Qualitative Impact Assessment of Land Management Interventions on Ecosystem Services ("QEIA")

Report-3 Theme-5A: Biodiversity - Cropland

30-June-2023

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Authors:

Joanna Staley, Marc Botham, Richard Broughton, Claire Carvell, Richard Pywell, Markus Wagner & Ben Woodcock

UK Centre for Ecology & Hydrology

Direct Contributors:

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Other Contributors (alphabetical):

Chris Bell[1], Laura Bentley[1], Jeremy Biggs[8], Jonathan W. Birnie[5], Mike Bowes[1], Christine F. Braban[1], Annette Burden[1], Giulia Costa Domingo[9], Julia Drewer[1], Francois Edwards[1], Bridget Emmett[1], Chris D. Evans[1], Christopher Feeney[1], Angus Garbutt[1], A.E.J. Hassin[5], Mike Hutchins[1], Laurence Jones[1], Clunie Keenleyside[9], Ryan Law[5], Owen T. Lucas[5], Elizabeth Magowan[3], Lindsay Maskell[1], Robert Matthews[7], Eiko Nemitz[1], Paul Newell Price[2], Lisa Norton[1], Qu Yueming[1], Gavin Siriwardena[6], Amanda Thomson[1], Prysor Williams[4], John Williams[2]

[1] UK Centre for Ecology & Hydrology, [2] ADAS, [3] Agri-Food and Biosciences Institute, [4] Bangor University, [5] Birnie Consultancy, [6] British Trust for Ornithology, [7] Forest Research, [8] Freshwater Habitats Trust, [9] Institute for European Environmental Policy

External Reviewers:

Felix Eigenbrod[1], Mike Garratt[2], Jonathan Storkey[3]

[1] University of Southampton, [2] University of Reading, [3] Rothamsted Research

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This report is one of a set of reviews by theme:

Braban, C.F., Nemitz, E., Drewer, J. (2023). *Qualitative impact assessment of land management interventions on Ecosystem Services ("QEIA").* Report-3 Theme-1: Air Quality (Defra ECM_62324/UKCEH 08044)

Birnie, J., Magowan, E., Law, R., Lucas, O.T., Hassin, A.E.J. (2023). *Qualitative impact assessment of land management interventions on Ecosystem Services ("QEIA").* Report-3 Theme-2: Greenhouse Gases (GHG) (Defra ECM_62324/UKCEH 08044)

Newell Price, J.P., Williams, A.P., Bentley L. & Williams, J.R. (2023). *Qualitative impact assessment of land management interventions on Ecosystem Services ("QEIA")*. Report-3 Theme-3: Soils (Defra ECM_62324/UKCEH 08044)

Williams, J.R., Newell Price, J.P., Williams, A.P., Bowes, M.J., Hutchins, M.G. & Qu, Y. et al. (2023). *Qualitative impact assessment of land management interventions on Ecosystem Services ("QEIA")*. Report-3, Theme-4: Water (Defra ECM_62324/UKCEH 08044)

Staley, J.T., Botham, M.S., Broughton, R.K., Carvell, C., Pywell, R.F., Wagner, M. & Woodcock, B.A. (2023). *Qualitative impact assessment of land management interventions on Ecosystem Services ("QEIA")*. Report-3 Theme-5A: Biodiversity - Cropland (Defra ECM_62324/UKCEH 08044)

Keenleyside, C.B. & Costa Domingo, G. (2023). *Qualitative impact assessment of land management interventions on Ecosystem Services ("QEIA")*. Report-3 Theme-5B: Biodiversity - Grassland (Defra ECM_62324/UKCEH 08044)

Maskell, L. & Norton, L. (2023). *Qualitative impact assessment of land management interventions on Ecosystem Services ("QEIA")*. Report-3 Theme-5C: Biodiversity - Semi-Natural Habitats (Defra ECM_62324/UKCEH 08044)

Siriwardena, G.M. (2023). *Qualitative impact assessment of land management interventions on Ecosystem Services ("QEIA")*. Report-3 Theme-5D: Biodiversity - Integrated System-Based Actions (Defra ECM_62324/UKCEH 08044)

Bentley, L., Feeney, C., Matthews, R., Evans, C.D., Garbutt, R.A., Thomson, A. & Emmett, B.A. (2023). *Qualitative impact assessment of land management interventions on Ecosystem Services ("QEIA")*. Report-3 Theme-6: Carbon Sequestration (Defra ECM_62324/UKCEH 08044)

Short, C., Dwyer, J., Fletcher, D., Gaskell P., Goodenough, A., Urquhart, J., McGowan, A.J., Jones, L. & Emmett, B.A. (2023). *Qualitative impact assessment of land management interventions on Ecosystem Services ("QEIA")*. Report-3.7: Cultural Services (Defra ECM_62324/UKCEH 08044)

A list of all references used in the reports is also available as a separate database.

Foreword

The focus of this project was to provide a rapid qualitative assessment of land management interventions on Ecosystem Services (ES) proposed for inclusion in Environmental Land Management (ELM) schemes. This involved a review of the current evidence base by ten expert teams drawn from the independent research community in a consistent series of ten Evidence Reviews. These reviews were undertaken rapidly at Defra's request and together captured more than 2000 individual sources of evidence. These reviews were then used to inform an Integrated Assessment (IA) to provide a more accessible summary of these evidence reviews with a focus on capturing the actions with the greatest potential magnitude of change for the intended ES and their potential co-benefits and trade-offs across the Ecosystem Services and Ecosystem Services Indicators.

The final IA table captured scores for 741 actions across 8 Themes, 33 ES and 53 ES-indicators. This produced a total possible matrix of 39,273 scores. It should be noted that this piece of work is just one element of the wider underpinning work Defra has commissioned to support the development of the ELM schemes. The project was carried out in two phases with the environmental and provisioning services commissioned in Phase 1 and cultural and regulatory services in a follow-on Phase 2.

Due to the urgency of the need for these evidence reviews, there was insufficient time for systematic reviews and therefore the reviews relied on the knowledge of the team of the peer reviewed and grey literature with some rapid additional checking of recent reports and papers. This limitation of the review process was clearly explained and understood by Defra. The review presented here is one of the ten evidence reviews which informed the IA.

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1 INTRODUCTION AND SUMMARY OF CROPLANDS REVIEW APPROACH

This report is a rapid evidence summary review of the effects of proposed ELMS actions on biodiversity associated with arable agriculture and horticulture ('Croplands'). This review only contains evidence relevant to Croplands. Evidence of the effects of AES on biodiversity in agricultural grassland, semi-natural and priority habitats, and at larger scales are covered in reviews on Grasslands, Semi-natural habitats and Systems respectively. The list of proposed ELMs actions for review, and the list of ecosystem services against which actions were assessed (see Outcomes below), were defined by Defra. The Cropland review team wrote the rapid evidence review below, and using the lists of actions and ecosystem services (ES), scored the relevant actions in relation to likely benefits or dis-benefits for Cropland biodiversity. This Cropland rapid evidence review was carried out separately for each of several taxa (plants, butterflies, pollinating insects, other invertebrates, birds and mammals) and the ES mediated by biodiversity (*Pest and Disease Control* and *Pollination and seed dispersal*).

1.1 REVIEW METHODOLOGY

The timescales for this work unfortunately precluded a full systematic review. In order to identify key published evidence, keywords from the action description (e.g. 'inter-cropping') and the taxa or ES being reviewed (e.g. 'butterflies' or 'pest control') were used in searches of Google scholar. Papers titles and abstracts were read to identify relevant evidence. Papers specific to the UK, and those that were more recent, were prioritised where large amounts of evidence was available. Where published reviews or meta-analyses were available, these were prioritised for inclusion. For those actions with little published peer-reviewed literature, we used published reports and expert opinion (e.g. factsheets published for priority species by conservation organisations such as Butterfly Conservation). We have clarified in the text where evidence comes from peer-reviewed literature, as opposed to reports (grey literature) or expert opinion. Large reviews of AES effects on biodiversity (e.g. Bullock et al., 2011; Dicks et al. 2013) were also consulted, to check for consistency in the strength of the evidence and whether we had missed key older studies.

1.2 COUNTERFACTUAL

The evidence reviewed was used to attribute scores on the likely relative benefit / dis-benefit for each action, in relation to each taxa or ES reviewed. The scoring system is common across all chapters of this assessment. In all cases, croplands scores were attributed relative to a business-as-usual counterfactual (i.e. agriculture in the absence of agri-environment or other conservation scheme management). In some cases, actions had small or moderate benefits for a taxa, while a related action might provide larger benefits. These relative benefits are flagged up in the review text, but the scoring was based on a consistent comparison to a counterfactual of no AES (e.g. a wildflower plot was scored relative to an arable crop as counterfactual).

1.3 SCORING ACROSS TAXA

The scores for each taxon were then combined for the ES relating to effects on *wider biodiversity*, and *rare and priority species*. The median score was used where effects across multiple taxa were combined, with dis-benefits to one or more taxa included where the median score showed overall benefits across taxa (e.g. scores that were Amber D denote likely overall benefits with some dis-benefits). Scores for individual taxa are included at the beginning of the reviews below, to show the component parts of each overall score for wider biodiversity. The biodiversity outcomes defined by Defra (see Table x.1 below) did not directly include effects on wider biodiversity. For Croplands and the other biodiversity theme reviews, the *Enhance or Maintain condition of agricultural land* outcomes were interpreted as 'enhance or maintain abundance and/or species richness of wider farmland biodiversity'. Priority species were defined as those with Section 41 status in England (2006 Natural Environment and Rural Communities Act), or for those taxa with more recent red lists, as vulnerable, threatened, endangered or critically endangered.

1.4 Disparity in definitions of biodiversity ecosystem services / outcomes

For *Pollination and seed dispersal* and *Pest and disease control*, Defra provided likely indicators (Table 2.1), which were used to define the ES for the purpose of scoring. However, there is a likely disparity between scoring of the two ES as a result. The *Pollination and seed dispersal* indicator relates only to an increase in beneficial organisms: “Increased abundance, distribution & species richness of pollinators & seed dispersers”. For scoring, we have interpreted this indicator as an increase on the land under the ELMs action, e.g. more pollinating insects on a wildflower margin. However, this does not demonstrate that a pollination service is being delivered. For pollination to be delivered / enhanced under an ELMs action, the increased abundance / diversity of pollinators would need to spill over into a crop, and increases in both pollination and resulting yield be demonstrated. These more stringent demonstrations of pollination are rare in research on AES effects, but there are a very few studies that do so (e.g. Morandin et al. 2016). In contrast, the indicator for *Pest and disease control* relates to “Evidence of outbreaks of pests and disease”, which is more stringent than just showing an increase in beneficial organisms (predators and parasitoids) on the land under AES management. Due to these differences in indicators, the *Pest and disease control* ES has consistently lower scores than the *Pollination and seed dispersal* ES.

1.5 Summary of Findings

The actions reviewed under Croplands which are likely to have the strongest benefits for wider biodiversity are:

- **Sow and manage wildflower strips and patches (actions ETPW-116, ETPW-205C, ETPW-205EM)**
- **Creating and managing grass buffer strips or beetle banks (EBHE-117, ETPW-207)**
- **Create suitable habitats for beneficial insects to live near cropped land (ETPW-238)**
- **Extended over-winter stubbles followed by a fallow (Arable01 & ETPW-229)**
- **Fallows left to regenerate naturally (Arable02, part of EHAZ-024)**
- **Plant trees and hedges (EBHE-303)**
- **Use of herbal leys (ECPW-032, ETPW-202)**
- **Providing fallow plots / areas for ground-nesting birds and invertebrates (ETPW-202x)**
- **Leaving unharvested cereal headlands (ECPW-264)**

In addition, the following management interventions were identified as omissions with good evidence of beneficial effects:

- **Extended stubble - unharvested crop stubble followed by a one-year fallow**
- **Unvegetated, ploughed fallow (natural regeneration) for one year**
- **Annually cultivate headlands and leave unsown**

The actions within all these groups scored Green** or Green*** for wider biodiversity, indicating well-tested evidence from multiple sites, of moderate to major benefits for Cropland biodiversity. These management interventions also provided context specific beneficial effects for a wide range of other listed biodiversity outcomes.

In addition, creation and management of wild bird seed mix is likely to have strong benefits for Cropland biodiversity (e.g. **ETPW-260x** Provide feeding areas to support the lifecycles of wild birds (eg. wild bird seed mix)). Bird seed actions are not reviewed here, as they are covered within the Biodiversity – Systems theme (Report-3-5D).

The actions scoring the highest for wider biodiversity and high in relation to the increased abundance or species richness of pollinators, were sowing and managing wildflower strips and patches. These actions have received considerable research attention, perhaps indicating the level of interest in declining populations of some wild pollinator species.

There is increasing broader evidence that a combination of management or actions to increase landscape heterogeneity and reduce simplification of landscapes may benefit wider biodiversity and the services it supports (pollination and pest control). For example, a recent meta-analysis found that increased species richness of pollinators and natural enemies is linked to improved delivery of pollination and pest control, and that landscape simplification reduces delivery of these services by reducing species richness (Dainese et al. 2019), and another that high edge density of non-crop habitats can improve these services (Martin et al. 2019). Habitat and wider landscape heterogeneity could be increased by a wide range of the Cropland actions reviewed above, and to a greater extent by applying a combination of these actions. A targeted combination of different Cropland actions could better support some taxa by providing resources for different stages of lifecyles. For example, Lepidoptera (butterflies and moths) require a range of host plant species to meet the larval requirements of a range of species, and floral resources to provide nectar for adults. We have reviewed evidence and scored actions individually for Cropland biodiversity, as tasked by Defra, but it is possible that greater benefits could be realised through the targeted deployment of a combination of actions, as is done currently in the Countryside Stewardship scheme (i.e. the wild pollinator and farm wildlife package of options).

There is increasing evidence that crop yield may not necessarily be compromised by using small amounts of land for AES management, particularly if AES can be targeted to the less productive areas of farmland. Pywell et al. (2015) found that yield did not decrease over the medium term (5-year rotation), there is no adverse impact on yield of removing 3 or 8% of land at the field edge to create wildlife habitats, and that for some crops yield increased. This provides further support for the creation of AES habitats in Croplands, including the wildflower habitat actions reviewed above.

2 Outcomes And Scoring

2.1 Outcomes

The Croplands review addresses the biodiversity and related ES in Table 2.1.

Most of the ELMs actions were scored for the ES relating to wider biodiversity. As above, the biodiversity outcomes defined by Defra did not directly include effects on wider biodiversity. For Croplands and the other biodiversity theme reviews, the *Enhance or Maintain condition of agricultural land* outcomes were interpreted as ‘enhance or maintain abundance and/or species richness of wider farmland biodiversity’. Where evidence was found, many of the Croplands actions were also scored for *Presence of rare or priority species*, and for the ecosystem services *Pest and disease control* and *Pollination and seed dispersal* (see 1. Introduction for discussion of the disparity in these indicators).

Table 2.1 Ecosystem services / outcomes and suggested indicators provided by Defra for scoring each proposed ELMs action that relate to this review.

Service	Suggested indicator for services flow
Biodiversity	Biodiversity adaptation - maintaining / enhancing biodiversity under a changing climate
	Atmospheric deposition of N and exceedance of critical loads
	Connectivity of small 'feature' habitats
	Enhance condition of agricultural land (*interpreted as ’enhance abundance and/or species richness of wider farmland biodiversity’*)
	Enhance condition of semi-natural habitat
	Favourable condition of SSSIs
	Maintain good condition agricultural land (*interpreted as ‘maintain abundance and/or species richness of wider farmland biodiversity’*)

	Maintain good condition of semi-natural habitat
	Presence of rare (red list) species Presence of priority species
INNS	National species occurrence
Pest and disease control	Evidence of outbreaks of pests and disease
Pollination and seed dispersal	Increased abundance, distribution & species richness of pollinators & seed dispersers

Scant evidence was found for the outcome *Biodiversity adaptation - maintaining / enhancing biodiversity under a changing climate*. If there was evidence that the action enhanced or maintained abundance or species richness of wider biodiversity, this may lead to more resilient communities of farmland biodiversity. AES actions could be tailored to mitigate against trophic asynchrony, for example by designing seed mixes to provide floral and host plant resources at varying times of year as phenology changes. However, while AES actions could theoretically support biodiversity adaptation under a climate change, there is little empirical evidence of this. The *Biodiversity adaptation* outcome was therefore scored according to the impacts on wider biodiversity, but with a maximum score of Amber L due to the limited evidence.

The majority of actions reviewed under Croplands will not affect the condition of semi-natural habitat or SSSIs, as those actions were addressed by the Semi-natural habitats review. Outcomes related to conditions of priority and protected habitats were rarely scored in the Croplands review.

3 MANAGEMENT BUNDLES

In order to enable a rapid review of evidence and report the results efficiently, a decision was made to group similar management actions into ‘action groups’. These are listed below together with the specific actions and codes, and with the management bundles which were defined more broadly for evidence reviews across all the themes.

The action groupings assessed for Croplands biodiversity are:

- Create and manage wildflower habitats
- Grass margins, strips and corners
- Beetle banks
- Low input cropped margins
- Unharvested cereal headlands
- Annually cultivated margins
- Double drill headlands
- Create fallow plots for arable flora, ground-nesting birds and invertebrates
- Trees / scrub / hedges
- Actions for Integrated Pest Management
- Cover crops
- Undersown spring cereals
- Crop diversity
- Reduced tillage
- Grass in the arable rotation
- Fallow in the arable rotation
- Enhanced overwinter stubble
- Reduced fertiliser use
- Whole crop cereal

- Soil surface structure
- Lowland agricultural and farmed peatland management

3.1 Cropland Action Bundles

The following actions or action groups had full evidence reviews under Cropland biodiversity, following the process outlined above.

3.1.1 Create and manage wildflower habitats

Bundle: Habitat creation/Cropland

ETPW-116 Provide a flower-rich habitat for wild pollinators with a range of flowering times and flowering structures
ETPW-205C Create flower-rich and species rich grass margins, field corners, and plots
ETPW-205EM Enhance/ manage flower-rich and species rich grass margins, field corners, and plots
ETPW-168 Collect and sow locally sourced grass and wildflower seed

Bundle: Specific wildlife targeted actions

ETPW-189 Plant/ manage wildflowers

Bundle: Restoration, management and enhancement /Cropland

ECPW-237 Create/ enhance/ manage in-field vegetation including grass, scrub, trees and wildflower/legume rich swards

<u>Overall RAG ratings for each action and ecosystem service</u>

ETPW-116 Provide a flower-rich habitat for wild pollinators with a range of flowering times and flowering structures
ETPW-205C Create flower-rich and species rich grass margins, field corners, and plots
ETPW-205EM Enhance/ manage flower-rich and species rich grass margins, field corners, and plots
ETPW-189 Plant/ manage wildflowers
ECPW-237 Create/ enhance/ manage in-field vegetation including grass, scrub, trees and wildflower/legume rich swards

GREEN*** maintaining species / wider biodiversity
AMBER TL* presence of rare or priority species
AMBER L** pest and disease control
GREEN*** pollination
AMBER L** biodiversity adaptation - maintaining / enhancing biodiversity under a changing climate – see climate change or adaptation subsection below.

ETPW-168 Collect and sow locally sourced grass and wildflower seed

Amber TL** maintaining species / wider biodiversity
GREEN*** pollination

3.1.1.1 Causality

RAG ratings by taxa / ecosystem service

- BUTTERFLIES – **ETPW-116**, **ETPW-205C** & **ETPW-205EM** **GREEN***** for maintaining habitats and populations / species (**ETPW-168** sow locally sourced grass is unlikely to be useful when applied to **ETPW-205C** & **ETPW-205EM** field margins **AMBER L*** evidence, but may be useful to the wider **ETPW-116** & **ECPW-237** **AMBER L***** where whole field-scale grassland meadow creation or reversion may be the aim.
- BUTTERFLIES – maintaining rare and priority species **AMBER TL*** **ETPW-116**, **ETPW-205C**, **ETPW-205EM**
- MOTHS – **ETPW-116**, **ETPW-205C**, **ETPW-205EM** & **ETPW-189** **GREEN*** for maintaining habitats and populations and species.
- POLLINATORS - **ETPW-116**, **ETPW-205C** & **ETPW-189** **GREEN***** for maintaining habitats and populations / species and **GREEN***** for pollination services. **ETPW-168** 'sow locally sourced grass and wildflower seed' (also known as "green hay") is unlikely to be useful when applied to **ETPW-205C** creation of field margins on cropland (**AMBER L*** evidence), but may be useful in the wider **ETPW-116** option (**AMBER L***** evidence for species and pollination) and **ECPW-237** 'Create/ enhance/ manage in-field vegetation' (**AMBER L**)** where whole field-scale grassland meadow creation or reversion may be the aim. **AMBER TL*** rare or priority pollinators
- CARABIDAE – **ETPW-116** & **ETPW-205C** **GREEN***** for maintaining habitats and populations / species (**ETPW-168** sow locally sourced seed is unlikely to be useful when applied to **ETPW-205C** & **ETPW-205EM** creation of field margins **AMBER L*** evidence, but may be useful in the wider **ETPW-116** option **AMBER** L***evidence).
- OTHER COLEOPTERA - **ETPW-116** & **ETPW-205C** **GREEN**** for maintaining habitats and populations / species (**ETPW-168** sow locally sourced grass is unlikely to be useful when applied to **ETPW-116** creation of field margins **AMBER L*** evidence, but may be useful in the wider **ETPW-205C** option **AMBER** evidence).
- ARANAE – **ETPW-116** & **ETPW-205C** **GREEN***** for maintaining habitats and populations / species (**ETPW-168** sow locally sourced grass is unlikely to be useful when applied to **ETPW-116** creation of field margins **RED*** evidence, but may be useful in the wider **ETPW-205C** option **AMBER L***** evidence).
- SOIL MACROFAUNA - **ETPW-116** & **ETPW-205C** **GREEN**** for maintaining habitats and populations / species (little specific evidence for **ETPW-168** – **AMBER L***).
- PREDATORY INVERTEBRATES – **ETPW-116** & **ETPW-205C** AMBER L* for Pest and disease control
- MAMMALS – **ETPW-189** & **ECPW-237** **GREEN***** for maintaining populations and species
- BIRDS – **ETPW-189**, **ETPW-205C**, **ETPW-205EM** & **ECPW-237** **GREEN**** for maintaining populations and species.
- ARABLE PLANTS – **ETPW-116** **ETPW-205C** **ETPW-168** **ETPW-189** **ECPW-237** **RED*** for maintaining arable plant richness and maintaining rare arable plants.
- PLANTS - **ETPW-116** **ETPW-205C** **ETPW-189** **ECPW-237** **GREEN***** for maintaining plant populations / species (more widely than for arable plants).

There is strong evidence that provision of wildflowers in cropland habitats can provide nectar resources for adult butterflies, with a resulting increase in adult butterfly species richness and abundance (Feber 1996; Pywell et al. 2004). Several studies have tested effects of AES wildflower margins or pollinator flower mixes against counterfactuals on butterflies, with most finding significant positive effects with regard to adult abundance (e.g. Meek et al. 2002; Potts et al. 2009; Korpela et al. 2013) and one finding no effect (Brereton 2005). Three studies addressed butterfly species richness, two of which reported significant positive effects (Meek et al. 2002; Aviron et al. 2009; Potts et al. 2009).

Recent studies on flower rich margins in the Netherlands and Germany have also shown positive effects on both butterfly abundance and species richness, with some species found only on margins with wildflower enhancement (Buhk et al. 2018; Wix et al. 2019; Scheper et al. 2021). Feber et al. (1996) also showed an increase in butterfly abundance on margins sown with a grass and wild flower seed mixture on experimental field edges: mowing regime had an impact on the species richness with those plots cut in spring or autumn or not cut at all attracting more species than those cut in summer. The abundance of adult butterflies was most closely associated with the abundance of flowers of key nectar source species. Modelled data varying the quality (density of nectar sources) in field margins showed a moderate increase in fecundity and lifespan of a common generalist butterfly, *Maniola jurtina* (Evans et al. 2019). A recent Belgian study has shown wildflower strips can provide host plant resources for butterflies as well as nectar resources, particularly for the more generalist, abundance butterfly species (Kolkman et al. 2022).

There is less evidence that wildflowers in croplands benefit S41 or rare butterfly species. Evidence of positive impacts on rarer and habitat specialist species is lacking and a study in Sweden showed that while wildflower margins supported much higher abundances and species numbers of butterflies than grass only 'greenways', it was mostly only common species that were found in these margins (Haaland & Gyllin, 2010). As mentioned, there has been successful targeted higher level margin management for particular species which require tailored planting and/or management and a study in Switzerland showed that 'Improved field margins' planted with target plant species were more effective than general wildflower strips: these margins did not significantly differ from regional biodiversity hotspots but contained significantly more species and individuals than wildflower strips, which supported greater species and abundance of butterflies than conventional field margins (Jacot et al. 2007).

Most red list and S41 butterfly species have specialist habitat requirements, which are less likely to be provided by an increase in wildflowers in general cropland habitats. However, increasing specific wildflower species that are the larval host plants of habitat specialist species is likely to help some species if the correct management is also put in place as has been the case in some HLS options for example, for marsh fritillary *Euphydryas aruinia* (Bourn et al. 2013).

Margins sown with wildflower mixes are associated with greater species richness of moths (Blumgart 2021). Positive but not significant effects of wildflower margins were observed on both macro-moth abundance and species richness in a controlled field experiment testing ELS agri-environment options (Defra/NE Hillesden Project https://assist.ceh.ac.uk/hillesden), but these differences were not significant, likely due to scale of response including i) other landscape factors such as proximity to woody features and ii) mobility of macro-moths and the sensitivity of survey methodology using light traps which may attract from a substantial radius. Significant differences were found in the same study for micro-moths for both abundance and diversity when compared to standard cross-compliance margins and also for abundance when compared to standard grass margins. Although more relevant to pastoral farmlands, it is also worth noting that there was a significant positive effect on the abundance and richness of micro-moths, and on the species richness of macro-moths and those moths showing significant long-term declines in species-rich grasslands created under AES compared to those areas on conventional farms further demonstrating the positive effects of botanical enrichment on farmland (Fuentes-Montemayor et al. 2011). Field margins are crucial habitats for the following priority species: Four-spotted (*Tyta luctuosa*), Grey Carpet (*Lithostege griseata*) and Pale Shining Brown (*Polia bombycina*). The last recorded 'stronghold' of *Polia bombycina* was on field margins in Oxfordshire where numbers were found to be greater on wide field margins compared to standard margins and were significantly greater at sites with hedgerow trees (Merckx et al. 2010).

