertebrate food	3	2	3	2	2	3	2	Vickery *et al.* 2009[12], Dicks *et al.* 2013[10], Holland *et al.* 2013[18]
Mammals	**Diversity**	2	3	2	2	2	3	1	Vickery *et al.* 2009[12], Dicks *et al.* 2013[10], Holland *et al.* 2013[18]
	Abundance	2	3	2	2	2	3	1	Vickery *et al.* 2009[12], Dicks *et al.* 2013[10], Holland *et al.* 2013[18]
Pollinators	**Food sources**	2	2	3	3	1	2	2	Scheper *et al.* 2013[11], Dicks *et al.* 2013[10], Holland *et al.* 2013[18]
	Species richness	2	2	3	3	2	2	1	Scheper *et al.* 2013[11], Dicks *et al.* 2013[10], Holland *et al.* 2013[18]
	Abundance	2	2	3	3	2	2	1	Scheper *et al.* 2013[11], Dicks *et al.* 2013[10], Holland *et al.* 2013[18]
	Hibernation sites	3	3	2	1	0	0	0	Scheper *et al.* 2013[11], Dicks *et al.* 2013[10], Holland *et al.* 2013[18]
Non-target arthropods	**Spiders**	3	3	2	1	2	2	1	Dicks *et al.* 2013[10], Holland *et al.* 2013[18]
	Beetles	2	3	2	2	2	2	1	Dicks *et al.* 2013[10], Holland *et al.* 2013[18]
	Parasitic Wasps	2	2	3	2	1	1	1	Dicks *et al.* 2013[10], Holland *et al.* 2013[18]
	Soil invertebrates	3	3	2	2	1	1	1	Dicks *et al.* 2013[10], Holland *et al.* 2013[18]

Environmental Benefit	Attribute	NR	GR	WF	P&N	WBS	AC	CH	Additional sources and references
Plants	**Overall**	2	1	2	1	1	3	3	Dicks *et al.* 2013[10], Holland *et al.* 2013[18]
	Annual arable weeds	1	-1	-1	1	2	3	3	Dicks *et al.* 2013[10], Holland *et al.* 2013[18]
	Perennial wildflowers	3	2	3	1	1	1	1	Dicks *et al.* 2013[10], Holland *et al.* 2013[18]
Aquatic	**Aquatic Invertebrates**	3	3	2	1	1	1	1	Based primarily on runoff and spray drift rankings (CORPEN 2007[9])
	Plants	3	3	2	1	1	1	1	Based primarily on runoff and spray drift rankings (CORPEN 2007[9])
Pest Management	**Weeds**	1	3	2	1	1	1	1	Dicks *et al.* 2013[10], Holland *et al.* 2013[18]
	Invertebrate	2	3	3	2	1	1	1	Based primarily on non-target arthropod ranking as well as difference in management and plant species composition of field margins and arable crops.
Runoff	**Pesticides**	3	3	2	2	1	1	0	CORPEN 2007[9]
	Sediment	3	3	2	2	1	1	0	CORPEN 2007[9]
	Phosphorus	3	3	2	2	1	1	0	CORPEN 2007[9]
	Nitrogen	3	3	2	1	1	2	2	CORPEN 2007[9]
Spray Drift	**Pesticides**	3	3	3	2	2	2	2	CORPEN 2007[9]
Soil	**Soil erosion**	3	3	3	2	2	1	1	CORPEN 2007[9]

6. Discussion

The potential for field margins to provide multiple benefits for the environment depends on a number of factors related to management. As discussed in Section 3, multiple management decisions relating to the size, maintenance and location of field margins can have an impact on the biodiversity within field margins, in particular, and the potential for field margins to reduce transfer of crop related pollutants to off crop areas.

Different taxonomic groups of species can respond in different ways to different management actions. Some environmental benefits are enhanced by reduced disturbance compared to the cropped area (e.g. soil invertebrates, perennial plants) while others rely on disturbance similar to the cropped area but without the additional disturbance such as pesticide application (e.g. annual arable weeds).

Individual species will also vary in their response to a particular type of management depending on the time of year. For example, disturbance of wildflower margins is required to allow the wildflowers to compete with grass species. Action such as mowing may benefit pollinators by promoting nectar producing wildflowers; however, mowing in itself may also reduce the shelter and nesting sites of the same pollinators.

Birds generally benefit from features which provide reliable food resources in both summer and winter and most benefits can be provided by specific wild bird seed mixtures in field margins and annual cultivation. Unharvested conservation headland options can also potentially provide stable food supplies in winter and spring. Birds can also benefit from field margins which provide more stable conditions, compared to the crop, where they provide nesting sites. Small mammals benefit from more stable vegetation and are generally more diverse and abundant when field margins provide abundant shelter and disturbance is reduced or eliminated. This is provided by more permanent features such as sown grass and wildflower mixes.