There is strong evidence that the creation of flower-rich habitats on farmland leads to local increases in abundance and number of species of pollinating insects including bumblebees (e.g. Meek et al. 2002; Carvell et al. 2004; 2006; 2007; 2011; Pywell et al. 2005b), solitary bees (Wood et al. 2015, Carvell et al. 2021) and hoverflies (Grass et al. 2016; Boetzl et al. 2021; Carvell et al. 2021; McHugh et al. 2022) found in those habitats (for additional references see Dicks, Showler and Sutherland 2010). For three common farmland bumblebee species (*Bombus terrestris*, *B. lapidarius* and *B. pascuorum*), the proportion of high-value foraging habitat in the colony's vicinity (up to 1,000m) has been shown to increase between-year survival (Carvell et al. 2017), providing good evidence for population-level benefits of **ETPW-116**, **ETPW-205C** and **ETPW-189**. However, the Carvell et al. (2017) study suggested that provision of summer flower resources alone was not sufficient to have positive benefits on bumblebee survival, and that season-long provision is critical to maintain populations throughout their colony cycle. Further, studies by Wood et al. (2015; 2016) showed that the wildflower mixtures typical of Entry Level and Higher Level Stewardship Schemes in England were not sufficient to benefit the abundance of many solitary bee and wasp species (which may prefer plants that persist unaided in the wider environment such as scentless mayweed, hogweed, and dandelion). At the end of the summer, ivy is a key resource for many pollinators, including representing 89% of pollen collected by six honey bee hives in southern England in autumn (Garbuzov and Ratnieks 2014). Together these studies show that for **ETPW-116**, **ETPW-205C** & **ETPW-189** to be successful for a range of pollinating insect species, they must provide a range of flowering times and flowering structures. This may need to be delivered through a combination of options such as **ETPW-116**, **ETPW-205C** and **ETPW-189**, including sown field margins/ corners or plots as well as less intensive management of existing spring-flowering hedgerows and field boundary vegetation. There is also increasing evidence for spillover of pollinators and pollination services into flowering crops (Pywell et al. 2015, and see 3.1.1.1.1.10). For example, a trial across six farms in Scotland found that the presence of sown wildflower strips significantly increased the number of visits to adjacent commercial strawberry crops by pollinating insects (Feltham et al. 2015). In apple orchard systems in Kent, England, the addition of wildflower margins and/or plots has been shown to increase solitary bee numbers visiting apple flowers by over 20% (Garratt et al. 2022). A meta-analysis of 17 studies on wildflower plantings found flower strips had varying effects on crop pollination, and that perennial and older strips with higher plant diversity enhanced pollination more effectively (Albrecht et al. 2020). Further direct evidence for significant benefits to crop yield and fruit quality is needed, and the design of wildflower seed mixes may be key to their efficacy.

There is reasonable evidence that where established within or near to the known ranges of rare and priority S41 bumblebee and solitary bee species, newly created or enhanced flower-rich habitats will attract these species. This has been shown for example with the bumblebee *Bombus ruderatus* being attracted to legume-rich field margins in England (Carvell et al., 2006; Pywell et al. 2006; Redhead et al. 2016;) and *Bombus sylvarum* being recorded on newly created or enhanced flower-rich habitats within farmed landscapes (Carvell 2000 and subsequent reports from the Bumblebee Conservation Trust). In addition, Wood et al. (2015) recorded 21 wild bee and wasp species of conservation concern on a range of farms in Countryside Stewardship schemes containing 21–22% semi-natural habitat.

There is little evidence for the specific benefits of **ETPW-168** Collect and sow locally sourced grass and wildflower seed on pollinators. Where adjacent to existing protected habitats such as lowland or upland unimproved meadows, and for creating or managing in-field vegetation, including grass, scrub, trees and wildflower/legume rich swards (**ECPW-237**), local sources of seed should be selected as a precautionary measure although there is little evidence for the impacts of this approach on the resulting pollinator community (as reviewed for other invertebrates below). A recent study in Finland (Alanen et al. 2011) found that bumblebee abundance and species richness were rapidly increased on sown in-field set-aside plots.

The density of floral resources in a habitat is almost always identified as a key predictor of both abundance and species richness of the pollinator community observed foraging there (e.g. Carvell et al. 2004; 2007; Wood et al. 2015). This in turn is influenced by the success in establishment and maintenance of wildflower habitats on cropland as reviewed in 3.1.1.1.7. While most evidence for the outcomes of creating wildflower habitats on pollinators is focussed on foraging requirements, there has been relatively little testing of the impacts of creating or enhancing nesting habitat opportunities for wild bees, (Bartholomée et al. 2020). Options linked to **ETPW-116** and **ETPW-189** may provide nesting habitats for bumblebees within areas of undisturbed rough grassland for surface-nesting species (e.g. *Bombus pascuorum*), or rodent holes (see below) for ground-nesting bumble bees (e.g. *Bombus terrestris*) as evidenced by observations of nest-searching queens in the spring (Lye et al. 2009). Studies of adding bare ground to Cropland as a nesting resource for ground-nesting solitary bees are lacking (Dicks, Showler, and Sutherland 2010, but see Garratt et al. Submitted and see option **ETPW-200x** under Create fallow plots below). Similarly, while nest substrate or box provision (e.g. hollow reed stems, cardboard tubes, drilled wooden boards) can increase the numbers of cavity-nesting solitary bees over time (Dicks, Showler and Sutherland 2010), there is no evidence for the value of wildflower habitat creation in providing such niches and it is likely that annual autumn cutting management would remove any suitable habitat for stem-nesting solitary bees within grass and wildflower strips or plots (Nowakowski and Pywell, 2016).

There is wide scale evidence that the species richness of ground beetles, rove beetles and a range of other phytophagous beetle species, as well as spiders are likely to benefit from floristically diverse field margins and similar features (Woodcock et al. 2005; Woodcock et al. 2008a; Woodcock et al. 2010; Sustainable Arable Farming for an Improved Environment: SAFFIE, DEFRA link project LK0926; NERC Centre for Ecology and Hydrology 2007; Heard et al. 2011). Many of these taxa are associated with the provision of natural pest control (Olson et al. 2007; Tschumi et al. 2015, 2016; Woodcock et al. 2016a), including potential reduction of weed species (e.g. through weed seed granivory, see Petit et al,'s 2018 review). Maino et al. (2019) suggests also that these field margins may act as a refuge for pest genes that could help contribute to good pesticide resistance management. These field margins may also benefit the biodiversity of soil macrofauna (including earthworms), with potential knock-on benefits for decomposition rates although this was not shown within the adjoining crop (Smith et al. 2008, 2009; BD1624 BUZZ). Management of fields may affect the benefits of field margins on soil macrofauna. Carlesso et al (2022) found the direction of tramlines in field management altered the abundance of Collembola and Acari in margins. In the case of option Collect and sow locally sourced grass and wildflower seed (**ETPW-168**) the evidence for the importance of this comes from the topic of grassland reversion or recreation (Jones et al. 1999; Edwards et al. 2007; Czerwiński et al. 2018; Wagner et al. 2021). There is strong evidence in this area that the use of local provenance seeds can increase rates at which grasslands replicate target communities of arthropods (in particular beetles), although this is not normally compared to simple, commercially sourced seed mixtures (Woodcock et la 2008; Woodcock et al. 2010; Woodcock et al. 2012). However, as field margins are typically high fertility establishment success is likely to be limited suggesting that the use of hay spreading techniques to introduce local provenance seeds into **ETPW-116** is not cost effective. Without direct tests in field margins there is no evidence to support the utility of this approach (**ETPW-116**), however for the more general option of 'Provide a flower rich habitat for wild pollinators with a range of flowering times and flowering structures' (**ETPW-205C**) (which may include grassland restoration) this could be a useful technique with some evidence supporting its value. For example, Albrecht et al. (2020)'s meta-analysis showed a benefit of flower strips in enhancing pes control in adjacent fields by 16% on average, from a synthesis of 17 studies.

For mammals, there is evidence that wildflower margins or plots (**ETPW-189**) are attractive to small rodents and hold larger populations than in cropped areas (Tattersall et al. 1999; Aschwanden et al. 2007). There is further evidence that diversifying in-field habitats (**ECPW-237**), including with areas of wildflowers, is strongly beneficial to priory brown hares and western European hedgehogs (Hof & Bright 2010; Petrovan et al. 2012) by providing habitat for foraging and resting that is associated with increased abundance on croplands.

For farmland birds, strips, margins and corners of wildflowers or flower-rich grass have been demonstrated to have effects that range from negligible at the field scale to highly positive at the field and farm scale (Vickery et al. 2009). These actions, and also enhancing trees and scrub within cropland landscapes, are widely identified as important for increasing landscape heterogeneity, which has broad and substantial benefits for farmland birds (Hinsley & Bellamy 2019). Clarke et al. (1997) found higher bird counts (including priority yellowhammer and linnet) on wildflower margins compared to grassy margins. Schmidt et al. (2021) found a positive effect of increased breeding bird species richness and territory density on arable fields with perennial wildflower strips in Germany, particularly when close to woody vegetation (hedgerows or woods). This included priority species such as corn bunting, skylark, yellowhammer and also common whitethroat, but not priority linnet, lapwing, tree sparrow or yellow wagtail. Pywell & Nowakowski (2008) found very low numbers of farmland birds using wildflower plots in winter, and no significant difference from control crops. Redhead et al. (2013) found only weak positive benefits of floral margins on breeding parameters of blue tits and great tits that were used as indicators of cropland habitat quality for birds, with tree and hedgerow metrics being dominant drivers of breeding productivity. Henderson et al. (2012) found that are of uncropped land including wildflower areas had a significant effect on the abundance of key bird species, and also that the spatial configuration had a weaker effect for some bird species. For example, linnet abundance was greater on contiguous blocks of habitat, while skylarks were associated with a larger edge effect (Henderson et al. 2012).

Sixteen out of 21 studies looking at effects of wildflower strips on plants found higher plant cover, diversity or species richness, while three studies showed no effects and one study negative effects on plant diversity or species richness (Dicks et al. 2013). Over time, plant species richness in sown wildflower plots may decrease (Cauwer et al. 2006) due to high levels of soil fertility. Targeted monitoring of a wide range of arable field margin types at 116 sites managed under the Countryside Stewardship Scheme in England showed that sown margins had more grass and fewer weed species than naturally regenerated sites. Grass margins contrasted with normally cropped sites, having greater species richness of grasses, forbs and perennials and more bird, butterfly larva and bumblebee food plants. Mesotrophic grassland forbs were scarce in margins established from basic grass seed mixtures but significantly more abundant if included in the seed mixture (Critchley et al., 2006).

Being typically made up of native grassland perennial species, and managed by annual or more frequent cutting y, flower-rich margins prevent rare arable annual plant species from establishing and persisting (NERC Centre for Ecology & Hydrology 2007; Albrecht et al. 2016). This means that, while they might increase plant species richness locally, they negatively affect species richness of the resident rare arable flora compared to management options targeted to the specialist requirements of these species. In some European countries, experimental wildflower strips containing rare arable species are currently being trialled, to test whether, like regular wildflower rich swards, they can also produce faunal benefits (Albrecht et al. 2016). If wildflower-rich swards were to be established using suitable arable species, and if done in the right way, they could potentially produce benefits for arable plants. This would require rotational establishment and destruction of perennial wildflower habitats to enable rare annual plants to establish and set seeds.

3.1.1.2 Co-Benefits and Trade-offs

The strongest co-benefits associated with create wildflower habitat management bundle (specifically **ETPW-116** & **ETPW-205C**) are associated with supporting species (Pywell et al. 2005b; Carvell et al. 2007; Woodcock et al. 2008; Woodcock et al. 2010; Woodcock et al. 2012) and the provision of key ecosystem services such as reducing outbreaks of pests and diseases (Woodcock et al. 2016; Tschumi et al. 2015, 2016; Albrecht et al. 2020) and the increased abundance, distribution and species richness of pollinators and seed dispersers (Pywell et al. 2015). If done well and successfully established, wildflower habitats on cropland also provide cultural services in the form of aesthetic enjoyment (Bullock et al. 2021).

In relation to ecosystem services not related to biodiversity, Bullock et al. (2021) found wildflower margins in arable fields did not prevent run-off of nutrients and sediment into waterways, and showed limited carbon sequestration or reduction of greenhouse gas emissions. In contrast, a multi-site study conducted on six arable farms found that establishing perennial wildflowers on arable field margins resulted in a significant (25%) increase in soil carbon after 5 years (as measured by loss on ignition) compared with the cropped to the edge control treatment. However, this increase was limited to the top 5cm of the soil (NERC Centre for Ecology and Hydrology 2007).

3.1.1.3 Magnitude

For bumblebees, Carvell et al. (2017) showed that survivorship of family lineages increased almost linearly with increasing proportions of flower-rich semi-natural habitat (including sown field margins) within 1 km of colony locations, in the range from 2-10% semi-natural habitat. With 2% flower-rich habitat, survival probability from summer worker to spring queen stage was less than 20%, rising to almost 60% when the landscape had 10% semi-natural habitat. Dicks et al. (2015) combined estimates of pollen demand by six wild bee species with pollen supply from hedgerow and wildflower creation agri-environment options. They calculated that 2% flower-rich habitat and 1 km flowering hedgerow per 100 ha of farmland, are sufficient to supply these common pollinator species with enough pollen to feed their larvae at lowest estimates, using minimum demand and maximum supply values for estimated parameters where a range was available. There was a very wide range of uncertainty, and with high end estimates of pollen demand and low estimates of supply, the study suggested the six bee species would need 44% of the farmed landscape sown as well-managed flower-rich (margin) habitat and 13.8 km of flowering hedge per 100 ha to meet their pollen demands through the season.

In a trial of wildflower strips sown adjacent to strawberry crops, Feltham et al. (2015) found that on average, the frequency of pollinator visits was 25% higher for crops with adjacent flower strips compared to those without, with a combination of wild and commercial bumblebees (*Bombus* spp.) accounting for 67% of all pollinators observed. This effect was independent of other confounding effects, such as the number of flowers on the crop, date, and temperature.

Natural pest control within wheat crops adjoining flower rich field margins has been shown to be improved, with sentinel cereal aphid colonies disappearing from wheat crops in under 5 days as opposed to c. 15 days in the absence of this margin type (Woodcock et al. 2016a). Tschumi et al. (2015, 2016) found improved pest control in association with flower rich areas for both wheat and potato crops. Tschumi et al. (2015) found a 61 % reduction in leaf damage from Oulema spp. pests of wheat where sown flower strips were present, however, it should be noted that in the UK this is an economically irrelevant pest. In potato crops, the sowing of flower rich strips increased the laying of eggs by aphid predators (hoverflies and lacewings) by respectively 27% and 48% (Tschumi et al. 2016).

Clarke et al. (1997) found average counts of 45-131 birds on strips sown with wildflowers compared to those with grass mixtures (18-121 birds) or a grass and wildflower mix (33-100 birds). Schmidt et al. (2021) reported that species richness and territory density of priority farmland birds was double that of controls. Henderson et al. (2012) found 60% greater bird abundance on farms with 10% uncropped land, though in this study uncropped land included a range of interventions including wildflower strips, so attribution of effects is more complex. Field et al. (2010b) found double the density of yellowhammers in hedgerows alongside floristically enhanced grassy margins, compared to controls hedgerows without a grass margin.

3.1.1.4 Timescale

There is a strong suggestion that the benefits associated with enhancing wider populations of beneficial insects may take several years to come into effect following habitat creation, predominantly in the form of flower rich margins and field corners (Pywell et al. 2015; Heard et al. 2011). Here it took 2-3 years before populations of beneficial insects increased sufficiently to start having positive effects on crop yield, although this effect was a combination of both pollination and pest control. It is likely this reflects the time required for populations to colonise and reproduce within such habitats (Blaauw & Isaacs 2014; Krimmer et al. 2019). Albrecht et al.’s (2020) meta-analysis has a similar finding, pollination services increased by 27% on average in 2-year old wildflower strips. However, over longer timescales wildflower strips may deteriorate and become dominated by grasses. Appropriate management and seed mixes are key to avoiding wildflower strips degrading over time – see Section 3.1.1.1.7 Maintenance below.

A study in Germany showed that species richness and abundance of butterflies was greatest in flower strips in the first growing season compared to the second (Wix et al. 2019). This was related to flower abundance which was lower in the second growing season showing the importance of maintenance on these wildflower habitats after establishment.

3.1.1.5 Spatial Issues

Landscape context may affect the response of butterflies to wildflowers. Korpela et al. (2013) found that the proportion of forest surrounding farms had a significant influence on the number of specialist butterfly species found on wildflower strips. Similar results are found with moths, with proximity to semi-natural habitat greatly affecting how effective the AES margins are, although this was not specific to wildflower margins (Alison et al. 2016).

There is strong evidence that landscape context can affect the success of wildflower habitat creation for pollinators (Carvell et al. 2011; Scheper et al. (2013). It has been argued that landscape complexity may be more important than local management, with positive benefits of management seen only in simple landscapes where few alternative flower resources exist (Tscharntke et al. 2005). In a meta-analysis of studies from across Europe, Scheper et al. (2013) suggest that the ecological contrast in floral resources created by schemes drives the response of pollinators to newly created habitats but that this response is moderated by landscape context and farmland type, with more positive responses in croplands (vs. grasslands) located in simple (vs. cleared or complex) landscapes. However there is also evidence for landscape-wide benefits of creating wildflower habitats in intensively farmed areas: in a replicated study in thirty-two 10 km grid squares across England (Pywell et al. 2006), the abundance of long-tongued bumblebees, mostly common carder bee *B. pascuorum* and garden bumblebee *B. hortorum*, recorded on field margins (various planting treatments) was positively correlated with the total number of pollen and nectar-mix agri-environment agreements in each 10 km square. Redhead et al. (2016) suggested that high coverage and low fragmentation of semi-natural vegetation across cropped landscapes, including managed agri-environmental wildflower margins, led to reduced foraging distances in worker bumblebees, including the rare *Bombus ruderatus*.

In the case of predatory species (i.e. those supporting a reduction in the outbreak of pests and diseases) Karp et al. (2018) in his meta-analysis of 6,759 worldwide sites demonstrated a lack of a consistent response for predatory species to overall landscape structure. This lack of an overall response was also seen when predation rates were directly measured, as well as for indicators of crop damage or yields. However, within this overall analysis individual studies showed both positive and negative trends for all of these metrics. Note this contrasts with the earlier findings of Bianchi et al. 2006 who suggested based on a meta-analysis that heterogeneity (which could be increased by this type of management option) would have benefits on biodiversity and the suppression of pest species. It is likely in the UK that overall landscape structure plays at least some role in defining communities of predatory arthropods, although this may be very taxa specific. The importance of flower rich field margins in supporting spill-over of natural pest control into crops also has a spatial element. In a multi-site study, sentinel cereal aphid colonies were more rapidly eaten by generalist arthropod predators when they were placed adjacent to wildflower margins compared with simple grass margins (Woodcock et al. 2016). However, this spill over of the pest control service diminished rapidly at distances of more than 50m from the crop edge for both margin types (Woodcock et al. 2016).

In addition to other landscape variables affecting the success of wildflower habitat creation, the spatial configuration of the wildflower strips may be important. Henderson et al. (2012) found that are of uncropped land including wildflower areas had a significant effect on the abundance of key bird species, and also that the spatial configuration had a weaker effect for some bird species. For example, linnet abundance was greater on contiguous blocks of habitat, while skylarks were associated with a larger edge effect (Henderson et al. 2012).

3.1.1.6 Displacement

It is possible that sowing perennial wildflower species could cause the displacement of rare annual plant species associated with arable habitats. It is therefore important to provide information on the distribution of these rare species. For invertebrate species associated with cropped landscapes, it is unlikely that the establishment of wildflower areas will cause native species displacement, however, the choice of seed mix used in their creation will impact on species utilisation. For ground beetles and other epigeal arthropods there is often a need to include some kind of low level structures, e.g. tussock grasses, or other mat forming vegetation within which they can seek refuge (Luff 1966; Dennis et al. 1998; Woodcock et al. 2007). Choice of flowers sown into the margin will also affect species foraging on them for pollen and nectar, including many species associated with natural pest control such as hoverflies and parasitic Hymenoptera. These short tongues species may benefit from the inclusion of umbellifers or brassicas with more open flower structures with short-corolla flowers in the seed wildflower mixtures (Wäckers, et al. 2013; Campbell et al. 2012; Rijn et al. 2016). Campbell et al (2017) recommend 'multi-functional' flower strip compositions with opposing floral traits to improve both crop yield and pest control services in apple orchards.

3.1.1.7 Maintenance and Longevity

There is good evidence showing positive relationships between the density of floral resources in a habitat and the abundance and species richness of the pollinator community found foraging there (so long as the appropriate suite of plant species is provided). Further, cutting and mowing frequency of agri-environment options including hedgerows (Staley et al. 2016) and field margins sown with wildflowers influence floral resources available for pollinators including butterflies (Pywell et al. 2011b).

The establishment and management of wildflower areas has been comprehensively reviewed in Nowakowski and Pywell (2016) and this should be referred to. In summary it is likely to involve a number of key stages:

1) SEEDBED PREPARATION: The seedbed needs to resemble a "spring barley" seedbed, being firm, fine, weed free (potentially use pre-cultivation Glyphosate to achieve this). Soil particles need to be fine enough for seed to remain on the surface when you sow. A puffy seedbed can be ring rolled.
2) SEED SOWING: Sowing is likely to be required in the majority of cases to overcome limited seed banks, although natural regeneration may be appropriate in some specific cases. Broadcasting rather than drilling the seeds is preferable so they remain on the soil surface. Most drills can be used, however, it is advisable to roll following sowing to promote seed to soil contact. See above comments in relation to option **ETPW-168** sow locally sourced grass as soil fertility may make the expense associated with this of limited utility for field margin areas;
3) SOWING DATES: Autumn sow from late July to the end of August. In a warm moist open autumn this date can be extended by 7-10 days maximum. If seedbeds are difficult to produce then it is better to delay sowing until April the following year. The seedbed may need another Glyphosate pre-sowing to control emergent weeds, but not another cultivation. Where slug pressure is high use conventional control methods as you would for crops. Where Blackgrass is an issue a spring April sowing may be better.
4) ESTABLISHMENT: Year 1) If annual weed pressure is high 3 or more cuts might be necessary. As a rule autumn sowing will need its first cut in April, while spring sowings will need a first cut in July. Where possible cuttings should be removed. If this is not possible more frequent cutting is less likely to leave a damaging mulch on the surface. Make a final cut each year when growth has stopped around mid-September; Year 2 onwards). Depending on weed pressure a single autumn cut will be required. Although a variety of ongoing management practices have been investigated (including scarification and the use of graminicides; e.g. Woodcock et al. 2005; Sustainable Arable Farming for an Improved Environment: SAFFIE, DEFRA link project LK0926), cutting remains the most common of these and is accessible to most farmers. A multi-site study showed that native wildflower species sown on arable land persisted >8 years (Bullock et al., 2007), and in some cases up to 21 years (Pakeman et al. 2002). However, persistence can be as little as 3-4 years where simple seed mixtures based on agricultural cultivars of legumes are sown (Woodcock et al. 2014a), or if not managed sympathetically (Smith et al. 2010).

Cutting regime greatly affects the magnitude of the benefits wildflower margins can have on butterflies, particularly species richness. Field edge plots cut in spring or autumn, or not cut at all, attracted more species than those cut in summer (Feber et al. 1996). The abundance of adult butterflies was most closely associated with the abundance of flowers of key nectar source species. These margins provide other resources, such as larval host plants and overwintering sites, and thus a more complex mowing regime would be yet more beneficial where some areas are cut in summer to extend the flowering season, while others are cut in spring or autumn, or not at all (Pywell et al. 2011b). Sybertz et al. (2017) also showed that time of mowing as well as grass-herb-ratio and width of margin are important factors determining the quality of field margin habitats for butterflies.

3.1.1.8 Climate Adaptation or Mitigation

Memmott et al. (2010) suggested that climate change (specifically global warming) may limit foraging resources for insect pollinators by advancing flowering phenology and thereby disrupting the overlap between plant flowering and pollinators' flight seasons. As a result, sowing of targeted early and late-flowering species may help future-proof sown wildflower habitats for insect pollinators under these scenarios (Memmott et al. 2010). In another study conducted across agricultural landscapes in Germany, a high proportion of semi-natural habitats was shown to decrease the detrimental effect of warmer temperatures on bee species richness and abundance (Papanikolaou et al. 2017), providing support for **ETPW-116**, **ETPW-205C**, **ETPW-205EM** and **ECPW-237**.

3.1.1.9 Climate Factors / Constraints

Bullock et al. (2021) conducted a replicated experiment on a commercial farm in southern England and found over two years that wildflower margins in arable fields showed limited carbon sequestration or reduction of greenhouse gas emissions. In contrast, a multi-site study conducted on six arable farms found that establishing perennial wildflowers on arable field margins resulted in a significant (25%) increase in soil carbon after 5 years (as measured by loss on ignition) compared with the cropped to the edge control treatment (NERC Centre for Ecology and Hydrology 2007). However, this increase was limited to the top 5cm of the soil. Both these studies may be too short timescales to draw firm conclusions, as long-term wildflower margins may be more effective at capturing carbon over decadal time series.

3.1.1.10 Benefits and Trade-offs to Farmer/Land manager

Benefit: There is increasing evidence of positive effects of habitat creation (specifically sown wildflower margins or blocks alongside crops) on crop production, yield and quality. Pywell et al. (2015) showed that in the six years following habitat creation across a large estate, crop yields at the field scale were maintained for winter wheat and oilseed rape, and yields were enhanced in field bean crops where either 3% or 8% of land had been removed from production and sown with flower-rich habitat. Bullock et al. (2021) showed that higher invertebrate numbers as provided by enhanced wildflower margins did appear to promote pollination and yield for oilseed rape and pest control on wheat crops. However, while that study found direct effects of floristically enhancing margins on wheat yield, there was no direct effect on oilseed rape yield after one year (Bullock et al. 2021). In high value fruit systems such as apple orchards, the addition of wildflower margins and/or plots has been shown to boost the abundance of solitary bee pollinators visiting nearby apple blossom, and orchards with a greater abundance of solitary bees and bumblebees saw reduced deficits in measures of fruit size and fruit set (Garratt et al. 2022). Further evidence is required for direct effects of habitat creation on fruit crop production deficits (AMBER L***).

Trade-off: The removal of land from production may be viewed as detrimental to profitability at the field scale. However, in the Pywell et al. (2015) study, winter wheat, beans and oilseed rape crops all showed consistent and marked reductions in yield at the field edge (0–9 m; the area typically used for creation of wildflower habitat) compared with the rest of the field. Habitat creation in these lower yielding areas led to increased yield in the cropped areas of the fields, and this positive effect became more pronounced over six years. Wildflower patches could provide habitat for crop pests, such as rabbits, or could be perceived to do so, although this has not been tested.

3.1.1.11 Uptake

There is evidence that to be done well, the creation of flower-rich habitat for wild pollinators with a range of flowering times and flowering structures on cropland requires not only motivation of the farmer, but also previous experience in environmental management such as via training in sowing and establishing flower mixes (McCracken et al. 2015). In addition, some crop systems may respond better than flower margins than others, and margin composition may need to be tailored to the specific cropping system, for example through selection of species with specific floral traits for seed mixes (Campbell et al. 2012, 2017).

3.1.1.12 Other Notes

None

3.1.2 EBHE-117: Create/enhance/manage contour grass strips

Bundle: Soil management and protection /Cover cropping

Overall RAG ratings for each ecosystem service

GREEN** maintaining species / wider biodiversity
GREEN* presence of rare or priority species
AMBER L* pest and disease control
AMBER TL** pollination

3.1.2.1 Causality

RAG ratings by taxa / ecosystem service

- CARABIDAE – **EBHE-117** **GREEN*** for maintaining species.
- STAPHYLINIDAE – **EBHE-117** **GREEN*** for maintaining species.
- ARANAE – **EBHE-117** **GREEN*** for maintaining species.
- BUTTERFLIES - **EBHE-117** **GREEN*** for maintaining populations
- MOTHS - EBHE–117 **GREEN**** for maintaining populations
- POLLINATORS - EBHE–117 **AMBER TL**** for maintaining populations and species, **AMBER TL**** for pollination services.
- MAMMALS – **EBHE-117** **GREEN***** for maintaining species, **GREEN*** for presence of rare and priority species.
- BIRDS – **EBHE-117** **GREEN**** for maintaining species, **GREEN**** for presence of rare and priority species
- ARABLE PLANTS – **EBHE-117** **RED*** for maintaining arable plant richness and for maintaining rare arable plants.
- PLANTS – **EBHE-117** **GREEN**** for maintaining species / diversity of plants more widely.

Most of the evidence for field margin effects on moth populations are from studies carried out on grassy field margins. Works by Thomas Merckx (2009a, 2009b, 2010, 2012) has showed that wide field margins are beneficial to macro-moths, increasing abundance and diversity, compared to standard margins although there is an even stronger effect of hedgerow trees which is related to shelter. Richness of macro-moths was higher in AES grassy field margins compared to conventional field margins in farms across Scotland but not significantly so, while there was a significant positive effect for both abundance and species richness of micro-moths (Fuentes-Montemayor et al. 2011). In the Hillesden Project (Heard et al. 2011), there was no significant effect of 6m grassy field margins compared to standard (1-2m) cross-compliance margins on either abundance or diversity of macro-moths or micro-moths, although both were generally higher on grassy field margins for both moth groups. For priority species, there was no difference between grassy margins and standard margins. This grouping consisted of very few priority species and is likely related to a lack of suitable host plants on grassy margins for those species with larvae that feed on herbaceous forbs rather than grasses, further exemplified by an increased abundance and species richness on more forb-rich wildflower margins compared to both standard and grassy margins. Grassy margins can support a large range of moth species as there are many species with grass-feeding larvae, which can be very abundant of farmland (Heard et al. 2011, Blumgart 2021) but these margins can be significantly improved for moths by the provisioning of host plants and shelter through diverse grass and wildflower mixes (Blumgart 2021) and hedgerow trees (e.g. Merckx et 2009b).

There are a number of generalist butterfly species that could benefit from grass only strips as their larvae feed on a range of common grass species. These species generally account for a large proportion of total abundance/biomass in UK butterfly communities across many habitats and are therefore important as prey for a wide variety of invertebrate and vertebrate predators. However, the benefits of grassy margins may be fairly limited as adult nectar sources and suitable overwintering habitat through suitable management are of great importance to butterflies (Pywell et al. 2011b). In addition, the relatively few species that are likely to benefit most from grass-only strips are generally common and widespread and found in other habitats.

Field et al. (2005) found a significant increase in the total abundance of all butterflies in 6m grassy margins compared to control sections. At species level this was only significant for *Maniola jurtina*, the UK's most widespread generalist butterfly with grass feeding larvae and total species richness was actually greater on the control sections. A similar study was also conducted on 2m field margins in which significantly greater abundance of three generalist grassland butterfly species was found compared to control sections (Field et al. 2007). There was limited evidence of increased species richness with more butterfly species recorded combined across all grassy margins (19 species) compared to across all control sections (12 species) but the mean species richness per margin was actually higher in control sections. Meek at al. (2002) found no significant effect on abundance or species richness of butterflies on grassy margins, although there was a tendency towards higher abundance. This, however, was species specific and was mostly attributable to *Maniola jurtina,* in line with other studies.

For pollinators, as with farmland birds, grass margins or corners have not commonly been assessed in isolation but may provide some value for nesting within a matrix of other habitats, or for foraging depending on the context of whether they also contain either sown or weedy forb species (hence Amber TL**). Undisturbed tussocky grass margins with a reasonable amount of thatch or mossy litter material may provide nesting habitats for surface-nesting bumblebees (e.g. *Bombus pascuorum*), or rodent holes for ground-nesting bumblebees (e.g. *Bombus terrestris*) as evidenced by observations of nest-searching queens in the spring (Lye et al. 2009). Grass margins supporting weedy species such as dead-nettles or thistles can attract early queen or late season male bumblebees respectively (Carvell et al. 2004) but typically overall grass-only margins are considered of low benefit for most pollinators (Carvell et al. 2007).

Grass only contour strips have value for epigeal arthropod populations that have a strong reliance on physical structures, such as tussock grasses to support populations, both in the growing season and over the winter period. This is likely to include ground beetles, rove beetles and spiders, in particular wolf (Lycosidae) and money (Linyphiidae) spiders (Luff 1966, Kromp et al. 2992; Bayram et al. 1993, Dennis et al. 1998; Legrand et al. 2011). However, this type of margin has a significantly lower benefit for wider biodiversity when compared to more floristically diverse margin types - especially if those margins included a grass as well as forb component (Woodcock et al. 2005, Woodcock et al. 2009). There is some evidence that grasshoppers (Orthoptera) may prefer grass only field margins over more floristically diverse ones (Badenhausser et al. 2012).

Additionally, small mammal populations and diversity show a very strong positive response to the installation of grassy margins (Macdonald et al. 2007; Broughton et al. 2014), and they are also favoured by priority brown hares (Petrovan et al. 2012) and, to some extent, by western European hedgehogs (Hof & Bright 2010) compared to cropped areas of the field.

For farmland birds, grass margins or corners have not commonly been assessed in isolation, and so other enhancements (such as cover crops) are likely to have contributory or dominant effects (e.g. Stevens & Bradbury 2006; Redhead et al. 2018). Kleijn et al. (2006) found no significant benefits of 6 m grass margins (sown or natural regeneration) on breeding or foraging farmland birds. However, the priority yellowhammer appears to be a significant beneficiary of grassy margins and strips, particularly those alongside hedgerows. Perkins et al. (2002), Stoate & Moorcroft (2007) and Davey et al. (2010) reported higher foraging activity or abundance of yellowhammers, and higher nest survival, associated with grass margins, although Field et al. (2010b) found that increased yellowhammer abundance was reliant on grassy margins being floristically enhanced. Ewald also reported mixed results for priority grey partridges, with the proportion of grassy strips being related to smaller brood sizes and smaller ratio of juveniles to adults (reflecting productivity and recruitment), but a positive relationship between the proportion of grass strips and overall density and winter survival of grey partridges.

Several studies from the UK and elsewhere in Northern Europe have found that planting grass buffer strips increased the cover and species richness of plants (Dicke et al. 2013). Targeted monitoring of a wide range of arable field margin types at 116 sites managed under the Countryside Stewardship Scheme in England showed that sown margins had more grass and fewer weed species than naturally regenerated sites**.** Grass margins contrasted with normally cropped sites, having greater species richness of grasses, forbs and perennials and more bird, butterfly larva and bumblebee food plants (Critchley et al. 2006). Meek et al. (2002) showed that compared to an arable crop, a tussocky grass margin could have 20 times more plant species. However, within grass only contour strips / sown grass margins, resident arable plant species may show some establishment in the year when the strip/margin is first established but tend to be no longer present from year 2 onwards, being outcompeted and prevented from establishing by sown grasses (Asteraki et al. 2004, NERC Centre for Ecology & Hydrology 2007, Marshall 2009). Compared with other non-crop field margin management option, sown grass margins neither produce value for arable plant diversity (Critchley et al. 2004a), nor for rare arable plant species where such species are present (Critchley et al. 2005).

3.1.2.2 Co-Benefits and Trade-offs

There are no direct co-benefits for invertebrates, however this type of margin has a significantly lower benefit for wider biodiversity when compared to more floristically diverse habitat types (e.g. flower-rich field margins) - especially if those margins included a grass as well as forb component (Woodcock et al. 2005, Woodcock et al. 2009). This may represent a trade-off for net biodiversity gain on a farm.
For small mammals, co-benefits or trade-offs of increased abundance of rodents and shrews include the provision of prey for predators (which may be wanted or unwanted species), such as raptors, owls and mustelids (**ECPW-251** & **ETPW-271**).

The potential trade-off for butterflies and moths is reduction in diversity of host-plants and adult nectar sources reducing overall butterfly species richness. There is some evidence that butterfly species richness, for example, may be higher in un-managed farmland margins than in grass-only margins so a trade-off for the increased abundance of some generalist species with grass feeding larvae may be an overall reduction in species richness. In addition, evidence for benefits to the abundance of those few species is mixed, with some species showing no increase compared to control treatments, suggesting even the benefit to abundance may be limited (Field et al. 2005). Most studies evaluating flower-rich margins compared to grassy margins have shown that floristic enhancement greatly increased the benefits of margins for Lepidoptera, but grasses are a critical component and Jacot et al. (2000) showed that the highest butterfly species numbers and abundances were found in margins sown with both grass and wildflower seeds, when compared to margins sown with wildflowers only.

There is some evidence that grass buffer strips may protect vegetation in boundaries, and slightly reduce the ingress of weedy species into the edge of fields though no effect was found on weedy species in field centres (Marshall 2009). In addition, Marshall (2009) found that grass buffer strips may disadvantage rare arable weeds, as discussed in Section 3.1.2.1.1 above.

Falloon, Poulson & Smith (2004) estimated annual accumulation of carbon following the establishment of a grass field margin on arable land to be 1.30% yr±1 of the starting SOC value, and a value of 1.23% yr±1 for grass margins with hedgerows. These estimates were based on data from long-term experiments at Rothamsted.

3.1.2.3 Magnitude

Meek et al. (2002) showed that compared to an arable crop, a tussocky grass margin could have 20 times more plant species, 2.5 times more butterflies (abundance), 3.8 times more carabid beetles and 2.3 times more spiders. For all taxa surveyed, the increase in species richness or abundance was even greater on margins planted with wildflowers, than grassy margins (Meek et al. 2002).

For small mammals, after the installation of grassy field margins to replace conventional cropped to the field edge, the diversity increased from one species to seven (including priority harvest mouse). Overall, abundance of small mammals quadrupled within two years and remained at this higher level until at least five years (Broughton et al. 2014).

Field et al. (2010b) found that the density of yellowhammers in hedgerows was no different if the adjacent habitat was an unenhanced grassy margins compared to a control (though yellowhammers were more abundant if floristically enhanced grass margins were adjacent, as discussed in 3.1.1 above).

3.1.2.4 Timescale

For small mammals, rapid benefits of diversity and abundance were achieved within 1-2 years, with full benefits achieved after 3-5 years as the habitat matured into a tussocky structure (Broughton et al. 2014).

3.1.2.5 Spatial Issues

Woodcock et al. 2010 showed that the functional diversity of ground beetles was directly affected by the cover of tussock grass field margins in the surrounding landscape. In general, no specific spatial issues linked to the effectiveness of the creation of grass areas in supporting species or the control of outbreaks of pests and disease have been identified. When Karp et al. (2018) looked at data from 6,759 worldwide sites they found that overall landscape structure in general did not consistently predict and the abundances of natural enemies, predation rates, crop damage or yields with individual studies showing different (both positive and negative) trends. Note this contrasts with the earlier findings of Bianchi et al. 2006 who suggested based on a meta-analysis that heterogeneity (which could be increased by this type of management option) would have benefits on biodiversity and the suppression of pest species, and a more recent meta-analysis which suggests that edge density of habitat can affect the abundance of pollinators and natural enemy species (Martin et al. 2019).

Broughton et al. (2014) found an apparent overspill effect for small mammals from grassy margins onto conventional cropped field edges, which also experienced increased species diversity and abundance after installation of grassy margins on some fields.

As for wildflower margins, the effects of grassy margins is affected by proximity to semi-natural habitats (Jowett et al. 2019). In addition, detailed studies by Thomas Merckx (e.g. Merckx et al., 2009a) have shown that the positive effects of grassy field margins vary across species, with no significant positive effects being found in highly mobile moth species. In the Hillesden Project, effects of macro-moths were non-significant, likely related to the higher mobility compared to most micro-moths (Heard et al. 2011). These larger and more mobile species are likely to be responding at a greater spatial scale than the farm scale.

3.1.2.6 Displacement

No assessment.

3.1.2.7 Maintenance and Longevity

There is a strong suggestion that that this type of grass only habitat feature will take time to mature, with MacLeod et al. (2004) finding that they supported increased overwintering populations of Carabidae and Staphylinidae in final three years of a seven-year successional study. Thomas et al. (2002) suggests that beetle banks may support habitats for predatory invertebrates for at least a decade. The raised nature of beetle banks may make some management operations (such as cutting) impractical reducing farmer uptake, likewise the raised bank infrastructure may reduce appeal to many farmers preferring more flexible management solutions to supporting natural pest control (e.g. field margins or sown in-field strips that are not raised into banks).

Broughton et al. (2014) showed that benefits for small mammals were increased and retained over at least 5 years after grassy margin installation. Cutting of margins has a generally negative impact on small mammals by removing cover, taller structures used for nesting, and seeding plants (Feber et al. 2019). Avoiding cutting every year, partial or no cutting, or leaving cuttings in situ are mitigations.

3.1.2.8 Climate Adaptation or Mitigation

It has been suggested that arable field margins more broadly (including those sown with wildflower seeds, legumes, wild bird seed, grass and cultivated / low-input margins) may play a role in allowing some species to move within a landscape and find new locations locally or as part of a larger-scale change in distributions (Natural England and RSPB 2019). However, this will vary with the mobility of the taxa and species, and the specific role of linear features in connectivity to support climate change adaptation is largely unproven. Direct evidence for these benefits are sparse in the peer-reviewed literature.

3.1.2.9 Climate Factors / Constraints

Falloon, Poulson & Smith (2004) estimated annual accumulation of carbon following the establishment of a grass field margin on arable land to be 1.30% yr±1 of the starting SOC value, and a value of 1.23% yr±1 for grass margins with hedgerows. These estimates were based on data from long-term experiments at Rothamsted.

3.1.2.10 Benefits and Trade-offs to Farmer/Land manager

Increased abundance of small mammals as prey may attract predators (which may be wanted or unwanted species), such as raptors, owls and mustelids (**ECPW-251** & **ETPW-271**).

There is some evidence that grass buffer strips may protect vegetation in boundaries, and slightly reduce the ingress of weedy species into the edge of fields though no effect was found on weedy species in field centres (Marshall 2009).

Anecdotal discussions with farmers and expert opinion has some indication that trade-offs for managers may also include unwanted access by members of the public who mistake grassy margins for paths, increasing trespass, footfall damage and dog disturbance to the margin & priority species. Signage and careful positioning of margins (away from rights of way) can be used to dissuade such access.

3.1.2.11 Uptake

Not assessed

3.1.2.12 Other Notes

None

3.1.3 ETPW-207: Create/enhance/manage beetle banks

Bundle: Restoration, management and enhancement /Grassland

Overall RAG ratings for action and ecosystem service

GREEN** maintaining species / wider biodiversity
AMBER L** presence of rare and priority species
AMBER L* pest and disease control
AMBER L* pollination

3.1.3.1 Causality

RAG ratings by taxa / ecosystem service

- CARABIDAE – **ETPW-207** **GREEN***** for maintaining species and **AMBER L**** for the control of outbreaks of pests and disease.
- STAPHYLINIDAE – **ETPW-207** **GREEN***** for maintaining species and **AMBER L**** for the control of outbreaks of pests and disease.
- ARANAE – **ETPW-207** **GREEN***** for maintaining species and **AMBER L**** for the control of outbreaks of pests and disease.
- BUTTERFLIES & MOTHS – **ETPW-207** **AMBER L**** for maintaining species
- POLLINATORS - **ETPW-207** **AMBER L*** for maintaining populations and species, and pollination services.
- MAMMALS – **ETPW-207** **AMBER L**** for maintaining populations of priority species.
- Pest and disease control in open arable farming **ETPW-207** **AMBER L*** for reducing outbreaks of pests and diseases as spill over effects on pest species have rarely been assessed.

There are limited studies on the effects of beetle banks on Lepidoptera. Thomas (2001) found generalist butterfly species on beetle banks, but fewer butterfly species were found on beetle banks than on hedge banks within same farms (Thomas 2001). There was a relationship between botanical diversity and butterfly species richness on the beetle banks, which are thought to become more botanically rich over time. The richness and abundance of butterflies (and moths) is likely to be enhanced on beetle banks: while lacking the shelter benefits of some grassy margin types usually associated with boundary features, such as hedgerows, they are likely to perform similarly to grassy margin enhancements.

For pollinators, as with grass margins, beetle banks may provide some value for nesting bumblebees within a matrix of other habitats, or for foraging depending on the context of whether they also contain flowering forb species as floristic diversity increases with time (Thomas et al. 2002). However, there is no evidence in the UK for specific effects of beetle banks on pollinators (hence AMBER L*) and given they support less herbaceous cover and fewer nectar-providing plants compared with adjacent conventional field margins (Thomas et al. 2002) they are unlikely to provide significant benefits, even if done well.

Beetle banks are typically floristically poor being dominated by grass species (although the floristic diversity increases with time) (Thomas et al. 2002; Sotherton 1995). This may increase their value in supporting populations of species requiring structural refuges within the sward, both within the crop growing season, as well as during the overwintering period (Thomas et al. 2002). Indeed, beetle banks have been shown to support the densities of both ground beetles (Carabidae), rove beetles (Staphylinidae) and spiders that are key to controlling invertebrate crop pests (Sotherton 1995; MacLeod et al. 2004; Collins et al. 2002). Predator densities found in beetle banks may be comparable to those found in hedgerows, although those in beetle banks appear to be far more temporally variable (Collins et al. 2003).

For priority mammals, a relatively high density of harvest mouse nests was found on beetle banks compared to grassy field margins (Bence et al. 2003).

Beetle banks have been shown to have no effects on wider plant diversity, or to slightly reduce plant species richness, in contrast to grassy margins (Dicks et al. 2013). However, compared to a counterfactual of a cropped field edge, beetle banks are likely to have similar positive effects on plant communities as grass margins (see review for action **EBHE-117** above).

3.1.3.2 Co-Benefits and Trade-offs

Where beetle banks pass through field centres they remove potentially productive agricultural land. This impact is likely to be greater than that of equivalent field margins because of the reduction in crop yield seen at the edge of the majority of fields (Sparkes et al., 1998). There is no available cost-benefit analysis as too how much the increase in natural pest control offsets this loss in yield following the removal of this land. The raised nature of beetle banks makes them harder to manage by conventional cutting. As such, a recent (but comparable) management option of floristically diverse in-field strips may provide an alternative more compatible with many farming systems. The pest control viability of these in the UK is currently being assessed as part of the ASSIST project (https://assist.ceh.ac.uk/) (Tschumi et al. 2015, 2016). Both beetle banks and the in-field flower strips being assessed under ASSIST may give a greater capacity to increase pest control than field edge strips, with greater potential spill-over and the potential to control pests in higher-yielding parts of a field.

3.1.3.3 Magnitude

There is evidence to show that predatory arthropods (e.g. Carabidae, Staphylinidae, Linyphiidae and Lycosidae) dispersing into fields from beetle banks may contribute to the control of the aphid pest *Sitobion avenae* in wheat (Collins et al. 2002). Assessed using enclosures (e.g. open to predators arthropods vs. predatory arthropods excluded) aphid numbers were found to be 34% higher where the predators were excluded. However, this lacks a general control (e.g. compared to field with no beetle banks) and as such only demonstrated that predatory insects help control aphids and cannot predict the relative value of beetle banks in supporting their numbers. However, as beetle banks do increase the densities of these predator insects it is likely that they have a positive effect on pest control. The effects of predation on aphid pest numbers decreased with distance from the beetle banks, suggesting a spill-over effect (Collins et al. 2002).

Harvest mouse nest density on beetle banks was found to be 117/ha compared to 14/ha on field margins (Bence et al. 2003).

3.1.3.4 Timescale

There is a strong suggestion that beetle banks take time to mature, with MacLeod et al. (2004) finding that they supported increased overwintering populations of Carabidae and Staphylinidae in the final three years of a seven year successional study. Thomas et al. (2002) suggests that the retention of dense vegetation means that beetle banks may provide a valuable habitat for predatory invertebrates for at least a decade (> 10 years). It is likely that populations of beneficial arthropods are far more variable in beetle banks than hedgerows (Collins et al. 2003).

High densities of harvest mouse nests were recorded after 4-6 years of establishment and sowing of tussocky grasses (Bence et al. 2003), although no surveys were conducted prior to or after this period.

3.1.3.5 Spatial Issues

No specific spatial issues linked to the effectiveness of beetle banks in supporting species or the control of outbreaks of pests and disease have been identified. When Karp et al. (2018) looked at data from 6,759 sites worldwide they found that overall landscape structure in general did not consistently predict and the abundances of natural enemies, predation rates, crop damage or yields with individual studies showing different (both positive and negative) trends. However, a slightly more recent meta-analysis suggests that edge density of habitat (which would be increased by this type of habitat) can affect the abundance of pollinators and natural enemy species (Martin et al. 2019).

3.1.3.6 Displacement

No specific issues.

3.1.3.7 Maintenance and Longevity

Thomas et al. (2002) suggests that beetle banks may support habitats for predatory invertebrates for at least a decade. The raised nature of beetle banks may make some management operations (such as cutting) impractical reducing farmer uptake, likewise the raised bank infrastructure may reduce appeal to many farmers preferring more flexible management solutions to supporting natural pest control (e.g. field margins or sown in-field strips that are not raised into banks).

3.1.3.8 Climate Adaptation or Mitigation

It has been suggested that arable field margins more broadly (including those sown with wildflower seeds, legumes, wild bird seed, grass and cultivated / low-input margins) may play a role in allowing some species to move within a landscape and find new locations locally or as part of a larger-scale change in distributions (Natural England and RSPB 2019). However, this will vary with the mobility of the taxa and species, and the specific role of linear features in connectivity to support climate change adaptation is largely unproven.

3.1.3.9 Climate Factors / Constraints

No assessment.

3.1.3.10 Benefits and Trade-offs to Farmer/L-and manager

The raised nature of beetle banks may make some management operations (such as cutting) impractical reducing farmer uptake, likewise the raised bank infrastructure may reduce appeal to many farmers preferring more flexible management solutions to supporting natural pest control (e.g. field margins or sown in-field strips that are not raised into banks).

3.1.3.11 Uptake

The raised nature of beetle banks may make some management operations (such as cutting) impractical reducing farmer uptake. However, there are no specific studies showing this to be the case.

3.1.3.12 Other Notes

None

3.1.4 ETPW-240: Use low input cropped margins

Bundle: Restoration, management and enhancement/Cropland

Overall RAG ratings for action and ecosystem service

AMBER L** maintaining species / wider biodiversity
GREEN** presence of rare or priority species
AMBER L* pollination

3.1.4.1 Causality

RAG ratings by taxa / ecosystem service

- ARABLE PLANTS – **ETPW-240** **GREEN*** ** for maintaining arable plant richness and maintaining rare arable plants.
- MAMMALS – **ETPW-240** **AMBER L*** for maintaining species.
- BIRDS – **ETPW-240** **GREEN**** for maintaining species.
- POLLINATORS - **ETPW-240** **AMBER L*** for maintaining species and pollination services.

There is some evidence suggesting that low input cropped margins ('conservation headlands') are of limited value for pollinating insects. Kells et al. (2001) counted bumblebees and honeybees *Apis mellifera* on field margins managed as conservation headlands, and ten naturally regenerated, uncropped field margins in the West Midlands, England. They recorded averages of less than three bees/transect in conservation headlands, compared to averages of between 10 and 50 bees/transect in naturally regenerated margins. A replicated controlled trial in East Anglia and the West Midlands, England, found no significant difference in bumblebee species richness and abundance when 16 conservation headlands were compared with paired conventional field margins (Pywell et al. 2005b). In both types of field margin, a few species of plant contributed to the vast majority of foraging visits by bumblebees, mainly thistles, *Cirsium* spp. In a replicated controlled trial at six sites across central and eastern England, Carvell et al. (2007) found that unsprayed conservation headlands did not support more bumblebee individuals or species than conventional cropped field margins. However, weedy species may provide floral resources at times of year when other florals are limited, e.g. early in spring (Bretagnolle & Gaba 2015).

There is very little specific evidence for the effectiveness of conservation margins/low input margins for mammals on croplands. Tew et al. (1992) and de Snoo (1999) found that wood mice significantly preferred to forage in low input margins compared to standard cropped areas. The logic chain and expert opinion suggests a potential positive (but low) impact for other species, possibly through improved foraging (plant and insect diversity) for e.g. brown hares, western European hedgehogs and other small mammals, such as harvest mice, as found on other margin types and unsprayed headlands that increased vegetation and resource diversity (Fisher et al. 2007; Macdonald et al. 2007; Feber et al. 2019).

Priority grey partridges had significantly larger brood sizes and chick survival in fields with unsprayed margins, which was attributed to enhanced chick food (insects) (Sotherton 1998; Natural England 2009). Stevens & Bradbury (2006) reported that farmland birds, including priority corn bunting, lapwing, skylark, linnet and yellowhammer, were positively associated with conservation headlands and general low inputs of herbicide to the crop, although negative associations were detected for a smaller number of other species.

Through restrictions on herbicide use and fertiliser application, low input cropped margins ('conservation headlands') benefit arable plant diversity (Critchley et al. 2004a, Walker et al. 2007; Wagner et al. 2017), and help maintain extant populations of rare arable plants where these are present (Critchley et al. 2004a,b, Walker et al. 2007). There is some evidence that by also reducing cereal density, benefits of this action can be further increased, both for maintaining arable plant diversity (Wagner et al. 2017) and for maintaining rare arable plants (Rotchés-Ribalta et al. 2020). The benefits to arable plants that are provided by low input cropped margins can be quite pronounced, particularly for those rare arable species that are most adapted to cereal cultivation (Wagner et al. 2016). However, in some instances, annually cultivated uncropped margins might provide larger benefits (Critchley et al. 2004a; Walker et al. 2007).