Birds and mammals will also benefit from field margins which provide additional invertebrate food resources. The importance of different attributes of field margins varies widely between species groups. Generally, field margins with higher plant species richness and less disturbance of soil and vegetation will support a wide variety of species groups as they provide abundant food resources and refuge and hibernation sites. However, reduced disturbance of soil and vegetation generally result in reduced plant species richness. Therefore, in some cases mowing, cultivation or re-seeding may be required to maintain highly diverse plant communities and the invertebrates they support. Pollen and nectar sown margins can support very high numbers of invertebrates (particularly pollinators). However, sown wildflower mix margins generally support higher diversity and variety of invertebrate groups compared to pollen and nectar mix margins.

Although mixtures which include annual and perennial species can be sown to produce high plant species richness, this does not benefit plant conservation in arable landscapes unless locally sourced seed mixtures are used. For plant species, a balance is generally required between promoting rare and locally important species associated with arable landscapes and preventing problem weeds in the cropped area. High disturbance will favour annual species, while perennials favour more stable conditions. Where a diverse local seed bank exists or where rare arable weed species may be present options such as annual cultivation or conservation headland options may be most beneficial. Where weeds are an issue sown grass mix field margins are most favourable.

The use of field margins and buffer strips for reduction of runoff and spray drift is well researched and guidance is available which provides good detail on management requirements and priorities for placement of features. For runoff control and mitigation, field margin features are important both adjacent to watercourses and within the wider catchment. The width and vegetation component of catchment and riparian field margins are important features which affect their performance. Field margins which form a dense and thick vegetation component (preferably of grass) and are permanent to semi-permanent, such as natural regeneration and grass and wildflower sown seed mixes, are most beneficial for the reduction of most types of pollutants.

Width of field margins is similarly important for spray drift reduction. Height of vegetation can also be important with trees and hedgerows having highest capacity for attenuation of drift. As tree growth will not be favourable in some arable agricultural situations, drift reduction can also be enhanced by allowing tall grass and herb vegetation growth directly adjacent to boundary features.

Based on this review it is clear that all field margin types can produce multiple benefits. However, all field margin types are identified as having at least one environmental measure for which they provide little or no benefit. Longer term and less disturbed field margins such as natural regeneration, grass sown or wildflower sown field margins appear to provide the most consistent environmental benefits. However, none of these field margin habitats are likely to provide sufficient winter seed food resources for birds. They are also likely to be of little benefit for rare annual wildflowers and arable weeds. Natural regeneration could possibly provide suitable germination sites for rare annual wildflowers and arable weeds in the 1st year following introduction but due to frequent mowing, as prescribed in the ELS guidance[6], this is unlikely to provide much long term benefit. An option to solve this issue is to include conservation headlands in combination with a more permanent option, such as NR, GR or WF. Depending on management this could provide a wider range of environmental benefits, covering all generalised categories, while allowing farmers the option of gaining a crop based economic return. The two options may also benefit each other as the CH could reduce transfer of chemicals to the permanent margins and the permanent margins could act as a refuge and source population for beneficial insects. Other field margin types, such as P&N or WBS, included in the wider landscape can provide resources which are required at specific times of the year at a scale which is appropriate for the migration capability of target groups including birds and pollinators.

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Appendix A – Literature search terms and returns

The following search terms were used:
Search Engine: SCOPUS

Table 11 General SCOPUS Search Criteria

Search Field	Abstract Title, Abstract, Keywords
Published	All years
Subject Areas	All

Table 12 Field margins SCOPUS Search Term

Terms	"farm* boundar*" OR "field boundar*" OR "grass boundar*" OR "reseeded boundar*" OR "wildlife boundar*" OR "vegetated boundar*" OR "flower boundar*" OR "buffer strip*" OR "grass strip*" OR "reseeded strip*" OR "wildlife strip*" OR "vegetated strip*" OR "flower strip*" OR "plant strip*" OR "buffer zone*" OR "buffer corridor*" OR "field corridor*" OR "grass corridor*" OR "reseeded corridor*" OR "wildlife corridor*" OR "vegetated corridor*" OR "flower corridor*" OR "farm* margin*" OR "buffer margin*" OR "field margin*" OR "grass margin*" OR "reseeded margin*" OR "wildlife margin*" OR "vegetated margin*" OR "flower margin*" OR "plant margin*"

Table 13 Water and Soil SCOPUS Literature Search Results

Search terms:	Field margins search term (Table 12) **AND** "water quality" OR "nutrient*" OR "fertiliser*" OR "sediment*" OR "pollution" OR "soil" OR "erosion" OR "manure*"
Results	1916
Additional references added	1916 (first search)

Table 14 Pesticides SCOPUS Literature Search Results

Search terms:	Field margins search term (Table 12) **AND** "*ticide*" OR "plant protection product*" OR "Agrochemical*" OR "spray drift" OR "transfer*" OR "wind break" OR "runoff" OR "drainage" OR "runoff"
Results	1463
Additional references added	630
Total Results	2546