To benefit rare arable plants, low input cropped margins should be are targeted in areas with a diverse seedbank and where there are existing diverse or important arable plant communities which are often found on lighter soils. Plantlife have published a report advising on targeting of priority sites for conservation of rare arable plants (Byfield & Wilson 2005). Fields that are dominated by strongly competitive species, for example blackgrass or thistle, should be avoided as rare arable species may be unlikely to establish there (though thistle can be of benefit to pollinating insects).

Twenty-two studies from 14 experiments showed conservation headlands had higher plant or invertebrate diversity than other habitats, 12 studies from ten experiments did not (Dicks et al. 2013).

3.1.4.2 Co-Benefits and Trade-offs

While species such as thistles (*Cirsium* spp.) may be of benefit to pollinating insects as discussed above, there is a potential for these to be a source of weeds that may spread further into the crops, which some landowners may not want.

[TOCB Report-3-6 *Carbon* **ETPW-240**] Manufactured fertilisers are associated with GHG production at the point of manufacture, which can be avoided by reducing application, at the potential cost of productivity (Alison et al., 2019). Organic inputs are associated with an increase in soil organic matter when carefully targeted, and when substituting for manufactured fertilisers. Liming may also be associated with direct GHG emissions, but may decrease the dependence of productivity on fertiliser applications (Alison et al., 2019). Using margins for diverse grassland swards is likely to have better outcomes for carbon sequestration (see section 3.5.3.1 in the carbon sequestration review, Report-3-6 *Carbon*). Overall, the effect of reduced inputs on soil carbon is likely to be site specific and has the potential to reduce crop residues in soil if productivity decreases as a result.

Food and fibre production	Area under production or yield and outside of ELM	**N**
Global, regional & local climate regulation	Above ground carbon sequestration	**N**
	Below ground carbon sequestration	**LTD***

3.1.4.3 Magnitude

Grey partridge brood sizes were up to five times larger on unsprayed field margins compared to conventional crops, although 32% more pairs were present on conventional fields than those with unsprayed margins (Rands 1985). Stevens & Bradbury (2006) found the strongest selection for unsprayed margins was shown by priority yellowhammer and also whitethroat, greenfinch and chaffinch.

3.1.4.4 Timescale

Not assessed

3.1.4.5 Spatial Issues

To benefit rare arable plants, it is important that low input cropped margins are targeted in areas with a diverse seedbank. Fields that are dominated by strongly competitive species, for example blackgrass or thistle, should be avoided as rare arable species may be unlikely to establish there (though thistle can be of benefit to pollinating insects).

Landscape context may also be important in spatial targeting of these options for arable plants. Metcalfe et al. (2019) found that neighbouring and boundary habitats were important in ensuring the success of conservation of ruderal arable plant species, and that this type of habitat should be placed along margins with limited potential for ingress of competitive perennial plant species.

3.1.4.6 Displacement

Not assessed

3.1.4.7 Maintenance & Longevity

Not assessed

3.1.4.8 Climate Adaptation or Mitigation

It has been suggested that arable field margins more broadly (including those sown with wildflower seeds, legumes, wild bird seed, grass and cultivated / low-input margins) may play a role in allowing some species to move within a landscape and find new locations locally or as part of a larger-scale change in distributions (Natural England and RSPB 2019). However, this will vary with the mobility of the taxa and species, and the specific role of linear features in connectivity to support climate change adaptation is largely unproven.

3.1.4.9 Climate factors/constraints

Not assessed

3.1.4.10 Benefits & trade offs to farmer/land manager

Not assessed

3.1.4.11 Uptake

Not assessed

3.1.4.12 Other notes

None

3.1.5 ECPW-264 – Leave unharvested cereal headlands

Bundle: **Restoration, management and enhancement /Cropland**

<u>Overall RAG ratings for action and ecosystem service</u>

GREEN ** for maintaining species / wider biodiversity
GREEN *** presence of rare and priority species

3.1.5.1 Causality

- MAMMALS – **ECPW-264** **AMBER L*** for maintaining species.
- BIRDS – **ECPW-264** **GREEN**** for maintaining species.
- ARABLE PLANTS – **ECPW-264** **GREEN**** for maintaining arable plant richness and **GREEN***** maintaining rare arable plants.

There is very little specific evidence for the effectiveness for mammals on croplands. Tew & Macdonald (1993) found high predation of wood mice after harvesting, and a rapid 80% decrease in population, which would be mitigated by unharvested cereal headlands. The logic chain and expert opinion suggests a potential positive (but low) impact for other species, possibly through increased habitat heterogeneity, foraging and cover for other small mammals, such as harvest mice, and brown hares (Feber et al. 2019).

For birds, Henderson et al. (2004) reported high densities of priority corn buntings and yellowhammers using unharvested cereals (wheat), in relation to other wild bird options (cover crops or stubbles), and it also ranked highly for priority skylarks, but few other species used it significantly. A review by Stoate et al. (2004) found preferential use of unharvested wheat and millet by priority farmland birds, but not maize (which was favoured only by woodpigeons, corvids and non-native pheasants and red-legged partridges).

No-fertiliser conservation headlands benefit arable plant diversity (Critchley et al. 2004a, Walker et al. 2007; Wagner et al. 2017), and help maintain extant populations of rare arable plants where these are present (Critchley et al. 2004a,b, Walker et al. 2007). As many UK rare arable species are late flowering (Storkey et al. 2010), additional benefits for priority rare arable species could accrue from leaving such unfertilised conservation headlands unharvested.

3.1.5.2 Co-Benefits and Trade-offs

Use of maize, as opposed to wheat or millet, may favour undesirable bird species, such as woodpigeons and corvids, and is also favoured by non-native commercial species (pheasant and red-legged partridge). Johnstone et al. (2019) found that priority farmland birds (yellowhammer and reed bunting) commonly used unharvested cereals during winter, but usage declined by January due to seed depletion. Breeding densities of these species were not increased by the availability of unharvested cereals.

3.1.5.3 Magnitude

Priority yellowhammer density on unharvested cereals was found to be 4-6 birds/ha in October-December, but declining to c.1/ha by January due to seed depletion. Comparative winter densities of reed bunting were 2 birds/ha (Johnstone et al. 2019).

3.1.5.4 Timescale

Not assessed

3.1.5.5 Spatial Issues

Landscape context may also be important in spatial targeting of these options for arable plants. Metcalfe et al. (2019) found that neighbouring and boundary habitats were important in ensuring the success of conservation of ruderal arable plant species, and that this type of habitat should be placed along margins with limited potential for ingress of competitive perennial plant species.

3.1.5.6 Displacement

Not assessed

3.1.5.7 Maintenance and Longevity

Cereals can produce abundant autumn seed, but use by farmland birds declines in late winter as seed is depleted (Stoate et al. 2004; Johnstone et al. 2019), although seeded Italian ryegrass performs better than cereals in retaining seed into late winter (Johnstone et al. 2019).

3.1.5.8 Climate Adaptation or Mitigation

It has been suggested that arable field margins more broadly (including those sown with wildflower seeds, legumes, wild bird seed, grass and cultivated / low-input margins) may play a role in allowing some species to move within a landscape and find new locations locally or as part of a larger-scale change in distributions (Natural England and RSPB 2019). However, this will vary with the mobility of the taxa and species, and the specific role of linear features in connectivity to support climate change adaptation is largely unproven.

3.1.5.9 Climate factors/constraints

Not assessed

3.1.5.10 Benefits & trade offs to farmer/land manager

Not assessed

3.1.5.11 Uptake

Not assessed

3.1.5.12 Other Notes

None

3.1.6 Arable-03: Annually cultivate headlands and leave unsown

Bundle: Restoration, management and enhancement /Cropland

<u>Overall RAG ratings for action and ecosystem service</u>

GREEN** maintaining species / wider biodiversity
GREEN** presence of rare and priority species
GREEN** pollination

3.1.6.1 Causality

RAG ratings by taxa / ecosystem service

- ARABLE PLANTS – **Arable-03** **GREEN***** for maintaining arable plant richness and for maintaining rare arable plants.
- POLLINATORS – **Arable-03** **GREEN** ** for maintaining habitats and species and for pollination services.

This action was added by the Croplands review team, and was not part of the original Defra spreadsheet of actions.

For pollinators, annually cultivated margins can be considered to have moderate benefits if done well, in the context of the resulting seed bank and presence of flowering plant species that result. Nine bee species were recorded on a single naturally regenerated field margin strip established for three years in Hampshire, England (Carreck et al. 1999), the same number of species as on three strips sown with a diverse wildflower seed mix in the same study. A replicated trial of UK arable field margins allowed to regenerate naturally for one year found that they supported significantly more honeybees and bumblebees than unsprayed cropped margins managed as conservation headlands (averages between 10 and 50 bees/transect on naturally regenerated margins compared to <3 bees/transect in conservation headlands; Kells et al. 2001). Bumblebee foraging activity and species richness were significantly enhanced on 18 uncropped, regularly cultivated field margins where natural regeneration had been allowed to take place for five years, compared to paired control sites of conventionally managed cereal, in East Anglia and the West Midlands, England (Pywell et al. 2005b). A further trial in North Yorkshire found 6m wide naturally regenerated, uncropped field margin plots supported significantly more foraging bumblebees than margins sown with tussocky grass and control cropped field margins in their first year (2001) due to the presence of spear thistle *Cirsium vulgare* (Carvell et al. 2004). In the other two years of this study (2000 and 2002), the naturally regenerated field margins did not support significantly more bumblebees than control or grass-sown margins. A similar pattern was found in Carvell et al. (2007) suggesting that the value of this option is greatest if implemented annually as suggested above for arable plants. Note however, that as discussed above for low input cropped margins (Section 3.1.4), arable plants may not establish well in margins that are dominated by *Cirsium* spp., and this action should be targeted to areas with a diverse arable plant seed bank.

Annually disturbed non-crop habitats, such as annually cultivated headlands, have been shown to support a greater abundance of invertebrates food for farmland plants than perennial habitats such as grass margins (Storkey et al. 2013), and are highly likely to benefit farmland birds.

Annually cultivated uncropped margins can help maintain arable plant diversity (Critchley et al. 2004a, Critchley et al. 2006b, NERC Centre for Ecology & Hydrology 2007), and extant populations of rare arable plants (Wagner et al. 2016). The observed benefits to arable plant tend to be larger for this action than for conservation headlands (Critchley et al. 2004a; Walker et al. 2007). However, if uncropped cultivated margins are non-rotational, undesirable grass and perennial weeds can increase, particularly with repeated shallow cultivation (Critchley 1996; Critchley et al. 2006b). If such problem weeds remain unchecked , their increase in density can eventually negatively affect desirable annual arable species (Critchley 1996; Critchley et al. 2006b), including rare arable species (Wagner et al. 2016). Where necessary, application of selective grass herbicides can counteract increases in undesirable weedy grasses and ensure the benefits of uncropped cultivated margins to arable plants are delivered (Pywell et al. 2010, Wagner et al. 2016). A suitable alternative might be to implement cultivated headlands rotationally in the same way as conservation headlands associated with a particular crop in the rotation (Wagner et al. 2016).

3.1.6.2 Co-Benefits and Trade-offs

While species such as thistles (*Cirsium* spp.) may be of benefit to pollinating insects as discussed above, there is a potential for these to be a source of weeds that may spread further into the crops and limit the establishment of desirable annual arable species, as discussed in the arable plant paragraph above.

[TOCB Report-3-6 *Carbon* **Arable03**] No empirical evidence is available for the effect of this specific action on carbon sequestration. However, leaving bare ground may increase the susceptibility of below ground carbon to erosion (see Report-3-6 *Carbon*, section 3.12). However, natural regeneration of grassland species could occur at an annual scale to some extent, which may contribute some below ground carbon sequestration (see section 3.10.1.2 of Carbon report).

Food and fibre production	Area under production or yield and outside of ELM	
Global, regional & local climate regulation	Above ground carbon sequestration	**N**
	Below ground carbon sequestration	**LD***

3.1.6.3 Magnitude

Not assessed

3.1.6.4 Timescale

Not assessed

3.1.6.5 Spatial issues

To benefit rare arable plants, it is important that annually cultivated headlands are targeted in areas with a diverse seedbank. Fields that are dominated by strongly competitive species, for example blackgrass or thistle, should be avoided as rare arable species may be unlikely to establish there (though thistle can be of benefit to pollinating insects as discussed above).

3.1.6.6 Displacement

Not assessed

3.1.6.7 Maintenance and Longevity

As discussed above under causality, if uncropped cultivated margins are non-rotational, undesirable grass and perennial weeds can increase, particularly with repeated shallow cultivation (Critchley 1996; Critchley et al. 2006b). If such problem weeds remain unchecked , their increase in density can eventually negatively affect desirable annual arable species (Critchley 1996; Critchley et al. 2006b), including rare arable species (Wagner et al. 2016). Where necessary, application of selective grass herbicides can counteract increases in undesirable weedy grasses and ensure the benefits of uncropped cultivated margins to arable plants are delivered (Pywell et al. 2010, Wagner et al. 2016).

Landscape context may also be important in spatial targeting of these options for arable plants. Metcalfe et al. (2019) found that neighbouring and boundary habitats were important in ensuring the success of conservation of ruderal arable plant species, and that this type of habitat should be placed along margins with limited potential for ingress of competitive perennial plant species.

3.1.6.8 Climate Adaptation or Mitigation

It has been suggested that arable field margins more broadly (including those sown with wildflower seeds, legumes, wild bird seed, grass and cultivated / low-input margins) may play a role in allowing some species to move within a landscape and find new locations locally or as part of a larger-scale change in distributions (Natural England and RSPB 2019). However, this will vary with the mobility of the taxa and species, and the specific role of linear features in connectivity to support climate change adaptation is largely unproven.

3.1.6.9 Climate adaption or mitigation

Not assessed

3.1.6.10 Benefits & trade offs to farmer/land manager

Not assessed

3.1.6.11 Uptake

Not assessed

3.1.6.12 Other notes

None

3.1.7 ECPW-243 – Double drill headlands in arable crops

Bundle: Soil management and protection /Tillage

Overall RAG ratings for action and ecosystem service

RED* maintaining species / wider biodiversity
RED* presence of rare and priority species

3.1.7.1 Causality

RAG ratings by taxa / ecosystem service

- ARABLE PLANTS – **ECPW-243** **RED*** for maintaining arable plant richness and for maintaining rare arable plants.
- BIRDS – **ECPW-243** **RED*** for maintaining populations if drilled near crop edge as suggested in this action (beneficial if in mid-field locations)

A reduction in cereal tiller density can help maintain arable plant richness (Wagner et al. 2017) as rare arable plants where populations of them are present (Rotchés-Ribalta et al. 2020). Applying the same logic chain, double drilling of cereal headlands that produces increased tiller density, can be expected to exert a negative influence on arable plant diversity and on maintaining rare arable plants.

Double drilling in cereal crops can be used to provide nesting opportunities for ground nesting birds such as corn buntings (Setchfield & Peach 2016), but double-drilling close to crop edges as suggested under action **ECPW-243** ('double drill headlands') does result in relatively high rates of nest predation (Setchfield & Peach 2016).

3.1.7.2 Co-benefits and Trade-offs

Not assessed

3.1.7.3 Magnitude

Not assessed

3.1.7.4 Timescale

Not assessed

3.1.7.5 Spatial Issues

If this action would be applied in mid-field locations instead of in headlands, any potential negative effects to arable plants would be much reduced, and particularly in conventionally managed fields, there may not be any such negative effects, as the interior of such fields tends to be characterised by much lower richness of arable plants (Marshall 1989) and incidence of rare arable plants (Wilson & Aebischer 1995, Fried et al. 2009).

Similarly, double drilling in headlands, while providing benefits in the form of nesting opportunities for ground nesting birds, tends to result in relatively high rates of nest predation, compared to double drilling in mid-field locations (Setchfield & Peach 2016). It has thus been suggested that double drilling should be carried out in mid-field locations and not in headlands (Setchfield & Peach 2016).

Landscape context may also be important in spatial targeting of these options for arable plants. Metcalfe et al. (2019) found that neighbouring and boundary habitats were important in ensuring the success of conservation of ruderal arable plant species, and that this type of habitat should be placed along margins with limited potential for ingress of competitive perennial plant species.

3.1.7.6 Displacement

Not assessed

3.1.7.7 Maintenance & longevity

Not assessed

3.1.7.8 Climate adaption or mitigation

Not assessed

3.1.7.9 Climate factors/constraints

Not assessed

3.1.7.10 Benefits & trade offs to farmer/land manager

Not assessed

3.1.7.11 Uptake

Not assessed

3.1.7.12 Other Notes

None

3.1.8 Create fallow plots for arable flora, ground-nesting birds and invertebrates

Bundle: Specific wildlife targeted actions /

ETPW-200x - Provide nesting and roosting sites (e.g. fallow plots/areas for ground nesting birds and invertebrates)
EBHE-224 - Create cultivated fallow plots for arable flora and ground-nesting birds, potentially in association with grass margins, and areas where spring crops have been grown traditionally
ETPW-208 Create areas of bare ground for invertebrates and pollinating insects

<u>Overall RAG ratings for action and ecosystem service</u>

ETPW-200x - Provide nesting and roosting sites (e.g. fallow plots/areas for ground nesting birds and invertebrates)
GREEN ** maintaining species / wider biodiversity
AMBER TL* presence of rare and priority species
AMBER L** pollination

EBHE-224 - Create cultivated fallow plots for arable flora and ground-nesting birds, potentially in association with grass margins, and areas where spring crops have been grown traditionally
GREEN** maintaining species / wider biodiversity
GREEN* presence of rare and priority species
AMBER L** pollination

ETPW-208 Create areas of bare ground for invertebrates and pollinating insects
GREEN** maintaining species / wider biodiversity
GREEN* presence of rare and priority species
AMBER L** pollination
AMBER DTL* control of outbreaks of pests and diseases

3.1.8.1 Causality

RAG ratings by taxa / ecosystem service

- BUTTERFLIES – **ETPW-200x** & **EBHE-224** **GREEN*** maintaining species / wider biodiversity
- POLLINATORS - **ETPW-200x**, **EBHE-224** & **ETPW-208** **AMBER L**** for maintaining species and pollination services.
- NATURAL PEST CONTROL - **ETPW-208** AMBER DL*
- BIRDS – **EBHE-224** & **ETPW-200x** **GREEN**** for maintaining species.
- MAMMALS – **ETPW-200x** **AMBER L*** for maintaining species.
- ARABLE PLANTS – **EBHE-224** **GREEN*** for maintaining arable plant richness and maintaining rare arable plants and **ETPW-200x** **AMBER TL*** for maintaining arable plant richness and maintaining rare arable plants.
- WIDER PLANT COMMUNITY – **ETPW-200x**, **EBHE-224** & **ETPW-208** **GREEN***

A dominant application of these actions is to create potential breeding plots for skylarks, lapwings and stone curlews. Skylark plots are typically up to $16m^2$ in size (and multiple plots within a field) whereas lapwing and stone curlew plots are typically 1-2 ha.

Butterflies were more abundant on fallow plots created for stone curlews than on counterfactual cropped areas, as were bumblebees (MacDonald et al. 2012). Given their likely prevalence of bare ground patches, fallow plots have potential to support ground-nesting solitary bees and wasps, indeed there is some evidence that artificially exposed areas of bare soil can be successfully colonised by these pollinators in the first or second year (reviewed in Dicks, Showler, and Sutherland 2010). For example, one trial on heathland in Southern England found that shallow bays (3 x 5 m), with a rear vertical face (30 cm), dug to attract ground-nesting bees and wasps were colonised in the first year with 80 solitary bee and wasp species recorded in the following three years (Gregory and Wright 2005). However, there has been little testing of the impacts of creating or enhancing nesting habitats for wild bees and other invertebrates via the creation of fallow plots targeted at farmland birds. In addition, fallow plots for ground-nesting bees need to be in place for more than season, and without tillage taking place (as this can increase ground-nesting bee mortality, Antoine & Forrest 2021).

Creation of bare ground (**ETPW-208**) may increase activity of ground beetles by removing vegetation that may inhibit their running activity, possibly increasing encounter rates with pests (Rouabah et al. 2015). However bare ground provides foraging access for birds potentially increasing predation rates of insects by birds, including predatory insect species (Schon 2011). There is also evidence that reducing bare ground cover increases natural pest control, suggesting increased bare ground is detrimental for this ecosystem service (Schmidt et al. 2004).

There is strong evidence that skylarks benefit from fallow plots, by increasing their breeding density and productivity and extending their breeding season (Morris et al. 2004; Ogilvy et al. 2006; Stoate & Moorcroft

2007), although a large replicated study by Field et al. (2010b) did not detect population-level benefits. A review of the success of lapwing and stone curlew plots (Natural England 2009) outlines a significant population-level benefit for stone curlews and localised benefits for lapwings, indicating moderate to high value of the action. Other priority farmland species may also benefit from fallow plots over winter and for nesting (Stoate & Moorcroft 2007; Chamberlain et al. 2009).

Fallow plots for birds may have a theoretical beneficial impact on brown hares, by diversifying cropland habitats (Smith et al. 2005), but this has not been tested.

Cultivated fallow plots (**EBHE-224**) should have a positive effect on arable plant richness, and where present, on populations of rare arable species, but as the interior of arable fields tends to be characterised by comparatively low richness of arable plants (Marshall 1989) and low incidence of rare arable plants (Wilson & Aebischer 1995, Fried et al. 2009) compared to field headlands, such positive effects would be expected to be smaller and less consistent than those that can be achieved with via annually cultivated headlands that are left unsown. With respect to provision of nesting and roosting sites (**ETPW-200x**) there will be a strong context dependence, depending both on targeting and the exact method used to achieve this. If the fallow plot is left bare, this could produce benefits for arable flora. For example, four studies on skylark plots found benefits to plants, with increased species richness (Dicks et al. 2013).

3.1.8.2 Co-Benefits and Trade-offs

In relation to ecosystem services not linked to biodiversity, Bullock et al. (2021) found fallow areas in arable fields did not prevent run-off of nutrients and sediment into waterways, and showed limited carbon sequestration or reduction of greenhouse gas emissions.

[TOCB Report-3-6 *Carbon* **ETPW-208**] Whilst evidence has not been assessed applying specifically to this context, there is good evidence that the clearance of vegetation will reduce capacity for carbon sequestration and reduce carbon stocks, due to the removal of vegetation itself, and through disturbance of soil carbon stocks (Matthews, 2020). Bare soil is also more vulnerable to erosion. However, if soil disturbance is kept to a minimum, and the extent of cleared areas is not large or involving the removal of woody vegetation, the overall impact is likely to be small, based on expert opinion. A greater diversity of invertebrates can also potentially support a greater diversity of plant species (Rosas-Guerrero et al., 2014) which has been associated with greater productivity in grasslands and woodlands (Alison et al., 2019; Jucker et al., 2015).

Food and fibre production	Area under production or yield and outside of ELM	**N**
Global, regional & local climate regulation	Above ground carbon sequestration	*
	Below ground carbon sequestration	*

[TOCB Report-3-3 *Soils* **ETPW-208**/**EBHE-224** and others] Actions that set aside uncropped cultivated areas in arable fields with late establishment of vegetative cover are likely to increase the risk of erosion (Chambers et al., 2000), but will have benefits in terms of reduced nutrient inputs.

3.1.8.3 Magnitude

Ogilvy et al. (2006) reported that cereal fields with skylark plots held 30% more skylarks and 100% more nests than control fields, and nest productivity was 1.5 chicks greater than on controls. Morris et al. (2004) reported nest densities that were 50% higher in fields with skylark plots compared to other treatments and controls. Stoate & Moorcroft (2007) reported skylark breeding productivity that was 49% higher in the presence of skylark plots compared to controls. Lapwings bred on 25% of monitored lapwing plots (Natural England 2009), with hatching success on 85% of plots compared to 64% of controls and daily nest survival rates of 99% versus 96% (Sheldon et al. 2007). Chamberlain et al. (2009) found priority skylarks, grey partridges and yellow wagtails breeding in a respective 73%, 17% and 6% of lapwing plots. Providing fallow plots targeted at stone curlews contributed to a national population increase of 53% over 8 years.

3.1.8.4 Timescale

Not assessed

3.1.8.5 Spatial Issues

Plots are more successful if placed well away from woodland and field edges.

3.1.8.6 Displacement

Not assessed

3.1.8.7 Maintenance & Longevity

Not assessed

3.1.8.8 Climate adaption or mitigation

Not assessed

3.1.8.9 Climate Factors / Constraints

Bullock et al. (2021) found fallow areas in arable fields showed limited carbon sequestration or reduction of greenhouse gas emissions.

3.1.8.10 Benefits and Trade-offs to Farmer/Land-manager

Skylark plots within the crop results in only a minor loss of yield.

3.1.8.11 Uptake

Not assessed

3.1.8.12 Other Notes

None

3.1.9 Trees / scrub / hedges

Bundle: Systems action /Landscape actions
EBHE-303 Plant trees and hedges to mitigate the visual impact of polytunnels from the immediate view of neighbouring residential dwellings.

Overall RAG ratings for action and ecosystem service
GREEN** for maintaining species / wider biodiversity
GREEN** for presence of rare and priority species
AMBER L** for pollination
AMBER DL* pest and disease control
AMBER L** biodiversity adaptation - maintaining / enhancing biodiversity under a changing climate

3.1.9.1 Causality

RAG ratings by taxa / ecosystem service

- BUTTERFLIES – **EBHE-303** **GREEN**** for maintaining species
- MOTHS – **EBHE-303** **GREEN***** for maintaining species and populations
- POLLINATORS - **EBHE-303** **GREEN*** for maintaining species, depending on the species and flowering times of trees and hedge species planted, and **AMBER TL**** for pollination services depending on whether commercial bees are used in polytunnels.
- CARABIDAE – **ETPW-092** **GREEN**** for maintaining species.
- STAPHYLINIDAE – **ETPW-092** **GREEN**** for maintaining species.
- COCCINELLIDAE – **ETPW-092** **GREEN**** for maintaining species.
- ARANAE – **ETPW-092** **GREEN**** for maintaining species.
- MAMMALS – **EBHE-303** **GREEN***** for maintaining species.
- BIRDS – **EBHE-303** **GREEN***** for maintaining species.
- PLANTS – **EBHE-303** **GREEN**** for maintaining species

A total of 39 butterflies (64% of British species) have been recorded from hedgerows, with 26 of these potentially using hedgerows as breeding habitat (Dover and Sparks 2000). There is little evidence to suggest hedgerows per se support greater butterfly numbers or species richness than other AES treatments such as grassy margins, but together, these treatments are likely to support greater populations and species richness of butterflies than farmland with no management – hedgerows support different, additional species to grassland/wildflower margins, provide shelter and act as corridors for butterfly movement (Dover and Sparks 2000). Ouin and Burel (2002) found that hedge banks along with road verges had higher butterfly diversity than grasslands within a farmed landscape in France. Sparks & Parish (1994) found butterfly populations were enhanced in field boundaries containing large hedgerows. Planting of trees, similarly, although even less well documented, is likely to have a positive effect on butterflies, as it does for moths by providing shelter and nectar sources as well as by providing larval host plants for some woodland edge species such as White-letter Hairstreak (*Satyrium w-album*) and Purple Hairstreak (*Favonius quercus*), two species known to use their respective host trees within hedgerows.
Hedgerows are an important habitat for the priority butterfly species Brown hairstreak (*Thecla betulae*). Studies have shown that the timing and extent of management of hedgerows are crucial in supporting this species, as is a variable structure to provide warm pockets of microclimate (Merckx and Berwaerts 2010; Staley et al. 2018).

Hedgerows are a key habitat for many moth species (Merckx and Macdonald, 2015). Hedgerows and hedgerow trees provide additional host plants, nectar sources (Coulthard 2015), other adult feeding sources such as rotting fruits, and there are a large number of moth species whose larvae depend on woody plants, shrubs and trees as larval host plants for at least part of their life cycle. Whilst hedgerow trees have been shown to provide shelter (Merckx et al. 2010) and hedgerows themselves have been shown to act as dispersal pathways (Coulthard et al. 2016) and corridors between woodland patches (Slade et al. 2013), there is remarkably little evidence to show the likely positive benefits of hedgerows when compared to farmland landscape features without them. Planting of trees, especially those in hedgerows, are likely to have strong benefits. Many moth species are dependent on trees as larval host plants and through a number of studies on arable field margins throughout Oxfordshire over a 5-year period, the inclusion of hedgerow trees was shown to be more important than the margins themselves for macro-moths (Merckx et al. 2009). In one study, the presence of hedgerow trees resulted in 60% greater abundance and 38% greater diversity on wide margins on targeted farms (Merckx et al. 2009). Fuentes-Montemayor et al. (2011) found no enhancement of micro-moth or macro-moth populations in hedgerows under AES management in Scotland compared with those under standard management while in contrast Staley et al. (2016) found that some aspects of similar schemes in England resulted in greater abundance and diversity of Lepidoptera larvae and pupae. An important distinction here is in the Scottish study this was looking at adult moths attracted to light traps – other studies have shown that light traps may be a less sensitive way to assess moth numbers as the attractiveness of moth traps differs between species and habitats (Merckx and Slade 2004). Larval numbers provide a much more confident assessment that the moths are using the habitat being sampled. Facey et al. (2014) also showed that hedgerow management is critical, finding that hedgerows trimmed less often (once every 2 or 3 years) resulted in a greater abundance of concealed moth larvae compared to hedgerows trimmed annually. Froidevaux et al. (2019) found that macro-moth species richness increased by 32% on hedgerows not trimmed for at least three consecutive winters compared with those trimmed annually. This trend was even greater for shrub-tree feeding moths (macro- and micro-moths combined) which showed a 79% increase in species richness and a 123% increase in abundance on these more sympathetically managed hedgerows. Hedgerows surrounded by grassland rather than arable land enhanced moth numbers with the abundance of shrub/tree feeders predicted to be doubled along hedgerows surrounded by grassland.

Hedgerows are critical habitats for the following Priority moth species: Barberry Carpet (*Pareulype berberata*) and the Buttoned Snout (*Hypena rostralis*). Hedgerow trees were also associated with greater numbers of another priority species, the Pale Shining Brown (*Polia bombycina*), on farmland in Oxfordshire, England (Merckx et al. 2010).

Hedgerows can provide substantial floral resources for a range of pollinating insects (Dicks et al. 2015, Staley et al. 2020). If hedges contain species with a range of flowering seasons, including early flowering species such as blackthorn and willow, and late-flowering species such as bramble and ivy, they may benefit pollinating insects more than hedges consisting of a single woody species (Staley et al. 2019). In addition, hedges may provide habitat for ground-nesting bees (Antoine & Forrest 2021). Landscape context can affect the use of hedges by pollinating insects. Cranmer et al. (2012) showed that ‘better-connected hedges’ resulted in more bumblebee flight activity and also more visits to flowering plants, pollen receipt and subsequent seed set, when compared to hedges that were more poorly connected. Garratt et al. (2017) found that pollinating insects visited hedgerow floral resources more in poor landscapes with little (<5%) semi-natural habitat in a surrounding 500m buffer, where alternative floral resources may be more sparse than in landscapes with a greater quantity of semi-natural habitat. Recent modelling studies have shown that boundary habitats in the landscape, including hedgerows, can increase the abundance and stability of wild pollinator populations and increase pollination (Gardner et al. 2021, Image et al. 2022).

Hedgerows are likely to support both summer recruitment and provide overwintering habitats for ground beetles, rove beetles, spiders and a range of other insects (Maudsley et al. 2002; Benjamin et al. 2008; Amy et al. 2015; Graham et al. 2018). There is a suggestion that hedgerows may provide a key overwintering site for predatory ladybirds helping to support their populations and potential to prevent outbreaks of pests (Bianchi et al. 2003).

For mammals, hedgerows have been demonstrated to be beneficial to, or are preferred habitat of, priority western European hedgehogs, hazel dormice, bats and brown hares, and other small mammals and mustelids generally (Smith et al. 2005; Hof & Bright 2010; Feber et al. 2019).

For birds, hedgerows and trees have multiple significant benefits as nesting and foraging sites for a wide variety of priority farmland species, which are well-established for species richness and abundance (Hinsley & Bellamy 2000). Associations between birds and hedgerows tend to be stronger in cropland habitats than in pastoral, with benefits for the widest range of species where a diversity of hedgerow features are available (including trees, variable hedgerow height and width) (Hinsley & Bellamy 2000; Broughton et al. 2021).

Hedgerows and hedgerow trees can include plant communities not otherwise found in intensively-managed croplands, both in the woody linear element and in the herbaceous flora at the base of the hedge (Staley et al. 2013, Critchely et al. 2013). The woody species composition largely reflects the choice of species when the hedgerow was planted, though with time additional woody and semi-woody species may accumulate in hedgerows. The increase in woody species richness over time can be linked to historic management of hedges (Staley et al. 2013). The basal herbaceous flora is impoverished and in poor condition in the majority of hedgerows in England, probably due to nutrient and herbicide contamination, inappropriate management or neglect (Critchley et al. 2013). Appropriate management is important for a thriving herbaceous hedgerow flora (Stanbury et al. 2020), and recent research from Germany has also shown the importance of hedgerow structure in basal plant communities (Litza & Diekman 2017)

3.1.9.2 Co-Benefits and Trade-offs

Hedgerows can act as habitat corridors between woodland patches (Hinsley & Bellamy 2000; Slade et al. 2013).

3.1.9.3 Magnitude

Froidevaux et al. (2019) found that macro-moth species richness increased by 32% on hedgerows not trimmed for at least three consecutive winters compared with those trimmed annually. This trend was even greater for shrub-tree feeding moths (macro- and micro-moths combined) which showed a 79% increase in species richness and a 123% increase in abundance on these more sympathetically managed hedgerows.

Dicks et al. (2015) combined estimates of pollen demand by six wild bee species with pollen supply from hedgerow and wildflower creation agri-environment options. They calculated that 2% flower-rich habitat and 1 km flowering hedgerow per 100 ha of farmland, are sufficient to supply these common pollinator species with enough pollen to feed their larvae at lowest estimates, using minimum demand and maximum supply values for estimated parameters where a range was available. There was a very wide range of uncertainty, and with high end estimates of pollen demand and low estimates of supply, the study suggested the six bee species would need 44% of the farmed landscape sown as well-managed flower-rich (margin) habitat and 13.8 km of flowering hedge per 100 ha to meet their pollen demands through the season.

3.1.9.4 Timescale

Hazel dormice and some priority birds (such as tree sparrows) requite mature hedgerows, which may take decades to develop (Hinsley & Bellamy 2000; Bright & MacPherson 2002).

3.1.9.5 Spatial Issues

The effectiveness of hedgerows in enhancing moth populations has been shown to be strongly affected by the landscape: work by Froidevaux et al. (2019) showed that the amount of woodland in the landscape at their largest scale (3km) positively influenced the abundance of both macro-moths and grass/herb feeders (macro and micro-moths combined), while woodland connectivity had a significant positive effect on species richness of grass/herb- and shrub-tree feeders at the medium (1.5km) and largest (3km) spatial scales. In addition, they found that hedgerows surrounded by grassland supported more moths than those surrounded by arable, suggesting that both landscape and local habitats are important for hedgerows.

Landscape context can also affect the use of hedges by pollinating insects. Cranmer et al. (2012) showed that ‘better-connected hedges’ resulted in more bumblebee flight activity and also more visits to flowering plants, pollen receipt and subsequent seed set, when compared to hedges that were more poorly connected. Garratt et al. (2017) found that pollinating insects visited hedgerow floral resources more in poor landscapes with little (<5%) semi-natural habitat in a surrounding 500m buffer, where alternative floral resources may be more sparse than in landscapes with a greater quantity of semi-natural habitat. Across wider landscapes, recent modelling studies suggest hedgerows can help to increase and stability populations of wild pollinators (Gardner et al. 2021, Image et al. 2022).

Jopp et al. (2005) suggest that hedgerows may help to support the dispersal of ground beetles, in particular woodland associated species. This work suggests that wider field margins are better suited to supporting dispersal in this group.

Feber et al. (2019) reviewed the evidence for bats, underlining that hedgerows close to or connecting woodland patches were most beneficial.

3.1.9.6 Displacement

Not assessed

3.1.9.7 Maintenance and Longevity

Regular management is essential in retaining hedgerow form and function, but the interval can vary between annual trimming or much longer intervals. Excessive cutting (annual or too severe) can reduce benefits for birds (Hinsley & Bellamy 2000) and invertebrates (Staley et al. 2016, 2018). Hedges need infrequent restoration management, traditionally hedge-laying or coppicing, without which they become gappy and may die away (Staley et al. 2020).

3.1.9.8 Climate Adaptation or Mitigation

Hedgerows can store carbon at 42 t ha in woody above-ground biomass and 38.2 t C ha below ground for a typical 3.5 m hedge, with greater benefits of taller and wider hedgerows (Axe et al. 2017). Hedgerows can provide shelter from inclement weather and shade in otherwise open habitats (Dover and Sparks 2000). Hedgerows provide corridors for several taxa (e.g. bats and moths), for regular foraging and other daily movement (Staley et al. 2020, Slade et al. 2013). However, there is little evidence that populations move along hedges, for example to areas with more suitable climatic conditions, as a result of climate change.

3.1.9.9 Climate factors/constraints

Not assessed

3.1.9.10 Benefits and Trade-offs to Farmer/Land manager

Hedgerows provide protection against soil erosion and flooding in croplands (Mérot 1999).

3.1.9.11 Uptake

Not assessed

3.1.9.12 Other Notes

None

3.1.10 Integrated Pest Management

Bundle: Systems action /Pests and disease management

ECPW-231	Apply Integrated Pest Management (IPM)
ETPW-238	Create suitable habitats for beneficial insects to live near cropped land
ETPW-236	Develop, use and review an IPM Plan. To include a farm pest anti-resistance strategy
ETPW-233	Establish trap crops to reduce pest prevalence (edge of field)
ETPW-258	For pests with established thresholds: Only apply a pesticide if pest economic and/or environmental thresholds are exceeded
ETPW-230	Leave harvest stubble tall to encourage natural predators especially spiders
ECPW-269	Use bio pesticides or biological control in place of chemical pesticides
ECPW-031	Use companion crops
ECPW-240	Use cultural approaches to pest control in place of chemical pesticides

ETPW-254 Use pest resistant / tolerant crop varieties to reduce the need for pesticides which have multiple pest resistance properties and have a high resistance rating

Bundle: Soil management and protection /Cover cropping

ECCM-071 Use intercropping

<u>Overall RAG ratings for each ecosystem service</u>

ECPW-231 Apply Integrated Pest Management (IPM)
AMBER L** pest and disease control in open arable farming
AMBER TL** maintaining species / wider biodiversity
AMBER TL** pollination

ETPW-238 Create suitable habitats for beneficial insects to live near cropped land
AMBER L** pest and disease control in open arable farming
GREEN*** maintaining species / wider biodiversity
AMBER TL* presence of rare or priority species
GREEN*** pollination
AMBER L* connectivity of small 'feature' habitats

ETPW-236 Develop, use and review an IPM Plan. To include a farm pest anti-resistance strategy
AMBER L** pest and disease control in open arable farming
AMBER TL** maintaining species / wider biodiversity

ETPW-233 Establish trap crops to reduce pest prevalence (edge of field)
AMBER L** pest and disease control in open arable farming
AMBER TL** maintaining species / wider biodiversity

ETPW-258 For pests with established thresholds: Only apply a pesticide if pest economic and/or environmental thresholds are exceeded
AMBER L** pest and disease control in open arable farming
AMBER L** maintaining species / wider biodiversity

ETPW-230 Leave harvest stubble tall to encourage natural predators especially spiders
AMBER L* pest and disease control in open arable farming
AMBER DL** maintaining species / wider biodiversity
AMBER DL** presence of rare or priority species

ECPW-269 Use bio pesticides or biological control in place of chemical pesticides
AMBER L** pest and disease control in open arable
AMBER DTL** maintaining species / wider biodiversity

ECPW-240 Use cultural approaches to pest control in place of chemical pesticides
AMBER L** pest and disease control in open arable
AMBER TL*** maintaining species / wider biodiversity
AMBER L* presence of rare or priority species
AMBER TL** pollination

ETPW-254 Use pest resistant / tolerant crop varieties to reduce the need for pesticides which have multiple pest resistance properties and have a high resistance rating
AMBER L** pest and disease control in open arable

ECPW-031 Use companion crops
AMBER L** pest and disease control in open arable
GREEN** pollination
GREEN* maintaining species / wider biodiversity

ECCM-071 Use intercropping
AMBER L* pest and disease control
GREEN* maintaining species / wider biodiversity
GREEN** pollination
AMBER DTL* rare and priority species

3.1.10.1 Causality

RAG ratings by taxa / ecosystem service

- Overall the application of IPM (**ECPW-231**) and associated management practices to help deliver it (**ETPW-238**, **ETPW-236**, **ETPW-233**, **ETPW-258**, **ETPW-230**, **ECPW-269**, **ECPW-031**, **ECPW-240**, **ETPW-254**) has **GREEN*** evidence in general, but for open arable farming systems this should currently be considered **AMBER L**** as effective demonstrations at large scales that take into account full economic assessments are lacking. It is likely that IPM has significant potential to support pest control, particularly where future government or regulatory policy reduces the availability of plant protection products.
- **ECPW-269** Use of biopesticides includes risks to wider biodiversity (see review below), AMBER DTL*, though use of biological control within this action to reduce pesticide use could benefit wider biodiversity AMBER L***
- POLLINATORS - **ETPW-238** **GREEN*** for maintaining habitats, populations and species and pollination services; **ECPW-231** & **ECPW-240** as general approaches to IPM **AMBER TL**** with respect to evidence for the negative impacts of pesticides on pollinator species and pollination services. **ECPW-031** and **ECCM-071** **GREEN**** for effects of companion crops and intercropping on pollinator species and pollination.
- BUTTERFLIES - **ECPW-269** & **ECPW-240** **AMBER TL***** for maintaining habitats, populations and species. **ETPW-258** **AMBER L**** for maintaining species / wider biodiversity
- CARABIDS, EARTHWORMS **ECCM-071** **GREEN****
- BIRDS – **ETPW-230** **AMBER DL**** for maintaining species including priority species.
- ARABLE PLANTS – ARABLE PLANTS – **ECPW-240** **GREEN*** for arable plant species richness, **AMBER L*** for rare arable species (logic chain); **ECCM-071** **AMBER TD*** for arable plant species richness and **AMBER DTL*** for rare arable species (logic chain).

There is AMBER (L) evidence for the successful implementation of IPM (ECPW-231) in open arable farming systems** in terms of direct evidence for reduced outbreaks of pests and diseases, but **GREEN***** evidence in horticultural systems (Straub et al. 2008; Bailey et al. 2009; Ratnadass et al. 2012; Barzman et al. 2015).

The implementation of IPM in high value or niche crop systems has proved more viable than in open arable farming systems, where there is a need for farmers to actively consider the consequences of more immediately efficacious chemical control methods on the longer term support of biological control mediated by beneficial insects (Thomas et al. 1999; Bailey et al. 2009). Almost all farmers use IPM to some level, i.e. do not have a sole reliance on chemical control methods, but use cultural approaches when perceived economically viable (Bailey et al. 2009). However, a more defined implementation of IPM (**ECPW-231**) will be dependent on: 1) detailed planning focussing on identifying and monitoring pest populations, 2) the empirical evidence to underpin setting of action thresholds that define the point at which economic productivity is threatened (ETPW 258 – GREEN*** evidence), 3) supporting prevention though crop choice, utilising pest-resistant varieties, supporting habitat creation to maintain populations of beneficial insects (**ECPW-269** Use biological control – GREEN***) and cultural control methods including the timing of sowing and good crop sanitation or catch crops (**ECPW-240** Use cultural approaches to pest control - GREEN*** evidence; **ETPW-254** Use pest resistant / tolerant crop varieties - GREEN*** EVIDENCE); and 4) implementation of control methods when threshold damage has being reached – this should focus on lower impact interventional first (such as where possible mechanical control, disruptive pheromones or attract and kill traps) with the use of pesticides being a last option (Olesen et al. 2007; Harker et al. 2013; Gadanakis et al. 2015; Cuthbertson 2020). As a primary step (**ETPW-236** Develop, use and review an IPM Plan) this should involve engagement with the Voluntary Initiative/NFU IPM Plan for arable, forage and field vegetable crops[1]. Individual farmers IPM portfolio of options implemented though this will be affected by farm type, land tenure and current AES uptake, but may be more fundamentally affected by aspects of landscape context and regional species pools of beneficial insects, such as predators (Bailey et al. 2009; Woodcock et al. 2014b; Redhead et al. 2020). This action will require an effective advisory framework, as development of IPM plans is knowledge intensive. This could usefully be informed by recent work such as Riemens et al. (2022)'s integrated weed management framework.

Integrated weed management is an important component of IPM. A recent review flags up that advances in understanding of weed ecology are resulting in weed management options at the agroecosystem level, rather than aiming to eradicate weeds (MacLaren et al. 2020). This approach relies on manipulating crop management to reduce weed competitiveness, while promoting weed diversity, and includes approaches such as increasing crop diversity (reviewed in Section 3.1.13 below).

Pesticide anti-resistance strategies (**ETPW-236** Develop, use and review an IPM Plan - pest anti-resistance strategy) may have GREEN*** evidence for their efficacy. However, this is dependent on a number of assumptions. Specifically, where pesticide anti-resistance strategies promote the long term efficacy of active ingredients this will reduce the need of farmers to increase application frequency and rate (up to legal limits) to compensate for reduced efficacy. For example, there were circumstantial reports following the removal of neonicotinoid pesticides on oilseed rape that pyrethroid use increased dramatically in pesticide resistant areas of the UK. However, a detailed understanding of the mode of action classification of active ingredients is necessary to understand this effect (Beckie 2011; Sparks et al. 2015). This will require up to date information on the mode of action classified by the Insecticide Resistance Action Committee (IRAC) to develop an effective integrated resistance management strategy for a specific holding, and from the Weed Resistance Action Group (WRAG). This is needed to implement appropriate rotation, substitution or alternate management, and should be included within an IPM plan (**ECPW-231**). This plan should reduce the use of agrochemicals by promoting beneficial invertebrates to delay the action threshold tipping point, thus contributing to reduced insecticide use. In addition, the use of cultural approaches to control pests (**ECPW-240** Use cultural approaches to pest control – GREEN*** evidence; **ECPW-269** Use biological control - GREEN***) as well as the use of pest resistant / tolerant crop varieties (**ETPW-254** Use pest resistant / tolerant crop varieties - GREEN*** evidence) would all contribute to the delivery of **ETPW-236** (Harker et al. 2013; Barzman et al. 2015; Traugott et al. 2015). However, where resistance management strategies may advocate the use of simultaneous pesticide combinations with different modes of action or a 'high dose strategy' to remove resistance gene heterozygotes this may have immediate negative effects on native wildlife. Again the extent of this impact is highly dependent on the active ingredients (i.e. its detoxification rate) as well as the mode of application (spray, seed treatment as well as timing). Note, alternative control methods relying on non-standard modes of action (**ECPW-269** Use bio pesticides – GREEN***) may also have a role within an effective pesticide resistance strategy (Sparks et al. 2015). However, the use of biocide is not without risk to non-target beneficial insects (Cappa et al. 2019).

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[1] www.nfuonline.com/cross-sector/science-and-technology/crop-protection/crop-protection-must-read/time-to-fill-in-your-integrated-pest-management-plan/ipm-plan

Cultural control methods represent a major part of the effective implementation of IPM strategies (**ECPW-231**), although their effective use may need to be considered in a holistic way, applying them with other management practices so that small individual benefits may have a wider net contribution on the effectiveness of IPM (Hokkanen et al. 2018). Creating suitable habitats for beneficial insects to live near cropped land (**ETPW-238** – GREEN***) will have the direct benefit of increasing number of predator species and their abundance, and may act to reduce outbreaks of pests and diseases (Thies et al. 1999; Kromp 1999; Pywell et al. 2005a; Woodcock et al. 2005; Smith et al. 2008). These benefits are likely associated with the provision of both within cropping season breeding and refuge habitats. The impact of establishing such areas may extend beyond simply promoting abundance, but also affect functional diversity of taxa supporting pest control, which can have a direct effect on the effectiveness of pest control in an IPM situation (Pywell et al. 2011a; Woodcock et al. 2010; Greenop et al. 2018). Establishing semi-natural habitat can have direct effects on natural pest control, although this may be limited to the crop edge due to spill-over limitations for some beneficial taxa (Woodcock et al. 2016a; Ingrao et al. 2017). Field margins may have indirect roles by acting as refuges for susceptible pest genes that support pesticide resistance management (Maino et al. 2019).

The establishment of trap crops has potential to reduce pest prevalence (**ETPW-233** trap crops AMBER TL** evidence). The successful use of trap crops is knowledge dependent, requiring an understanding the behavioural responses of pest species in relation to the spatial, chemical and temporal characteristics of both the crop and trap crop (Shelton et al. 2006; Cook et al. 2007). Without this understanding, this approach may fail to effectively support the agronomic and economic requirements of a crop production system (Shelton et al. 2006). Although trap crops can be effective for some pests, this is not necessarily consistent across the suite of pests associated with some crops or in response to the choice of trap crop (George et al. 2019). For example, turnip rape has been used as a trap crop for oilseed rape and was effective in attracting *Psylliodes chrysocephala*, but showed no benefits in limiting damage associated with a *Ceutorhynchus pallidactylus* infestation (Barari et al. 2005). Evidence for reduced pest damage may thus not necessarily translate into economic benefits (George et al. 2019).

Use of intercropping (**ECCM-071** – AMBER L* evidence) has some evidence in support of its role in decreasing the outbreaks of pests and disease, although much of this originated from non-European systems (Trenbath 1993; Hassanali et al. 2008; Wezel et al. 2014). There is some evidence that intercropping can increase populations of beneficial insects or increase their retention within areas of diversified cropping, including generalist predatory ground beetles. However, the direct links between this and increased yield or net profitability of the systems are not clear (Kromp 1999; Sunderland et al. 2000; Hummel et al. 2012). In a review of 50 studies on intercropping in wheat it was suggested that pest abundance could be reduced using this system, although this was not directly measured but assessed based on perception (Lopez et al. 2016). However, there was limited evidence that this perceived decrease in pest numbers was associated with increased natural enemy occurrence (Lopez et al. 2016). Intercropping has been shown to increase the abundance and diversity of earthworms, and a review found abundance of ground beetles (but not diversity) was enhanced by intercropping relative to single crops (Dicks et al. 2013).

Use of companion crops (**ECPW-031** – AMBER L* evidence) has similarities to intercropping (**ECCM-071**) and catch crops (**ETPW-233**), and like these approaches may be based on the push (from crop) - pull (from non-profit crop) (Hassanali et al. 2008). As for these other options, much of the evidence for their utility is from non-European systems (Hassanali et al. 2008; Parolin et al. 2012; Pickett et al. 2014). Overall these approaches have significant potential to be incorporated into IPM strategies, although the current evidence is inconclusive as to their benefits (George et al. 2019). There is a lack of evidence, or a generalised predictive theory, as to how they impact on tri-trophic interactions and ultimately affect pest control (Parolin et al. 2012). Other cultural control methods will have value in supporting natural enemy populations, although little evidence was found in support of leaving harvest stubble tall to encourage natural predators especially spiders (**ETPW-230** - AMBER L*).

IPM has been specifically highlighted as an action that has benefits for pollinator conservation (Dicks et al. 2016; Egan et al. 2020) and is promoted through the National Pollinator Strategy for England (Steele et al. 2019). The evidence for **ETPW-238** "Create suitable habitats for beneficial insects to live near cropped land" in the context of flower-rich habitats is reviewed above and see Woodcock et al. 2016. One very recent study in the US has found IPM (via **ECPW-031**/ **ECPW-240**) can reduce insecticide applications by 95%, while maintaining or enhancing crop yields through wild pollinator conservation that was mediated entirely by wild bees (Pecenka et al. 2021). There is also strong evidence from both field and lab studies for direct and indirect impacts of pesticides (in particular neonicotinoids) on wild and managed bees (e.g. Whitehorn et al. 2012; Woodcock et al. 2016; 2017) which offers support for **ECPW-231** & **ECPW-240** combined with improved pesticide regulation. However, there is no specific evidence for beneficial impacts of implementing IPM at farm scale in the UK on local pollinator populations or communities. Recently, Egan et al. (2020) proposed a systematic framework for 'integrated pest and pollinator management' (IPPM) to address the diverse needs of crop pollination and pest control practices. Intercropping (**ECCM-071**) with a legume-cereal mix has recently been shown to increase the abundance of insect pollinators in an experimental study in Germany (Brandmeier et al. 2021).

Negative impacts of chemical pesticides have been shown on non-pest species of butterflies, with a number of species commonly found in arable field margins showing increased abundance in unsprayed field margins (Davis et al. 1991; de Snoo et al. 2009). If **ETPW-258** results in substantial reductions in pesticide application this is likely to benefit butterflies and other invertebrate taxa, though if pesticide application is only slightly reduced for some pest species, the action may have limited benefits.