Table 15 Non-bird vertebrate SCOPUS literature search results

Search for:	Field margins search term (Table 12) **AND** "Amphibia*" OR "fauna" OR "mammal*" OR "Reptil*" OR "Vertebrat*" OR "wildlife" OR "mouse*" OR "vole*" OR "shrew*" OR "frog*" OR "newt*" OR "lizard*"
Results	937
Additional references added	738
Total Results	3284

Table 16 Bird SCOPUS literature search results

Search for:	Field margins search term (Table 12) **AND** "bird*" OR "skylark*" OR "linnet*" OR "partridge*" OR "yellowhammer*" OR "sparrow*" OR "finch*" OR "bunting*" OR "ornith*"
Results	464
Additional references added	290
Total Results	3574

Table 17 Non-bee pollinator SCOPUS literature search results

Search for:	Field margins search term (Table 12) **AND** "butterfl*" OR "butter fl*" OR "lepidoptera" OR "Pieris" OR "Hoverfl*" OR "syrphid*" OR "diptera" OR "pollinator*"
Results	263
Additional references added	138
Total Results	3712

Table 18 Bees SCOPUS literature search results

Search for:	Field margins search term (Table 12) **AND** "bumblebee*" OR "Bombus" OR "Bee" OR "Bees" OR "Wild bee*" OR "bee conservation" OR "honey bee*" OR "honeybee*" OR "hymenoptera" OR "Wasp*" OR "apis" OR "pollinator*"
Results	138
Additional references added	27
Total Results	3739

Table 19 Plants SCOPUS literature search results

Search for:	Field margins search term (Table 12) **AND** "flora*" OR "Plant*" OR "weed*" OR "Botanical" OR "extrafloral" OR "Flower*" OR "legume*" OR "wildflower*" OR "grass"
Results	1993
Additional references added	658
Total Results	4397

Table 20 Biological-control invertebrates SCOPUS literature search results

Search for:	Field margins search term (Table 12) **AND** "predat*" OR "invertebrate*" OR "insect*" OR "invertebrate host*" OR "non-target arthropod*" OR "parasitoid*"
Results	174
Additional references added	29
Total Results	4426

Table 21 Invertebrates Spiders and Beetles SCOPUS literature search results

Search for:	Field margins search term (Table 12) **AND** "spider*" OR "araneae" OR "carabid*" OR "beetle*" OR "coleoptera" OR "staphylinid" OR "beneficial in*"
Results	319
Additional references added	75
Total Results	4501

Table 22 Soil invertebrates SCOPUS literature search results

Search for:	Field margins search term (Table 12) **AND** "soil in*" OR "earthworms" OR "collembolla" OR "litter-feeder*" OR "soil-feeder*"
Results	319
Additional references added	75
Total Results	4576

Table 23 Ecosystem services SCOPUS literature search results

Search for:	Field margins search term (Table 12) **AND** "ecosystem service*" OR "nectar" OR "pollinator*" OR "pollination"
Results	229
Additional references added	36
Total Results	4612

Table 24 Ecosystem services SCOPUS literature search results

Search for:	Field margins search term (Table 12) **AND** "ecosystem service*" OR "nectar" OR "pollinator*" OR "pollination"
Results	229
Additional references added	36
Total Results	4648

Table 25 Biodiversity SCOPUS literature search results

Search for:	Field margins search term (Table 12) **AND** "biodiversity" OR "species richness" OR "divers*"
Results	1417
Additional references added	285
Total Results	4933

Table 26 Biological control general SCOPUS literature search results

Search for:	Field margins search term (Table 12) **AND** "biological control" OR "natural enem*" OR "predat*" OR "beneficial in*"
Results	399
Additional references added	27
Total Results	4960

Table 27 Field margins total SCOPUS literature search results

Total Search Results	4960

European
Crop Protection

The European Crop Protection Association (ECPA) represents the crop protection industry at the European level. Its members include all major crop protection companies and national associations across Europe.

ECPA promotes modern agricultural technology in the context of sustainable development; to protect the health of humans and the environment, and to contribute towards an affordable healthy diet, competitive agriculture and a high quality of life.

ECPA members support fair, science-based regulation as a guarantee to the consumer, and the crop protection user, of high standards and safe products.

Cambridge Environmental Assessments

Cambridge Environmental Assessments (CEA) are part of ADAS UK Ltd., the UK's largest environment and agricultural consultancy. CEA are specialists in regulatory environmental risk assessments for chemicals, toxicology and REACH compliance, providing strategic support for product registrations across Europe.

In the pesticidal products area, CEA undertakes data evaluation, the preparation of risk assessments and regulatory documentation (dossier segments), including project management and co-ordination of work packages. In addition, CEA offer bespoke higher tier aquatic (mesocosms and laboratory studies) and higher tier environmental fate studies, according to GLP.

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