For farmland birds, long stubble (**ETPW-230**) has a mixed response by farmland birds. Butler et al. (2005) reported benefits of higher abundance (usage) of longer stubble for priority skylarks and grey partridges, probably due to better cover, but lower abundance (usage) of priority farmland granivorous birds, which preferred shorter stubble, probably due to better visibility of predation risk and access to seeds. Seed availability was similar on longer and shorter stubble, and seed depletion rates were not related to stubble length.

There is evidence from one experimental study that a reduction in herbicide applications and corresponding increase in cultivation by machinery as in action **ECPW-240** does support higher levels of arable plant species richness, as measured in the soil seed bank (Squire et al. 2000). Evidence for the effects of intercropping on arable plants (**ECCM-071**) is somewhat mixed, reflecting the fact that there is much variation regarding its implementation, depending on whether one main crop is accompanied by additional crop species, or whether farmers are similarly interested in achieving yield from each different component crop (Liebman and Dyck 1993). A more recent review confirms that increasing diversity of cropping systems does not necessarily result in greater arable plant diversity, and that positive results found in experimental settings may not be found on commercial farms (Adeux et al 2022). Negative effects on arable plant richness are particularly likely with the former, e.g. in "smother crop" systems in which one main crop is accompanied by additional low-growing weed-suppressive crop species (Liebman & Dyck 1993). On the other hand, the latter kind of intercropping with various species on an equal footing, and not necessarily increased overall planting density, can potentially result in increased overall arable plant richness, when carefully implemented (Palner and Maurer 1997). However, generally in intercropping systems, weed-suppressive outcomes appear to predominate (Liebman & Dyck 1993).

3.1.10.2 Co-Benefits and Trade-offs

IPM strategies (as outlined above) work by providing co-benefits, and it is unlikely individual practices will provide the overall solution. Effective IPM strategies need to minimise the trade-off and maximise the co-benefits and synergies. Thus, non-crop habitat creation / intercropping increasing the diversity and abundance of beneficial insects (**ETPW-238**, **ECPW-031**, **ECCM-071**) needs to work with threshold spraying to reduce reliance on insecticides (**ETPW-258**) and better agrochemical resistance management (**ETPW-236**). Likewise, trade-offs are fundamental to this approach, linking the economics of each management approach to a decision framework underpinned by the economic cost-benefit of each operation (Bailey et al. 2009). Co-benefits of an integrated pest management approach can include reduced costs (spending less on inputs), as well as reduced exposure to applicators and reduced pollution.

Tillage is an important component of integrated weed management, and the associated soil disturbance has important trade-offs (MacLaren et al. 2020). See discussion of reduced tillage actions in Section 3.1.14 below.

ETPW-230 longer stubble is preferred by some farmland birds (skylarks, partridges) but not others (seed-eating songbirds), and so maintaining a mixture of longer and shorter stubble is required for maximum benefits.

[TOCB Report-3-3 *Soils* **ECPW-031**] Companion and intercropping methods that integrate legumes can help reduce N inputs to arable systems. (Verret, V., Gardarin, A., Makowski, D., Lorin, M., Cadoux, S., Butier, A., & Valantin-Morison, M. (2017). Assessment of the benefits of frost-sensitive companion plants in winter rapeseed. European Journal of Agronomy, 91, 93-103.)

[TOCB Report-3-6 *Carbon* **ECPW-031**] Companion crops may interact with one another to influence below ground carbon sequestration, as a result of increased productivity due to disease or pest suppression, and therefore more crop residues entering the soil. Growing multiple crops simultaneously could also increase productivity due to reduced intraspecific competition. However, there is no empirical evidence for this process and interaction between crops could also no facultative interaction or a net reduction in soil carbon sequestration if the second crop is associated with a lower rate of below ground carbon sequestration in a given season. Overall, expert opinion suggests that companion crops are unlikely to have a significant effect on carbon sequestration at a national scale.

Food and fibre production	Area under production or yield and outside of ELM	**N**
Global, regional & local climate regulation	Above ground carbon sequestration	**N**
	Below ground carbon sequestration	**LTD***

3.1.10.3 Magnitude

The magnitudes of IPM based approaches are hard to quantify at a farm scale as each operation will be highly dependent on the individual farm characteristics, extent to which cultural control practices are set in place and the degree to which they use thresholds to offset agrochemical reliance. While this is easier to assess under closed, controlled farming systems (e.g. greenhouses), in open farming systems (e.g. arable) it has been hard to reliably quantify in a manner that can be extrapolated outside of a specific study farm or cropping system.

3.1.10.4 Timescale

Although not solely associated with biological control, there is a strong suggestion that the benefits associated with enhancing wider populations of beneficial insects may take several years to come into effect following habitat creation (**ETPW-238**) (Pywell et al. 2015). In this study, it took 2-3 years before populations of beneficial insects increased sufficiently to start having positive effects on crop yield, although this effect was a combination of both pollination and pest control. It is likely this reflects the time required for populations to colonise and reproduce within such habitats.

The effects of introducing an integrated weed management strategy are likely to vary in timescales, depending on the biology of the weed species. Some weed species with long-lived seed banks are likely to persist for several years.

3.1.10.5 Spatial Issues

There is strong evidence to suggest that landscape structure and context can have a direct effect on species associated with natural pest control, an integral part of the control of outbreaks of pests under an IPM strategy (Bianchi et al. 2006). However, when Karp et al. (2018) looked at data from 6,759 worldwide sites they found that overall landscape structure did not consistently predict and the abundances of natural enemies, predation rates, crop damage or yields with individual studies showing different (both positive and negative) trends. The functional diversity of ground beetles in the UK, which is likely to be linked to increased capacity to deliver natural pest control, was shown to increase with the cover of semi-natural habitat at a national scale (Woodcock et al. 2014b; Greenop et al. 2018). Ultimately the spatial structure of the landscape may have a crucial effect on species supporting IPM, but this effect may be unpredictable in the direction of this trend.

3.1.10.6 Displacement

Not relevant in the context of IPM and management associated with promoting it.

3.1.10.7 Maintenance and Longevity

The use of IPM strategies in open farming systems and its associated longevity is likely linked to the cost-benefit associated with its implementation given the availability of alternative and typically effective agro-chemical control methods (Bailet et al. 2009). Incentives and limitations on the availability and use of plant protection products may change this cost-benefit ratio in the favour of adoption of IPM and associated management practices as discussion in this section.

3.1.10.8 Climate Adaptation or Mitigation

There is limited evidence for the role of IPM approaches in climate adaptation and mitigation in relation to pest invertebrate species, although there is evidence for the value of creating semi-natural habitat to mitigate against the effects of climate change by promoting landscape-scale connectivity (e.g. Papanikolaou et al. 2017, but also overviewed in Lawton et al. 2010). Papanikolaou et al. (2017) conducted a study across agricultural landscapes in Germany and found a high proportion of semi-natural habitats was shown to decrease the detrimental effect of warmer temperatures on bee species richness and abundance, providing support specifically for **ETPW-238** (Create suitable habitats for beneficial insects to live near cropped land). If the 'suitable habitats' created include arable field margins (including those sown with wildflower seeds, legumes, wild bird seed, grass and cultivated / low-input margins), these may play a role in allowing some species to move within a landscape and find new locations locally or as part of a larger-scale change in distributions (Natural England and RSPB 2019). However, this will vary with the mobility of the taxa and species, and the specific role of linear features in connectivity to support climate change adaptation is largely unproven. Direct evidence for these benefits are sparse in the peer-reviewed literature.

Weed pressures may increase in response to climate change, particularly in combination with the evolution of herbicide resistance (Storkey et al. 2021). Storkey et al (2021) conclude that integrated weed management approaches may be necessary to maintain high yields under these combined pressures.

3.1.10.9 Climate Factors / Constraints

Castex et al. (2018) suggests that as climate change can alter species phenology and distribution this has the potential to have fundamental consequences on tritrophic interactions between crops, pests and beneficial natural enemies that are a key component of IPM strategies. While there is limited evidence of the extent to which this may occur it remains a potential risk and may mean that IPM strategies (**ECPW-231**) need to be constantly revised in the face of emerging evidence for the impact of climate driven shifts in underlying biotic interactions. This impact is particularly likely for pest species which have shown a far greater capacity to become invasive in new regions of the world compared to their associated predatory species (Dreves et al. 2011; but see Pervez et al. 2006).

3.1.10.10 Benefits and Trade-offs to Farmer/L-and manager

The establishment of effective IPM takes time, in particular that associated with the build-up of beneficial insects in response to changed land management (e.g. **ETPW-031**) or creation of new habitats (e.g. **ETPW-238**) (Pywell et al. 2015). The establishment of IPM strategies now, even when they may be argued to have marginal cost-benefit under current economic and agro-chemical regulatory conditions (Bailey et al. 2009), may ultimately increase resilience of farming systems should these change in the future (Straub et al. 2008; Schneider et al. 2018).

3.1.10.11 Uptake

As described above the uptake of IPM strategies in open farming systems is linked to the cost-benefit associated with its implementation given the availability of alternative and typically effective agro-chemical control methods (Bailet et al. 2009). Incentives and limitations on the availability and use of plant protection products may change this cost-benefit ratio in the favour of wider adoption of IPM and associated management practices as discussion in this section. Effective modelling and forecasting of pests also has the potential to increase uptake, and may reduce some of the need for field surveys of pests.

3.1.10.12 Other Notes

None

3.1.11 Cover crops

Bundle: Systems action /Pests and disease management
ECPW-241 Destroy cover crop using roller instead of spraying

Bundle: Soil management and protection /Cover cropping
ECAR-044 Ensure persistent continuous vegetation cover on land
ECPW-095 Maintain soil cover (e.g. grass, crop or geotextile), to reduce soil erosion and loss around field structures such as poly-tunnels, plastic sheeting /cloches or irrigation equipment used for horticultural crops.
EHAZ-007 Use cover crops
ECPW-242 Use direct drilling into crop stubble or cover crops
ECPW-279 Use of cover crops as an alternative to plastic mulch - Soil-enriching cover crops may be grown over the winter in the same beds where a food crop is to be planted the following spring and used in place as mulch

<u>**Overall RAG ratings for each action and ecosystem service**</u>

ECPW-241 Destroy cover crop using roller instead of spraying
AMBER L** maintaining species / wider biodiversity

ECAR-044 Ensure persistent continuous vegetation cover on land
AMBER DTL* maintaining species / wider biodiversity
AMBER L** pest and disease control
AMBER L** pollination

ECCA-001 Ensure persistent continuous vegetation cover on land
Duplicate of **ECAR-044** above, assessed with that action.

ECPW-095 Maintain soil cover (e.g. grass, crop or geotextile), to reduce soil erosion and loss around field structures such as poly-tunnels, plastic sheeting /cloches or irrigation equipment used for horticultural crops
AMBER L** maintaining species / wider biodiversity
AMBER L** pest and disease control
AMBER L** pollination

EHAZ-007 Use cover crops
AMBER DTL** maintaining species / wider biodiversity
AMBER L** pest and disease control
AMBER L** pollination

ECPW-242 Use direct drilling into crop stubble or cover crops
AMBER L** maintaining species / wider biodiversity
AMBER L** pest and disease control
AMBER L** pollination

ECPW-279 Use of cover crops as an alternative to plastic mulch - Soil-enriching cover crops may be grown over the winter in the same beds where a food crop is to be planted the following spring and used in place as mulch
GREEN** maintaining species / wider biodiversity
AMBER L** pest and disease control
AMBER L** pollination

3.1.11.1 Causality

RAG ratings by taxa / ecosystem service

- POLLINATORS - **ECAR-044**, **ECPW-095**, **EHAZ-007**, **ECPW-242**, **ECPW-279** **AMBER L**** for maintaining habitats and populations/ species, and pollination services.
- HYMENOPTERA PARASITICA (e.g. Braconidae) – **ECAR-044**, **ECPW-095**, **EHAZ-007**, **ECPW-242**, **ECPW-279**) **AMBER L**** in the UK for maintaining species and the control of outbreaks of pests and diseases (Exceptions - e.g. **ECPW-241** no evidence of benefits).
- CARABIDAE – **ECAR-044**, **ECPW-095**, **EHAZ-007**, **ECPW-242**, **ECPW-279**) **AMBER L***** in the UK for maintaining species and the control of outbreaks of pests and diseases (Exceptions - e.g. **ECPW-241** as no evidence of benefits).
- SOIL MACROFAUNA (including Earthworms)– **ECAR-044**, **ECPW-095**, **ECPW-241**, **EHAZ-007**, **ECPW-242**, **ECPW-279**) **GREEN**** in the UK for maintaining species soil biodiversity.
- MAMMALS – **ECAR-044** & **EHAZ-007** **AMBER L**** for maintaining species.
- BIRDS - **EHAZ-007** **AMBER DL***** for maintaining species. **ECAR-044**, **ECPW-095**, **ECPW-242** and **ECPW-279** **AMBER DL***** for maintaining species.
- ARABLE PLANTS – **EHAZ-007**, **ECAR-044**, **ECPW-095**, **ECPW-242** and **ECPW-279** **RED*** for maintaining arable plant richness and for maintaining rare arable plants.
- PLANTS - **EHAZ-007**, **ECAR-044**, **ECPW-095**, **ECPW-242** and **ECPW-279** **GREEN**** for wider plant richness / diversity

Cover crops can be grown either in the short-term over winter, or are sown in spring as a one-year fallow. Which type of cover crop is used will affect the benefits or disbenefits for biodiversity, hence most of the scoring above is context-dependant. Cover crops sown in spring as a one-year fallow will provide stronger benefits for biodiversity, see fallow section below (actions **ETPW-257**, **Arable01**, **Arable02**).

Some cover crops or "green manure" options grown over a whole season (sown fallows) may benefit flower-visiting insects including bees and flies where they include legumes (such as vetches, red clover, white clover, alsike clover, sweet clover, crimson clover, sainfoin, Lucerne, black medick, peas and beans), brassicas (such as mustards or radish) or herbs (such as phacelia, borage or linseed) (Defra, 2021). Many of these annual seed-bearing crops are commonly included in wild bird cover options (see above) under **EHAZ-007**. Three UK studies have tested their value for pollinators and found high visitation rates of bumblebees and butterflies to sown forage species (Carvell et al. 2006; Heard et al. 2011). Another study found that late-summer nectar supply was a strong predictor of bumblebee colony density in the following year (Timberlake et al. 2021) and used spatially explicit predictive models to propose the use of late-flowering cover crops such as red clover (eg. via options **EHAZ-007**, **ECPW-242**) as one strategy to boost resources for pollinators in croplands to reduce this resource bottleneck. There is further evidence from the US that annual cover crops including phacelia, sunflowers and oilseed crops can provide high floral density and attract diverse assemblages of wild and managed bees, and could be especially valuable if allowed to flower early or later in the season (Mallinger et al. 2019; Eberle et al. 2015; Bryan et al. 2021). There is no specific evidence of benefits for pollinators in the UK relating to **ECAR-044**, **ECPW-095**, **ECPW-242** and **ECPW-279**, but their value for flower visiting insects would follow the same principles as **EHAZ-007**. Winter cover crops sown in late autumn are likely to have little benefit for pollinating insects.

Information on the direct value of cover crops for supporting species or controlling the outbreaks of pests and diseases in the UK is limited. For suppression of weeds, MacLaren et al. (2019) found that the biomass of a cover crop was more important than the diversity of the cover crop in a study in South Africa. They recommend the competitiveness of individual species is considered when designing cover crop mixtures.

A study in the UK showed Turnip rape, a commonly sown cover crop, had good potential as a trap crop for oilseed rape invertebrate pests, particularly the pollen beetle (*Meligethes aeneus* (Fabricius) (Coleoptera: Nitidulidae)), as its odour was more attractive to both pests than that of the oilseed rape crop (Cook et al., 2006). Outside of the UK, cover crops can help support populations of parasitoid wasps important in the control of outbreaks of pests, particularly where Brassicaceae (i.e. mustard) were grown (Wanigasekara et al. 2021). The effectiveness of cover crop in providing this type of biocontrol of crop pests is dependent on the spatial and temporal dynamics of the crop cover within the farmed landscape (Schneider et al., 2015). Other positive effects of cover crops include increasing densities of soil mites (Acari) (Rowen et al. 2021) and other soil macrofauna (Kelly et al. 2021). Coraty et al. (2021) do however suggest that on UK heavy clay soil the benefits to epigeic earthworms are restricted to cover crops that include radishes. This increase in soil biodiversity is most likely associated with an increase in soil carbon in response to the use of cover crops (Kelly et al. 2021). The diversity of ground beetles (Carabidae) was highest in a mixed cover crop system and was 290% that of a conventional tillage approach in cotton fields (Hakeem et al. 2021). Chen et al. 2021 found a similar result in tea plantations with a significant increase in beetle abundance and species richness where cover crops were grown - they suggest that many of these species may contribute to pest control. Bowers et al. 2021 also suggests that cover crops can help support populations of predatory invertebrates that can help control outbreaks of pests, but provided no direct quantification of the extent of this effect. Although there is no direct evidence in the literature, it is reasonable to assume that Destroy cover crop using roller instead of spraying (**ECPW-241**) would be likely to be preferable from a biodiversity perspective. Where glyphosate is used to kill of cover crops this may impact on soil macrofauna biodiversity, such as earthworms (Pochron et al. 2021).

For small mammals, evidence is limited but in one study abundance was found to be higher in cover crops than in adjacent crops (Pywell et al. 2007), and expert opinion suggests that maintaining vegetation cover and diversity would have obvious benefits (Macdonald et al. 2007).

Cover crops (**EHAZ-007**) can benefit priority birds if they include wild bird cover options to provide seed-bearing crops over winter. Wild bird cover is associated with increased abundance, density and species richness of priority farmland birds, including grey partridges (Aebischer et al. 2000), skylarks, finches and buntings (Boatman et al. 2003; Henderson et al. 2004; Stoate et al. 2004; Vickery et al. 2009). Cover crops dominated by or including kale are used most widely by the greatest range and number of farmland birds (Boatman et al. 2003; Henderson et al. 2004). Wild bird cover crops are preferred habitat of priority skylarks and yellowhammers (Boatman & Bence 2000; Murray et al. 2002). Redhead et al. (2018) showed that provision of wild bird cover was associated with increased winter abundance that also enhanced breeding abundance of priority seed-eating finches and buntings at the farm scale. Regional variation in benefits of cover crops for birds have been reported, with increased winter abundance some regions but not others (Field et al. 2010a), and provision of cover crops did not prevent the decline in abundance of grey partridges on farms in one study (Browne & Aebischer 2003).

There is no specific evidence of benefits for birds relating to **ECAR-044**, **ECPW-095**, **ECPW-242** and **ECPW-279**, but their value for priority species would follow the same principles as **EHAZ-007**.

If over-winter cover crops do not include wild-bird cover options in the farmed landscape, they may disbenefit birds. However, there has been little research into the effects of cover crops on birds. In North America, Wilcoxen et al. (2018) found positive effects on densities of breeding birds, as measured by weighting bird responses by conservation priority, reflecting the provision of denser in-field vegetation for nesting and feeding, relative to bare fields. However, a critical over-winter habitat in Europe for granivorous farmland birds is crop stubble and bare plough is important foraging habitat or species such as golden plover and lapwing (Gillings et al. 2005, 2008, Moorcroft et al. 2002). Where the ground remains uncultivated through the winter provides the best foraging opportunities for surface-feeding seed predators (Holland et al. 2008). A key purpose of cover crops is to aid suppression of weed densities (Moonen & Barberi 2004) and weed seeds are a critical food resource for wintering farmland birds (Robinson & Sutherland 2001). Stubble habitats are replaced by cover crops, which would be expected to reduce the accessibility of seed food resources near the soil surface, reducing habitat quality for granivorous birds (Bradbury & Kirby 2006) and there is some evidence for such an effect in practice (Goławski et al. 2013). Even for nesting birds, key conservation priority species such as lapwing, stone-curlew and skylark prefer sparse vegetation (Wilson et al. 2005) and are likely to be affected negatively by cover crops. One farm-scale study has, accordingly, found no benefit of cover crops for skylark nesting densities, despite positive effects on invertebrate food items (Biffi 2020), consistent with contrasting effects on food abundance and accessibility.

Cover crops (**EHAZ-007**) have been shown to increase general plant diversity in six out of eight studies, with one study showing no effects and one negative effects (Dicks et al. 2013). This probably reflects the lack of species in the seed bank of most arable soils and the species-poor nature of overwinter stubbles (counterfactual), due to the widespread use of broad spectrum herbicides. In contrast, cover crops (**EHAZ-007**) can negatively affect the populations of rare arable plant species, both through competition as well as, e.g. in the case of grass–clover leys, the prevention of seed production through management by cutting and/or grazing (Albrecht et al. 2016). One study found that one year of a grass–clover cover crop, by preventing replenishment of the soil seed bank, resulted in seed bank declines of arable species by as much as a third (Albrecht 2005). The same would apply to maintenance of a continuous vegetation cover (**ECAR-044**). There is no specific evidence of benefits or disbenefits for arable plant richness or rare arable plants relating to actions **ECPW-095**, **ECPW-242** and **ECPW-279**,

3.1.11.2 Co-Benefits and Trade-offs

The principal co-benefit associated with the implementation of cover crops is linked to soil health (Bower et al. 2021) including an increase in soil carbon stocks (Poeplau & Don 2015).

3.1.11.3 Magnitude

Wanigasekara et al. (2021) showed that cover crops were effective in increasing resource availability for parasitoids that contributed to the effective control of cutworm (Lepidoptera: Noctuidae) pests. This benefit was facilitated where Brassicaceae (e.g. camelina, mustard, and oilseed rape) were grown. However, given most cover crops are grow overwinter in the UK it is unlikely that this benefit may be seen. Hakeem et al. (2021) showed that the diversity of predatory ground beetles (Carabidae) was highest in a mixed tillage system were c. 80% higher than conventional tillage, potentially helping to support populations of these species as well as wider control of outbreaks of pests. Wittwer et al. (2017) showed that cover crops could increase crop yields by up to 24%, although this was only seen in organic farming systems.

Field et al. (2010a) reported that the overall average density of seed-eating birds and skylarks on different wild bird-seed cover crops was 5-28/ha, compared to 2-17/ha on stubbles, but this was only statistically significant in one of the two regions studied. Boatman & Bence (2000) found that 55-76% of annual skylark territories were disproportionately located in the 8-10% of the field area that was sown with cover crops. Aebischer et al. (2000) found that grey partridge abundance was 600% higher on farms with cover crops (among other options, such as conservation headlands) than those without them. Henderson et al. (2004) found birds densities on kale-dominated cover crops being 50 times greater than on conventional crops. It is possible that more disbenefits of cover crops would emerge if all or most arable land were sown with them in a given region leading to reduced habitat heterogeneity. However, this is very unlikely as cover crops are generally only sown with spring crops which represent a relatively small proportion of the arable land cropped in most regions of England (note this is not the case for NE Scotland but this is out of scope).

3.1.11.4 Timescale

No specific issues identified. As cover crops are generally not re-sown every year in the same field there will not be the same issues associated with management feature maturation, such as occur in field margins and beetle banks that take time to accumulate biodiversity.

3.1.11.5 Spatial Issues

Beillouin et al. (2021) undertook an overall analysis of the value of crop diversification on biodiversity and ecosystem services based on 5156 separate experiments. They show that crop diversification enhances crop production (14 % increase on average), as well as overall biodiversity (increase of 24 %) and a 63% increase in the control of outbreaks of pests and disease. They highlight cover crops as one of the methods contributing to crop diversification, although it is likely only a small part of their overall reported effects.

Bird abundance is higher on cover crops near hedgerows than those in the field centre (Boatman et al. 2003). Field et al. (2010a) found regional variation in the benefits of cover crops for farmland birds, with increased winter abundance in one region of England but not in another, which suggests a contextual effect.

3.1.11.6 Displacement

Not assessed

3.1.11.7 Maintenance and Longevity

Cover crops are re-sown annually, typically preceding spring crops to be established in the following year. As such there is not specific issue on longevity. Maintenance and longevity will depend on the choice of cover crop (e.g. inclusion of forest-sensitive species). Winter cover crops will have limited benefit to pollinators, as discussed above under causality only those allowed to flower in spring (sown fallows) are likely to benefit pollinating insects.

3.1.11.8 Climate Adaptation or Mitigation

Not assessed

3.1.11.9 Climate factors/constraints

Not assessed

3.1.11.10 Benefits and Trade-offs to Farmer/L-and manager

The principal benefit associated with the implementation of cover crops is linked to soil health (Bower et al. 2021) including an increase in soil carbon stocks (Kelly et al. 2021).

3.1.11.11 Uptake

Not assessed

3.1.11.12 Other Notes

None

3.1.12 EHAZ-004: Use under and over sowing

Bundle: **Soil management and protection /Cover cropping**

Overall RAG ratings for action and ecosystem service (see also Cropland IA spreadsheet

AMBER TL* pest and disease control
AMBER TL* pollination
AMBER TL** Maintaining populations / wider biodiversity
AMBER DTL* presence of rare or priority species

3.1.12.1 Causality

RAG ratings by taxa / ecosystem service

- NATURAL PEST CONTROL - EHAZ 004 AMBER L* for the control of outbreaks of pests and disease.
- BIRDS – **EHAZ-004** **AMBER L**** for maintaining species.
- ARABLE PLANTS – **EHAZ-004** **RED*** for maintaining arable plant richness and for maintaining rare arable plants (logic chain).
- PLANTS – EHAZ 004 **AMBER L*** maintaining species / wider diversity of plants

Undersowing spring cereal crops with legumes may provide a practical means of increasing the rate of environmental enhancement for flower-visiting insects. These legume seed mixtures had the additional benefit of providing long-term control of weed species if a fallow period is included (Pywell et al. 2017).

Project BD5203 found that overall sowing simple seed mixtures of robust species (wild bird 32 seed crops, agricultural legumes) at low rates significantly and rapidly enhanced the value of fallow land on both heavy and light soils (Pywell et al. 2017). Undersowing spring cereal crops with legumes may provide a practical means of increasing the rate of environmental enhancement. These legume seed mixtures had the additional benefit of providing long-term control of weed species for the fallow period. On heavy soils naturally regenerated fallow performed very poorly and was 44 dominated by undesirable grass weed species. Autumn sown pollen and nectar seed mixes provided the greatest number of environmental benefits, followed by spring sown wild bird seed and spring cereal undersown with legumes (Pywell et al. 2017).

There is limited direct evidence that undersowing spring cereals will benefit natural pest control. Jowett et al. (2021) found greater carabid abundance in barley crops that were undersown with grass. Use of companion crops and intercropping suggests the potential for this as an approach for pest control that may have some benefits (Ratnadas et al. 2021). Undersowing may promote movement of predatory insects into crop fields following their overwintering in boundary vegetation although this has not been demonstrated.

Wakeham-Dawson et al. (1998) found significantly greater numbers of priority skylark territories on undersown spring barley than on other types of grassland, arable or set-aside. Further positive associations of increased activity of non-priority farmland birds on undersown spring barley were reported by Defra (2007). However, Ewald et al. (2010) found negative effects of the coverage of undersown spring cereals on the health and survival of priority grey partridges, although brood size and the ratio of young to old birds (reflecting recruitment) were unaffected. This result was probably related to spring cropping itself, and not the undersowing, due to bare fields being present in early spring, exposing birds to predation.

Undersown spring cereals have been shown to have no effects on plants in two studies (Dicks et al. 2013), but one study has shown they can support a greater density of weedy species for longer than conventional cereal fields (Moorcroft et al. 2002). However, the logic chain would suggest competition from undersown legumes and grasses would have potentially negative effects of populations of rare arable plants.

3.1.12.2 Co-Benefits and Trade-offs

There is the potential for undersowing to affect yield, though we found no direct evidence on this. Management may also be more challenging with an undersown crop.

3.1.12.3 Magnitude

Wakeham-Dawson et al. (1998) found that skylark territory densities were highest on undersown spring barley (2.2/10 ha), compared to other types of grassland, arable or set-aside (0.2-1.5/10ha).

3.1.12.4 Timescale

Not assessed

3.1.12.5 Spatial Issues

Not assessed

3.1.12.6 Displacement

Not assessed

3.1.12.7 Maintenance and Longevity

Not assessed

3.1.12.8 Climate Adaptation or Mitigation

Not assessed

3.1.12.9 Climate factors/constraints

Not assessed

3.1.12.10 Benefits and Trade-offs to Farmer/Land manager

Not assessed

3.1.12.11 Uptake

Not assessed

3.1.12.12 Other Notes

None

3.1.13 Crop diversity

Bundle: Restoration, management and enhancement /Cropland

ETPW-231 Establish a spatial spread of crops by not block cropping
ECCM-001 Diversify arable rotations (including cover and catch crops, over and under sowing).
ECPW-032 Use herbal and grass leys
ETPW-202 Plant/ maintain mass flowering crops e.g. legume leys

Overall RAG ratings for each action and ecosystem service

ETPW-231 Establish a spatial spread of crops by not block cropping
AMBER L** maintaining species / wider biodiversity
AMBER L* pest and disease control
AMBER L** pollination

ECCM-001 Diversify arable rotations (including cover and catch crops, over and under sowing).
AMBER L** maintaining species / wider biodiversity
GREEN** pest and disease control
AMBER TL** presence of rare and priority species
AMBER L** pollination

ECPW-032 Use herbal and grass leys
GREEN** maintaining species / wider biodiversity
AMBER TDL** presence of rare and priority species
AMBER L* pest and disease control
GREEN** pollination

ETPW-202 Plant/ maintain mass flowering crops e.g. legume leys
GREEN** maintaining species / wider biodiversity
AMBER TDL** presence of rare and priority species
AMBER L* pest and disease control
GREEN** pollination

3.1.13.1 Causality

RAG ratings by taxa / ecosystem service

- CARABIDAE, ARANAE - **ECPW-032** **GREEN*** ** for maintaining species (exceptions **ETPW-231** **AMBER L*** evidence).
- NATURAL PEST CONTROL - **ECCM-001** - **GREEN**** for the control of outbreaks of pests and disease (exceptions **ETPW-231** **AMBER L*** evidence).
- MAMMALS - **ETPW-231** & **ECCM-001** **AMBER L**** for maintaining species.
- BIRDS - **ETPW-231** & **ECCM-001** **GREEN***** for maintaining species. **ECPW-032** and **ETPW-202** **AMBER TL***** for maintaining species.
- POLLINATORS (and see above) - **ECCM-001** & **ETPW-231** **AMBER L**** for maintaining habitats and populations/ species and for pollination services. **ECPW-032** & **ETPW-202** **GREEN**** for maintaining pollinator species and pollination services).
- ARABLE PLANTS – **ECCM-001** **AMBER LDT*** (limited evidence) for maintaining arable plant richness and for maintaining rare arable plants. **ECPW-032**, **ETPW-202** **RED*** maintaining arable plant richness and for maintaining rare arable plants
- PLANTS - **ETPW-231** & **ECCM-001** **GREEN**** maintaining species richness / wider plant diversity. **ECPW-032** & **ETPW-202** **AMBER DL*** maintaining species richness / wider plant diversity.

Increasing crop diversity, in particular functional diversity (e.g. cereal vs. mass flowering crops, spring vs. winter sown crops, legumes vs. non-legumes etc) is likely to support increased species numbers and general biodiversity by optimising the continuity of resources utilised by wild species (including those supporting pest control and pollination) over space and time (Thomine et al. 2022). The best current evidence for the benefits of increasing crop diversity on species and the control of outbreaks of pests and disease comes from a meta-analysis by Beillouin et al. (2021). Within this study they undertook an overall analysis of the value of crop diversification on biodiversity and ecosystem services based on 5156 separate experiments. They showed that crop diversification enhanced crop production (14 % increase on average), as well as overall biodiversity (increase of 24 %) and resulted in a 63% increase in the control of outbreaks of pests and disease. They highlight that these benefits can be achieved through a range of different management approaches, including cover crops, agroforestry, crop rotation, intercropping and potentially variety mixtures. Another meta-analysis by Aizen et al. (2019) showed that pollination services are under threat by a lack of crop diversity.

The specific use of herbal and grass leys (**ECPW-032**) and legume leys (**ETPW-202**) has significant UK evidence for its potential to increase species of pollinators, spiders and ground beetles (DEFRA Wide Scale Enhancement of Biodiversity BD1466; Woodcock et al. 2012; Woodcock et al. 2013; Woodcock et al. 2014b; Savage et al. 2021). There is little evidence on the benefits or effects of the action Establish a spatial spread of crops by not block cropping (**ETPW-231**) on species or control of outbreaks of pests and diseases, although it is likely to contribute to promoting small scale heterogeneity which may have some beneficial effects (Bianchi et al. 2006). One study in Sweden recently found that landscape-level crop diversity (including cover of arable cereals, brassicas and beet, fallows, leys, pulses and fruit) within a 1.5 km radius enhanced bumble bee densities on insect-pollinated faba bean fields (Raderschall et al. 2021). This suggests that promoting crop diversity (e.g. via **ECCM-001**) alongside enhancements on non-crop habitats would provide valuable resource to support pollinators.

Increased crop diversity is positively associated with abundance and activity of priority brown hares (Smith et al. 2005), but otherwise the evidence for mammals is lacking.

For farmland birds, Redhead et al. (2018) found a positive association between the crop diversity (**ETPW-231** & **ECCM-001**) and the abundance of seed-eating birds. Providing cover crops in diversified rotations (**ECCM-001**), which include wild bird cover to provide seed-bearing crops over winter, is associated with increased abundance, density and species richness of priority farmland birds including priority grey partridges (Aebischer et al. 2000), skylarks, finches and buntings (Chamberlain & Gregory 1999; Boatman et al. 2003; Henderson et al. 2004; Stoate et al. 2004; Vickery et al. 2009). Wakeham-Dawson et al. (1998) found significantly greater numbers of skylark territories on undersown spring barley than on other types of grassland, arable or set-aside. Cover crops that include a large proportion of kale are used by the greatest range and number of farmland birds (Boatman et al. 2003; Henderson et al. 2004). Skylark densities are higher in wild bird cover crops than conventional crop habitat (Boatman & Bence 2000; Murray et al. 2002). Redhead et al. (2018) showed that provision of wild bird cover was associated with increased winter abundance that enhanced breeding abundance of priority seed-eating finches and buntings at the farm scale. (Field et al. 2010a) reported regional variation in benefits of cover crops for farmland birds, with increased winter abundance in one regions but not another. Provision of cover crops did not prevent the decline in abundance of grey partridges in one study (Browne & Aebischer 2003).

Poulsen et al. (1998) found territory abundance of priority skylarks to be lower on grass leys (**ECPW-032**) than on spring cereals, silage grass or permanent pasture, but slightly greater than on autumn sown cereals. Stein-Bachinger & Fuchs (2012) showed herbal and grass leys to be very attractive to skylarks, corn buntings and yellow wagtails, but frequent cutting could reduce breeding success and make them an ecological trap. Logical expert opinion suggests that excessive mob grazing on leys could have a similar counter-productive effect of destroying nests.

Diversified crop rotations increase both the spatial diversity of crops on a farm in a given year, and the temporal diversity of crops across years in any given field included in the rotation. The spatial diversity aspect is of particular relevance for mobile animal taxa that can visit a variety of habitats, whereas the temporal diversity aspect is of particular relevance for arable plants that are immobile except during seed dispersal and that rely on in situ establishment from seed produced in previous years. Crop choice affects arable plant communities mainly via the choice, timing, and intensity of management practices associated with the crop (Booth & Swanton 2002). Accordingly, in any given year during a crop rotation, arable plant communities tend to be strongly affected by the crop planted in that year (Hawes et al. 2010, Seifert et al. 2015). The received wisdom for arable plants is that simple rotations in which one crop features dominantly tend to promote those arable plant species best adapted to this crop and its management, resulting in their build-up in density over time and giving them an advantage over other, less well-adapted, arable species (Liebman & Dyck 1993). On the other hand, diverse crop rotations have been hypothesised to prevent a simplification of arable plant communities over time and help maintain species-rich arable plant communities (Doucet et al. 1999). Evidence for benefits of increasing the number of crops planted in sequence in a rotation on arable plant diversity has been found by some studies (e.g., Stevenson et al. 1997, Murphy et al. 2006), but not others (e.g., Smith & Gross 2007, Ulber et al. 2009). Rotational crop diversity encompasses more aspects than just the number of different crops planted in a rotation. For example, Doucet et al. (1999) found that the effects of management on arable plant species richness were much larger than the effects of crop rotation. Another important aspect with respect to arable plant diversity is to what extent the different crops in a rotation differ in terms of choice, timing and intensity of associated management practices, with greater diversity potentially allowing greater numbers of arable species to coexist over time. For example, combinations of spring- and autumn-sown cereals in rotation provide suitable allow coexistence of a wider range of species compared to repeated planting only of autumn-sown cereals (Hald 1999).

Diversification of crop rotations by introducing herbal and grass leys (action **ECPW-032**) or by introducing mass-flowering crops such as e.g. legume leys (action **ETPW-202**) may allow some establishment of arable species in the first year after sowing, but may not benefit arable plant species richness if leys remain in place for more than a single year only. For example, Critchley et al. (2004a) found for grass leys that this action resulted in particularly low richness of annual and dicot species, i.e. of typical arable plant species. For legume leys, Döring et al. (2017), in a study of organic fields, found a decline in arable plant species richness of over half in the second year of planting legume leys, compared to the first year. Studies exploring the effects of management actions on rare arable plants tend to focus on field edges, rather than on whole fields, and hence, we know of no study specifically investigating the effects of planting leys or mass flowering crops at the scale of whole fields on rare arable plants. However, the chain of logic would suggest that similar effects may be expected in response to such whole-field actions as have been confirmed for corresponding actions targeted instead specifically at the margins of fields, such as e.g. during the creation of grass strips (action **EBHE-117** above).

More broadly, there is limited evidence that increasing crop diversity may increase plant species richness (Dicke et al. 2013). Grass leys (one part of action **ECPW-032**) had lower plant species richness than nine other conservation measures (including wildlife seed mixtures, uncropped cultivated margins, undersown cereals and spring fallows; Critchley et al. 2004a), though this study did not include a comparison to a counterfactual ‘business as usual’ control.

3.1.13.2 Co-Benefits and Trade-offs

A detailed assessment of the socio-economic trade-offs and the required operational and institutional frameworks to drive crop diversification are given by Thomine et al. (2022). These are too complex to consider in with the scope of this review and this work should be consulted directly for further detail. Crop diversity can contribute to the stability of crop yields over time, although this effect did show variability between countries within the EU suggesting that local conditions can significantly alter the characteristics of this relationship (Renard et al. 2019; Egil et al. 2021).

3.1.13.3 Magnitude

Beillouin et al. (2021). Within this study they undertake an overall analyses of the value of crop diversification on biodiversity and ecosystem services based on 5156 separate experiments. They show that crop diversification enhances crop production (14 % increase on average), as well as overall biodiversity (increase of 24 %) and a 63% increase in the control of outbreaks of pests and disease.
Poulsen et al. (2002) found Skylark densities that were 2-3 times greater on set-aside and permanent pasture than on cereal crops, but densities on grass leys were similar to those on cereals at around 0.5/10 ha. However, Stein-Bachinger & Fuchs (2012) found skylark densities of up to 5.4/10ha on herbal-grass leys. Boatman & Bence (2000) found that 55-76% of annual skylark territories were disproportionately located in the 8-10% of the field area that was sown with cover crops. Aebischer et al. (2000) found that grey partridge abundance was 600% higher on farms with cover crops (among other options, such as conservation headlands) than those without them. Henderson et al. (2004) found bird densities on kale-dominated cover crops were 50 times greater than on conventional crops. Field et al. (2010a) reported that the overall average density of seed-eating birds and skylarks on different cover crops was 5-28/ha, compared to 2-17/ha on stubbles, but this was only statistically significant in one of the two regions studied.

Wakeham-Dawson et al. (1998) found that skylark territory densities were highest on undersown spring barley (2.2/10 ha), compared to other types of grassland, arable or set-aside (0.2-1.5/10ha).

3.1.13.4 Timescale

Not assessed

3.1.13.5 Spatial Issues

Crop diversity by definition will contribute to increased complexity of landscapes by increasing the range of crop types. Bianchi et al. 2006 showed in a meta-analysis that overall natural enemy populations were increased by 74 % while the pest populations were 45 % lower in complex landscapes when compared to simple landscape controls. However, Karp et al. (2018) suggested that there may exist considerable variability in the response of predatory invertebrates to landscape structure.

Bird abundance is higher on cover crops near hedgerows than those in the field centre (Boatman et al. 2003). Field et al. (2010a) found regional variation in the benefits of cover crops for farmland birds, with increased winter abundance one region of England but not in another, which suggests a possible contextual effect of local landscape and bird populations.

3.1.13.6 Displacement

Not assessed

3.1.13.7 Maintenance and Longevity

Not assessed

3.1.13.8 Climate Adaptation or Mitigation

Not assessed

3.1.13.9 Climate factors/constraints

Not assessed

3.1.13.10 Benefits and Trade-offs to Farmer/L-and manager

Crop diversity can contribute to the stability of crop yields over time, although this effect did show variability between countries within the EU suggesting that local conditions can significantly alter the characteristics of this relationship (Renard et al. 2019; Egil et al. 2021).

There may be greater challenges managing cropping cycles without block cropping, and introducing new crops to increase diversity. Block crops can reduce travel time between fields and increase efficiency, reducing block cropping may result in an efficiency reduction.

3.1.13.11 Uptake

A detailed assessment of the socio-economic trade-offs and the required operational and institutional frameworks to drive crop diversification are given by Thomine et al. (2022). These are too complex to consider in with the scope of this review and this work should be consulted directly for further detail.

3.1.13.12 Other Notes

None

3.1.14 ETPW-092: Use minimum-tillage or no-tillage cultivation

Bundle: Soil management and protection /Tillage

Overall RAG ratings for each action and ecosystem service
AMBER DTL** maintaining species / wider biodiversity
AMBER DTL** presence of rare or priority species

3.1.14.1 Causality

RAG ratings by taxa / ecosystem service

- CARABIDAE – **ETPW-092 GREEN***** for maintaining species.
- EARTHWORMS (LUMBRICINA) - **ETPW-092 GREEN***** for maintaining species and increased soil biodiversity
- BIRDS – **ETPW-092 AMBER TDL*** for maintaining species
- PLANTS – **ETPW-092 AMBER TDL**** for maintaining species
- ARABLE PLANTS – **ETPW-092 RED***** for maintaining arable plant richness and for maintaining rare arable plants.

Minimum tillage approaches were a key approach for supporting populations of key predatory ground beetle species within arable agriculture, in particular larger species such as *Pterostichus melanarius* (Holland et al. 2003; Legrand et al. 2011; Kennedy et al. 2013). However, there is some suggestion that this benefit may not be seen for some of the smaller species, such as Bembidion spp (Kennedy et al. 2013). The occurrence of granivorous arthropods associated with seed predation is also normally highest in under minimum tillage agriculture (Law et al. 2018). Earthworm numbers are typically higher under minimum tillage agriculture, having knock on benefits for soil health and wider soil biodiversity (Brown et al. 2003; Cunningham et al. 2004; Kennedy et al. 2013, but see Topoliantz et al. 2000).

Five studies have found positive effects of reduced tillage on farmland birds compared with conventional management, while three found no or negative effects (Dicks et al. 2013). While minimum or shallow tillage may have some positive effects for birds, no tillage may have negative effects. Both minimum-tillage and no-tillage are included in the wording of action **ETPW-092**, so any benefits for disbenefits will depend on how the action is applied.

Four studies found positive effects of reduced tillage on weedy plant species richness or abundance compared to conventional management, while three studies found no effect of reduced tillage or a negative effect on plant species richness (Dicks et al. 2013). Plant species may differ in their responses to reduced tillage, and the timing of the crops may also play a role. For example, goosefoot (*Chenopodium album*) and couch grass (*Elymus repens*) were more frequent under reduced tillage compared to ploughing in summer cereals, but less frequent under reduced tillage winter cereals. The opposite pattern was found for knotweed species (*Polygonum* spp.) and chickweed (*Stellaria media*, Gruber et al. 2000).

The effects of reduced tillage on arable plants, when not compensated for by simultaneous increased chemical weed control, vary with time. Reduced tillage in combination with reduced weed control can increase arable species diversity in the short term (Albrecht and Sprenger 2008). However, in the long-term, a build-up of problematic weeds with the potential to displace annual arable plants can result can result, including both a build-up of annual grass weeds (McCloskey et al. 1996, Holland 2004) and of biennial and perennial weeds (Moyse and Shellswell 2016). Such build-up of undesirable competitive species can also negatively affect any existing populations of rare arable species (Wagner et al. 2016). On the other hand, increases in herbicide application by farmers to control biennial and perennial species benefiting from reduced cultivation can result in even more pronounced long-term declines in arable plant diversity and in the occurrence of rare arable plants (Albrecht and Sprenger 2008). As reduced tillage tends to be more of a long-term measure, its effects on arable plants can be considered negative.

3.1.14.2 Co-Benefits and Trade-offs

The largest benefit to minimum tillage is likely linked with improved populations of earthworms which would have associated benefits for soil health (Doran et al. 2000). While Law et al. (2018) found an increase in the density of arthropods associated with seed predation (e.g. of weeds) this was not found to translate into an increase in the actual observed rates of seed predation. Slug damage and their population size may be greater under minimum tillage agriculture causing increases in damage to cereals (Kennedy et al. 2013). There are however some examples of minimum tillage practice having direct benefits in terms of reducing pest populations, such as the Colorado beetle on potatoes (Hunt et al. 1998). This is not directly applicable to the UK faming system however.

A trade-off of reduced tillage is the likely build-up of undesirable weed species. If reduced tillage systems rely on herbicides such as glyphosphates, problems may be exacerbated by increased resistance in weed species (e.g. Comont et al. 2019).

3.1.14.3 Magnitude

Conventional farming with no-tillage systems can increase crop yields by up to 8 % although this effect is likely to be highly context specific (Wittwer et al. 2017).

3.1.14.4 Timescale

Not assessed

3.1.14.5 Spatial Issues

Not assessed

3.1.14.6 Displacement

Not assessed

3.1.14.7 Maintenance and Longevity

Not assessed

3.1.14.8 Climate Adaptation or Mitigation

Not assessed

3.1.14.9 Climate factors/constraints

Not assessed

3.1.14.10 Benefits and Trade-offs to Farmer/L-and manager

The largest benefit to minimum tillage is likely linked with improved populations of earthworms which would have associated benefits for soil health (Doran et al. 2000). While Law et al. (2018) found an increase in the density of arthropods associated with seed predation (e.g. of weeds) this was not found to translate into an increase in the actual observed rates of seed predation. Slug damage and their population size may be greater under minimum tillage agriculture causing increases in damage to cereals (Kennedy et al. 2013). There are however some examples of minimum tillage practice having direct benefits in terms of reducing pest populations, such as the Colorado beetle on potatoes (Hunt et al. 1998). This is not directly applicable to the UK faming system however.

A trade-off of reduced tillage is the likely build-up of undesirable weed species. If reduced tillage systems rely on herbicides such as glyphosphates, problems may be exacerbated by increased resistance in weed species (e.g. Comont et al. 2019).

3.1.14.11 Uptake

Not assessed

3.1.14.12 Other Notes

None

3.1.15 Grass in the arable rotation

Bundle: Restoration, management and enhancement /Cropland

EHAZ-024 Use grass or encourage natural regeneration where this can be efficiently incorporated into the rotation

ETPW-232 Use grassland (grazed or ungrazed) in arable rotation as a break crop

<u>Overall RAG ratings for each action and ecosystem service</u>

EHAZ-024 Use grass or encourage natural regeneration where this can be efficiently incorporated into the rotation

AMBER TDL** maintaining species / wider biodiversity
AMBER TL* pest and disease control
AMBER L* pollination
AMBER TDL* rare or priority species

ETPW-232 Use grassland (grazed or ungrazed) in arable rotation as a break crop

AMBER DL** maintaining species / wider biodiversity
AMBER TL* pest and disease control
AMBER L* pollination

RED* rare or priority species

3.1.15.1 Causality

RAG ratings by taxa / ecosystem service

- CARABIDAE and ARANAE – **EHAZ-024**, **ETPW-232** **GREEN***** for maintaining species, **AMBER TL*** pest and disease control.
- ORTHOPTERA – **EHAZ-024**, **ETPW-232** **GREEN***** for maintaining species.
- POLLINATORS - **EHAZ-024**, **ETPW-232** **AMBER L*** for maintaining habitats and populations/ species and pollination services.
- PLANTS - **EHAZ-024** natural regeneration **GREEN**** for maintaining plant species richness and populations, **ETPW-232** and **EHAZ-024** use grass **AMBER L*** for maintaining plant species richness and populations.
- ARABLE PLANTS – **ETPW-232** & **EHAZ-024** except use of natural regeneration: **RED*** for maintaining arable plant species richness and rare arable plants. **EHAZ-024** natural regeneration **GREEN**** if single year in rotation for arable plant species richness and rare arable plants

A recent review highlighted the benefits of using clover in grass leys as a potential low or zero-cost opportunity to increase pollen and nectar availability and provide resources for wild and managed bees (Harris and Ratnieks, 2021). The disproportionate extinction of late summer-flying pollinating insects in the UK has been suggested to be due to the loss of late summer blooming plants (Balfour et al. 2018), of which white and red clover cover have declined by 40% and 58% respectively between 1978 and 2007 (from 1978–2007 Countryside Survey (Bunce et al. 2014)). However the use of long-corolla legumes alone within grass leys will only benefit a small portion of the overall pollinator fauna (bumblebees, honeybees and some long-tongued solitary bees), as shown in Wood et al. (2015) and a wider range of flowering plant groups must be encouraged to maintain a diverse bee community.

The specific use of grass leys in rotation with arable crops has significant UK evidence for its potential to increase species of spiders and ground beetles but without a sown floral component will not benefit insect pollinators (DEFRA Wide Scale Enhancement of Biodiversity BD1466; Woodcock et al. 2012; Woodcock et al. 2013; Woodcock et al. 2014; Savage et al. 2021). There is little evidence on the benefits or effects on species or control of outbreaks of pests and diseases, although it is likely to contribute to promoting small scale heterogeneity which may have some beneficial effects (Bianchi et al. 2006). It is likely that earthworm number will increase where conventional tillage practices have been stopped under grass over (BD1624 BUZZ).

Critchley et al (2004a) found that grass leys supported fewer plant species than nine other conservation measures (e.g. planting wildflower seeds, undersown cereals, conservation headlands, spring fallows). No comparison was made with a counterfactual (an arable crop with no grass in the rotation or other conservation measure), but it seems likely that any benefit to the wider plant community of including grass in arable rotations is likely to be small.

3.1.15.2 Co-Benefits and Trade-offs

Crop diversity by definition will contribute to increased complexity of landscapes by increasing the range of crop types. Bianchi et al. 2006 showed in a meta-analysis that overall natural enemy populations were increased by 74 % while the pest populations were 45 % lower in complex landscapes when compared to simple landscape controls. However, Karp et al. (2018) suggested that there may exist considerable variability in the response of predatory invertebrates to landscape structure.

The integration of leys and sheep into arable rotations in relation to soil health is the topic of a large, ongoing UKRI-funded project (https://gtr.ukri.org/projects?ref=BB%2FR021716%2F1). More evidence in this area will be available from this project.

3.1.15.3 Magnitude

Not assessed

3.1.15.4 Timescale

Not assessed

3.1.15.5 Spatial Issues

Not assessed

3.1.15.6 Displacement

Not assessed

3.1.15.7 Maintenance and Longevity

Not assessed

3.1.15.8 Climate Adaptation or Mitigation

Not assessed

3.1.15.9 Climate factors/constraints

Not assessed

3.1.15.10 Benefits and Trade-offs to Farmer/Land manager

Not assessed

3.1.15.11 Uptake

Not assessed

3.1.15.12 Other Notes

None

3.1.16 Fallow in the arable rotation

Bundle: Soil management and protection /Cover cropping
ETPW-257 Use vegetated fallow in arable rotations

Restoration, management and enhancement /Cropland
Arable01 Extended stubble - unharvested crop stubble followed by a one-year fallow
Arable02 Unvegetated, ploughed fallow (natural regeneration) for one year

Overall RAG ratings for each action and ecosystem service
ETPW-257 Use vegetated fallow in arable rotations
AMBER TL** Maintaining species / wider biodiversity
AMBER DL* presence of rare or priority species
AMBER TL** pollination
AMBER TDL** pest and disease control (AMBER TL** for predatory insects, D for potential pernicious weed disbenefit)

Arable01 Extended stubble - unharvested crop stubble followed by a one-year fallow
GREEN** maintaining species / wider biodiversity
GREEN*** presence of rare or priority species
AMBER TL** pollination
AMBER TDL** pest and disease control (AMBER TL** for predatory insects, D for potential pernicious weed disbenefit)

Arable02 Unvegetated, ploughed fallow (natural regeneration) for one year
GREEN** maintaining species / wider biodiversity
GREEN*** presence of rare or priority species
AMBER TL** pollination
AMBER TDL** pest and disease control (AMBER TL** for predatory insects, D for potential pernicious weed disbenefit)

3.1.16.1 Causality

RAG ratings by taxa / ecosystem service

- CARABIDAE – **Arable01**, **Arable02**, **ETPW-257** - **AMBER L*** for maintaining species.
- LUMBRICINA – **Arable01**, **Arable02**, **ETPW-257** - **AMBER L*** for maintaining species.
- BUTTERFLIES – **ETPW-257**, **Arable01**, **Arable02** – **GREEN**** for maintaining species.
- POLLINATORS – **ETPW-257**, **Arable01**, **Arable02** **AMBER TL***** for maintaining habitats and populations/ species and **AMBER** TL** for pollination services.
- MAMMALS – **Arable01**, **Arable02**, **ETPW-257** - **GREEN***** for maintaining species.
- BIRDS – **Arable01**, **Arable02**, **ETPW-257** - **GREEN***** for maintaining species.
- ARABLE PLANTS – **Arable01**, **Arable 02** **GREEN**** for maintaining arable plant richness and for maintaining rare arable plants, **ETPW-257** **RED*** for maintaining arable plant richness and for maintaining rare arable plants.

Arable01 and **Arable02** actions were added by the Croplands review team, and were not part of the original Defra spreadsheet of actions.

For butterflies, there is evidence from European studies that rotational fallows (**ETPW-257**, **Arable01**, Arable 02) can increase species richness and abundance (Kuussaari et al. 2011). One study on experimental fallows in Finland showed that butterfly and other pollinating insect (bumblebee and honeybee) abundance and species richness was greatest on two-year fallows, fallows that were undersown with uncompetitive grasses (e.g. **ETPW-257**) and naturally regenerated stubble (e.g. **Arable01**) and lower on fallows that were left for one year or undersown with competitive grasses (Kuussaari et al. 2011). Butterfly and other pollinating insect responses were driven by the species richness of flowering plants under the different fallow treatments. Butterfly abundance is positively correlated with the area of bare-ground in short-term fallows (Toivonen et al. 2016). Toivonen et al. (2015) found a greater abundance of butterflies on fallows planted with longer-term grassland mixtures, compared to shorter-term fallows planted with meadow seed mixes every 4-5 years. This last study is less directly relevant to these actions concerning shorter rotational fallows, but does show the value of longer-term fallows for butterflies.

One replicated study in the UK contrasted the performance of naturally regenerated fallows with those created by sowing very low rates (30%) of basic and more complex agri-environmental seed mixtures: wild bird seed, pollen and nectar, annual and perennial wildflowers (Pywell et al. 2017). These fallows were contrasted with conventionally managed cereal crop controls on contrasting light and heavy soil types over three years. Overall sowing simple seed mixtures of robust species (e.g. **ETPW-257**: wild bird seed crops or agricultural legumes at a cost of £30-£50 ha-1) at low rates significantly and rapidly enhanced the value of fallow land for bumblebees and butterflies on both heavy and light soils. The conventional cereal crop provided few benefits with the exception of the winter wheat left as a short-term food supply for farmland birds. The study recommended that naturally regenerated fallows (e.g. **Arable02**) on light soils can be beneficial to biodiversity, especially rare arable plants, pollinators and birds, but those on heavy soil are likely to be of little benefit being dominated by undesirable weed species. Fallows should only be left in place for 1-2 years to avoid the build-up of undesirable species that may compromise a rapid return to food production (Pywell et al. 2017).

There is some evidence (not from the UK) that fallow fields could provide an important breeding and overwintering habitat for ground beetles helping to support populations (Yamazaki et al. 2003; Tyler 2008), although this is most likely to be relevant for **Arable02** and **ETPW-257**. However, Feng et al. 2021 found that the abundance and species richness of ground beetles and money spiders (Linyphiidae) did not differ between fallows and cereal fields. While there was no overall effect, in the case of the money spiders their functional diversity did increase in fallows. Functional diversity has been shown to be a predictor of the effectiveness of arthropod communities providing natural pest control (Greenop et al. 2018). Earthworms may benefit from fallow land, but Pizl (1992) found that it takes four years of being under fallow for benefits to be seen.

For mammals, priority brown hares (Smith et al. 2005) and western European hedgehogs (Hof & Bright 2010) are positively associated with fallow land compared to cropped land. Small mammals are more positively associated with fallow land where this has a mixture of grasses and forbs and is adjacent to hedgerows, but show some avoidance where fallow land is cut. (Macdonald et al. 2007).
For farmland birds, there are few specific tests comparing different types of fallow or set-aside prescribed by **Arable01**, **Arable02** or **ETPW-257**. However, all fallow options have broadly similar benefits of greatly enhancing priority farmland birds by increasing breeding density, breeding productivity and/or winter abundance compared to cropped areas (Buckingham et al. 1999; Poulsen et al. 1998; Aebischer et al. 2000; Henderson et al. 2000; Firbank et al. 2003; Roberts & Pullin 2007; see also Van Buskirk & Willi 2004 for a meta-analysis of 127 studies). When available, fallow tends to be the preferred habitat of the widest groups of farmland birds, over all other cropped and non-cropped options (Henderson et al. 2000; Firbank et al. 2003). Overall, providing fallow has more positive influence on birds than the specific management regime of the fallow land (Firbank et al. 2003; Van Buskirk & Willi 2004).

Buckingham et al. (1999) found greater benefits for some species (finches, buntings) in the first year of fallow, but greater for other species (thrushes, grey partridge) in older fallow. Generally, larger and older areas of allow have greater benefits (Van Buskirk & Willi 2004). Poulsen et al. (1998) showed that skylark densities and breeding productivity were higher on permanent vegetated fallow (cf **ETPW-257**) than on cereal crops or grass leys, although Murray et al. (2002) found higher densities of skylarks on unmanaged fallow than on sown (kale dominated) cover crops or cropped areas. Donald et al. (2002) found higher predation rates of skylark nests on fallow compared to cereals. Henderson et al. (2000) and Firbank et al. (2003) demonstrated higher densities of most functional groups of farmland birds on rotational fallow (**ETPW-257**) compared to non-rotational, but all fallow out-performed cropped areas. Similarly, Aebischer & Ewald (2010) reported significantly higher densities of grey partridges on vegetated rotational fallow (using cover crops) than on cereals, with non-rotational fallow having negligible benefits.

One-year unvegetated fallow (**Arable02**) is expected to deliver benefits to arable plant species richness as well as to populations of rare arable priority species where such species are present. For example, Wilson (1992) found for the first year of unvegetated set-aside that this particularly benefits species richness of annual arable species, whereas fallow lasting two years or longer tends to result in an increase of problematic grass and arable weeds. Similarly, where populations of rare arable plants are present, short (1-year) unvegetated fallow periods have proved particularly useful, as these rare species then get the opportunity to reproduce, and subsequent inversion tillage allows incorporation of seeds into the soil seed bank (Albrecht et al. 2016; Pywell et al. 2017). Similar benefits both to arable plant species richness and to populations of rare arable plants where these are present would be expected from extended stubble

(**Arable01**), i.e., unharvested crop stubble followed by a one-year fallow, as e.g., observed for enhanced over winter stubble (**ETPW-229**), which is overwinter-stubble followed by spring fallow (Walker et al. 2007). The use of sown vegetated fallow in arable rotations (**ETPW-257**), on the other hand, may negatively affect populations of arable plants, including rare arable priority species, in a similar way as the use of cover crops (**EHAZ-007**), through competition and prevention of seed production (Albrecht et al. 2016).

There is the potential for pernicious weed populations to set seed and become established on fallow land if not controlled, and be a source of weeds for surrounding crops. Due to this, the pest and disease service score above includes D (disbenefits).

3.1.16.2 Co-Benefits and Trade-offs

Donald et al. (2002) found that nest survival of skylarks was only 22% in fallow habitat compared to 38% survival in cereals, due to higher predation rates.

3.1.16.3 Magnitude

Western European hedgehogs used fallow (set aside) land only marginally more than arable, and substantially less often than they used hedgerows and field margins. Of 20 European studies of brown hares, reviewed by Smith et al. (2005), three showed a neutral response and 17 showed a positive effect on abundance.

The majority of larger bird studies have focused on modelled associations and their relative strength rather than reporting comparable metrics or trends of abundance. Poulsen et al. (1998) found skylark breeding productivity to be 2.5 to 5 times greater on vegetated fallow than on cereals or silage grass, and breeding densities were 2-3 times greater. Aebischer & Ewald (2010) reported densities of grey partridges that were 3-4 times greater (up to 1.8 pairs/10 ha) in the presence of vegetated fallow than on control sites, with non-rotational fallow providing the greatest magnitude of impacts. Donald et al. (2002) found that 90% of 422 skylark territories on one farm were located on non-rotational fallow. Henderson et al. (2001) found that fallow (rotational and non-rotational) held an average of four times as many species as in crops, and the number of individual birds was 7.6 times greater.

3.1.16.4 Timescale

Tyler (2008) suggests that the age of fallows can have a positive effect on both the total mass of ground beetles found within this habitat, although this is over very long (>10 year) time scales. For the prescriptions suggested here (**Arable01**, **Arable02** and **ETPW-257**) which would typically last only a year these effects are not relevant. Feng et al. (2021) also highlight the importance of long term fallows over short single year fallows for both spiders and ground beetles. For earthworms, fields may need to be fallow for at least 4 years before benefits are seen for this group.

3.1.16.5 Spatial Issues

Crop diversity, of which fallow may be considered a component, will contribute to increased complexity of landscapes by increasing the range of crop types. Bianchi et al. 2006 showed in a meta-analysis that overall natural enemy populations were increased by 74 % while the pest populations were 45 % lower in complex landscapes when compared to simple landscape controls. However, Karp et a.l (2018) suggested that there may exist considerable variability in the response of predatory invertebrates to landscape structure.
Fallow land adjacent to hedgerows is more attractive to small mammals (Macdonald et al. 2007).

Ideally fallows should be targeted at fields with diverse plant communities and away from fields with high populations of pernicious weeds e.g. black-grass (Meyer et al. 2010).

3.1.16.6 Displacement

Not assessed

3.1.16.7 Maintenance and Longevity

Cutting negates positive effects on small mammals (Macdonald et al. 2007).

3.1.16.8 Climate Adaptation or Mitigation

Not assessed

3.1.16.9 Climate factors/constraints

Not assessed

3.1.16.10 Benefits and Trade-offs to Farmer/Land manager

Not assessed

3.1.16.11 Uptake

Not assessed

3.1.16.12 Other Notes

None

3.1.17 ETPW-229: Enhanced overwinter stubble

Bundle: Restoration, management and enhancement /Cropland

Overall RAG ratings for action and ecosystem service
AMBER L** maintaining species / wider biodiversity
GREEN** presence of rare and priority species

3.1.17.1 Causality

RAG ratings by taxa / ecosystem service

- MAMMALS – **ETPW-229** **AMBER L*** for maintaining species.
- BIRDS – **ETPW-229** **AMBER L**** for maintaining species.
- ARABLE PLANTS – **ETPW-229** **GREEN***** for maintaining arable plant richness and **GREEN***** maintaining rare arable plants.

Enhanced overwinter stubbles consist of leaving the stubble from the summer's crop until at least end of July the following year – this is an overwinter stubble followed by a short spring fallow period with natural regeneration. Much of the evidence on biodiversity benefits relate to basic overwinter stubbles which can be resown from March onwards. Enhanced overwinter stubbles are likely to provide greater biodiversity benefits than basic overwinter stubbles.

There is no specific evidence for the effectiveness of enhanced overwinter stubble for mammals on croplands, over existing knowledge for any other stubble regime, but this evidence and expert opinion suggests a potential positive impact for brown hares (Fisher et al. 2007). Tew & Macdonald (1993) found high predation of wood mice after harvesting, and a rapid 80% decrease in population, due to loss of cover and increased predation, and this may also apply to over-winter stubble.

For farmland birds, enhanced overwinter stubbles have received no specific testing, but other stubble options are known to be beneficial (Stevens & Bradbury 2006; Roberts & Pullin 2007), including additional benefits for skylarks of reduced herbicide use in Higher Level Stewardship stubbles (Field et al. 2010a). Additionally, targeted low-input overwinter stubbles are particularly beneficial to the recovering cirl bunting population in southwest England by increasing food availability, more so than conventional stubbles (RSPB 2004; Natural England 2009).

Five studies have shown plants benefit from overwinter stubbles, and one study has shown benefits for invertebrates (Dicks et al. 2013).

Positive effects of enhanced overwinter stubble on arable plant species richness have been found in a study by Walker et al. (2007), which referred to this action as 'Spring Fallow'. Benefits of enhanced winter stubble to overall plant species richness and that of annual plants and dicots of applying enhanced overwinter stubble are comparable to those conferred by low input cropped margins (**ETPW-240**), i.e., conservation headlands without fertiliser application (Walker et al. 2007). Enhanced overwinter stubble can benefit both spring-germinating arable plants (Walker et al. 2007) and autumn-germinating arable plants (Critchley et al. 2004a, Walker et al. 2007). Walker et al. 's (2007) study fell short of demonstrating benefits to the species richness of rare arable plants, but this was likely due to an overall very low incidence and uneven distribution of rare plant populations in their sample across the studied English regions. Benefits of overwinter stubble have been demonstrated for the seed production particularly of late flowering rare arable plants (Albrecht et al. 2016).

3.1.17.2 Co-Benefits and Trade-offs

No assessment.

3.1.17.3 Magnitude

Not assessed

3.1.17.4 Timescale

Not assessed

3.1.17.5 Spatial Issues

Not assessed

3.1.17.6 Displacement

Not assessed

3.1.17.7 Maintenance and Longevity

Not assessed

3.1.17.8 Climate Adaptation or Mitigation

Not assessed

3.1.17.9 Climate factors/constraints

Not assessed

3.1.17.10 Benefits and Trade-offs to Farmer/Land manager

Not assessed

3.1.17.11 Uptake

Not assessed

3.1.17.12 Other Notes

None

3.1.18 Reduced fertiliser use

Bundle: **Restoration, management and enhancement /Cropland**
ETPW-252 - Change to lower-input crop type or variety near sensitive habitats
ECCM-003 - Use improved crop varieties to increase nutrient use efficiency
ECAR-015 - Replace nitrogen fertiliser application by using clover in pasture or arable cropping systems

Overall RAG ratings for action and ecosystem service
ETPW-252 - Change to lower-input crop type or variety near sensitive habitats
AMBER L* maintaining species / wider biodiversity
AMBER TL* presence of rare and priority species
AMBER TL** Enhance or maintain condition of semi-natural habitat

ECCM-003 - Use improved crop varieties to increase nutrient use efficiency
AMBER DTL* maintaining species / wider biodiversity
AMBER DT* presence of rare and priority species

ECAR-015 - Replace nitrogen fertiliser application by using clover in pasture or arable cropping systems
AMBER TL* maintaining species / wider biodiversity
AMBER TDL* presence of rare and priority species
AMBER L** pollination
AMBER L** pest and disease control

3.1.18.1 Causality

RAG ratings by taxa / ecosystem service

- POLLINATORS – **ECAR-015** **AMBER L**** only for maintaining species and pollination service
- PEST AND DISEASE CONTROL - **ECAR-015** only **AMBER L****
- MAMMALS – **ETPW-252** **AMBER L*** for maintaining species.
- PLANTS – **ETPW-252**, **ECCM-033**, **ECAR-015** **AMBER L**** for maintaining species
- ARABLE PLANTS – **ETPW-252** **AMBER L*** for maintaining arable plant richness and **AMBER TL*** for maintaining rare arable plants; **ECCM-003** and **ECAR-015** **AMBER DL*** for maintaining arable plant richness and maintaining rare arable plants (logic chain due to different processes).

There is some evidence that reducing fertiliser use may benefit invertebrates (Gravesen 2008) and plants (e.g. Kleijn & Snoeijing 1997). However, many studies look at the combined effects of reducing fertiliser along with pesticides and / or herbicides (Dicks et al. 2013), making it difficult to separate the effects of reducing different agro-chemicals. General benefits might be expected for biodiversity, from reduced fertiliser run-off increasing plant diversity in adjacent habitats as well as in the field, depending on other management approaches. If conventional fertiliser is replaced with an organic fertiliser, this can have varying effects on pests and their natural enemies, depending on the type of organic fertiliser used (reviewed in Garratt et al. 2011). Where clover is grown in order to reduce fertiliser use (specifically **ECAR-015**), the benefits for flower-visiting and other insects, and pollination services, are likely to be similar to those of cover crops, reviewed for actions **EHAZ-007** and **ECAR-044** above.

There is no specific evidence for the effectiveness for mammals on croplands, but expert opinion suggests a potential positive impact for brown hares (Fisher et al. 2007). Tew et al. (1992) found that wood mice significantly preferred to forage in low input margins compared to standard cropped areas.

By itself, reduced use of nitrogen fertiliser is known to support the maintenance of species-rich arable plant communities (Wilson 1999). However, in the case of using clover cover crops to make up for reduced nitrogen application, such clover cover crops are also known for their ability to suppress the resident arable flora in arable rotations (e.g., McKenna et al. 2018) it thus appears likely that the use of clover cover crops might cancel out any expected benefits from fertiliser application. Furthermore, as the negative effects of nitrogen application on arable plants are due to increased levels of crop competition under high nitrogen availability (Kleijn & van der Voort, 1997), it can be expected that what matters is not the source of plant-available nitrogen, but its availability for plant growth. Similarly, the use of improved crop varieties characterised by high nutrient use efficiency may result in higher rates of nutrient acquisition and conversion into crop growth and might give the planted crop a relative competitive advantage over non-crop arable plants (e.g., Dawson et al. 2011). Hence, reduced fertiliser use in combination with the planting of more nutrient-efficient crop varieties (action **ECCM-003**) or the introduction of nitrogen-fixing clover cover crops into the arable rotation (action **ECAR-015**), will at best produce very limited benefits for arable plants, and at worst might produce disbenefits. In contrast, applying a similar logic chain to the proposed action of a change to lower-input crop type or variety near sensitive habitats to be able to reduce fertiliser inputs, might result in reduced levels of crop competition, all other things being equal, and likely limited benefits to arable plants diversity, and where such species are present, to populations of rare arable plant species.

3.1.18.2 Co-Benefits and Trade-offs

[TOCB Report-3-2 GHG **ECAR-015**] Benefits of reducing fertiliser use include the reduction of loss of N_2O into the atmosphere and reduced run-off, improving water quality. Trade-offs centre around the cost of establishing and maintaining clover / legumes in swards.

3.1.18.3 Magnitude

Not assessed

3.1.18.4 Timescale

Not assessed

3.1.18.5 Spatial Issues

Not assessed

3.1.18.6 Displacement

Not assessed

3.1.18.7 Maintenance and Longevity

Not assessed

3.1.18.8 Climate Adaptation or Mitigation

Not assessed

3.1.18.9 Climate factors/constraints

Not assessed

3.1.18.10 Benefits and Trade-offs to Farmer/Land manager

Not assessed

3.1.18.11 Uptake

Not assessed

3.1.18.12 Other Notes

None

3.1.19 ETPW: Use whole crop cereals

Bundle: **Soil management and protection /Cover cropping**

Overall RAG ratings for action and ecosystem service
AMBER TL** maintaining species / wider biodiversity
AMBER L* presence of rare and priority species

3.1.19.1 Causality

RAG ratings by taxa / ecosystem service

- MAMMALS – **ETPW-259** **AMBER L*** for maintaining species.
- BIRDS – **ETPW-259** **AMBER TL**** for maintaining species.
- ARABLE PLANTS – **ETPW-259** **GREEN*** for maintaining arable plant richness and maintaining rare arable plants.

There is no specific evidence for the effectiveness for mammals on croplands. Expert opinion suggests a potential positive impact for brown hares of increased habitat heterogeneity (Fisher et al. 2007). However, Tew & Macdonald (1993) found high predation of wood mice after standard crop harvesting, and a rapid 80% decrease in population, due to loss of cover and increased predation, and this would likely also apply to whole crop cereal harvesting.

For farmland birds, evidence for benefits of whole crop cereals are currently very limited due to a lack of studies. Peach et al. (2011) reported higher activity of a variety of species (including priority skylarks) on whole crop cereal silage than on grass or maize silage, including in summer and on winter stubbles. Granivores were the most abundant group of birds. However, Peach et al. (2011) noted that the timing or harvest was likely to destroy the nests of priority species, such as corn bunting, but this could be alleviated by delaying harvesting until August.

As whole crop cereal involves the leaving of overwinter stubble, it can potentially produce benefits for late flowering arable species in general and for some late-flowering rare arable plant species where such species are present (Albrecht et al. 2016).

3.1.19.2 Co-Benefits and Trade-offs

Not assessed

3.1.19.3 Magnitude

Skylarks were approximately 6-7 times more likely to use whole crop barley than wheat, maize or grass silage, and buntings (e.g. yellowhammer, corn bunting) were approximately four time more likely to use barley than the other crops. (Peach et al. 2011).

3.1.19.4 Timescale

Not assessed

3.1.19.5 Spatial Issues

Not assessed

3.1.19.6 Displacement

Not assessed

3.1.19.7 Maintenance and Longevity

Peach et al. (2011) recommended delayed harvesting after 1st August and selective herbicide use to maximise benefits for farmland birds.

3.1.19.8 Climate Adaptation or Mitigation

Not assessed

3.1.19.9 Climate factors/constraints

Not assessed

3.1.19.10 Benefits and Trade-offs to Farmer/Land manager

Not assessed

3.1.19.11 Uptake

Not assessed

3.1.19.12 Other Notes

None

3.1.20 Soil surface structure

Bundle: **Soil management and protection /Tillage**

ECPW-239 – Cultivate to create rough soil surface on bare land/stubble fields uncropped over winter
EHAZ-018 - Leave autumn seedbeds rough (instead of finely tilled seedbeds)

Overall RAG ratings for action and ecosystem service (see also Cropland IA spreadsheet
AMBER L** maintaining species / wider biodiversity

3.1.20.1 Causality

RAG ratings by taxa / ecosystem service

- BIRDS – **ECPW-239 AMBER L**** for maintaining species.

Moorcroft et al. (2002) showed that larger areas of bare soil within stubbles were beneficial for overwintering farmland birds, including priority linnet, corn bunting, yellowhammer and reed bunting, probably due to greater access to seeds. Bare soil and seed abundance was greater on barley than on wheat stubbles. Bare earth ranged from 5-69% of the area of the sample stubbles. There was a negative association between area of bare soil and the presence of undesirable woodpigeons. Henderson et al. (2004) found a negligible benefit of bare soil compare to other actions for wintering farmland birds, especially in relation to wild bird cover crops.

3.1.20.2 Co-Benefits and Trade-offs

Not assessed

3.1.20.3 Magnitude

The average percentage occupancy of a field by corn buntings increased approximately six-fold as bare soil increased from 40-70% cover, with little occupancy below 40% bare soil. For linnets, yellowhammers and reed buntings, the percentage occupancy increased (on average) steadily up to six or seven-fold as bare soil area increased from 5-70% (Moorcroft et al. 2002).

3.1.20.4 Timescale

Not assessed

3.1.20.5 Spatial Issues

Not assessed

3.1.20.6 Displacement

Not assessed

3.1.20.7 Maintenance and Longevity

Not assessed

3.1.20.8 Climate Adaptation or Mitigation

Not assessed

3.1.20.9 Climate factors/constraints

Not assessed

3.1.20.10 Benefits and Trade-offs to Farmer/Land manager

Not assessed

3.1.20.11 Uptake

Not assessed

3.1.20.12 Other Notes

None

3.1.21 Lowland agricultural and farmed peatland management

Bundle: Actions for habitats with specific hydrological characteristics/Peatlands and wetlands

EHAZ-134 Restrict deep ploughing on agricultural lowland peatland
ECCM-037 Restrict root crops in agricultural peatlands
ECCM-035 Use no-till cultivation on agricultural lowland peatland
ECCM-030 Raise water levels in areas of farmed peatland and adapt farming systems accordingly
ECCM-038 Raise water levels in areas of farmed peatland and adapt farming systems accordingly
Duplicate of **ECCM-030** above, scored together

Overall RAG ratings for action and ecosystem service

EHAZ-134 Restrict deep ploughing on agricultural lowland peatland
ECCM-037 Restrict root crops in agricultural peatlands

AMBER TL* wider biodiversity / maintaining species

ECCM-035 Use no-till cultivation on agricultural lowland peatland

AMBER TDL* wider biodiversity / maintaining species

ECCM-030 Raise water levels in areas of farmed peatland and adapt farming systems accordingly
ECCM-038 Raise water levels in areas of farmed peatland and adapt farming systems accordingly
Duplicate of **ECCM-030** above

AMBER TL* wider biodiversity / maintaining species
AMBER TL* rare or priority species

3.1.21.1 Causality

In 2013, it was estimated there were about 325,000 ha of remaining deep lowland peat soils (> 0.4m depth) that were formed under waterlogged conditions in fens and raised bogs (Graves and Morris, 2013). These agricultural lowland peatland habitats are degraded by intensive arable or horticultural production.

Lowland peat habitats have the potential to support both wider biodiversity and conservation priority species. For example, the decline and range contraction of the Large Heath butterfly (endangered; Fox and Dennis, 2021) has been largely attributed to the drainage of lowland peat bogs for agriculture (Bourn and Warren, 1997). Raising water levels (**ECCM-030** and **ECCM-038**) is likely to benefit both wider biodiversity and priority / rare species, including wintering wildfowl and breeding waders (Morris et al. 2010). Benefits to biodiversity are likely to be context specific, for example while rare waders may be benefitted, it is possible that skylarks may not.

The raising of water levels according to action **ECCM-038** might benefit specialist plant species of peats and groundwater gleys whose habitat preferences include both arable land and the drawdown zone around waterbodies. However, arable plant species typically growing on freely drained sands and silts might be disadvantaged by such wetter conditions.

The other three actions in this group relate to reduced disturbance to peatland soils, in the context of climate change. For biodiversity, no-till cultivation (**ECCM-035**) has been reviewed above under **ETPW-092**.

As above, this is likely to have beneficial effects on earthworms, but for wider biodiversity no-tillage may have disbenefits. Minimum tillage is likely to be beneficial to wider biodiversity.

Restricted ploughing and root crops may also benefit soil macrofauna. However, no published evidence was relating biodiversity to restricting ploughing and root crops specifically in agricultural lowland peatland, so the magnitude of any benefit is uncertain.

3.1.21.2 Co-Benefits and Trade-offs

Fenland peatland was found to have reduced soil carbon loss when managed under conservation grassland or with raised water levels, compared to intensive arable production (Graves and Morris, 2013).

[TOCB Report3-5B Grassland **ECCM-038**] Avoidance of GHG emissions from drained peatland. Water quality. Flood risk management.

[TOCB Report-3-6 Carbon **ECCM-035**] There is little research focusing specifically on the impact of no till on net carbon sequestration in agricultural lowland peatland. However, logic chains suggest that minimising disturbance on exposed peat would reduce losses of soil organic carbon to erosion. Taft et al. (2018) found that tillage practices had minor or non-significant impacts on soil carbon emissions or cumulative GHG emissions in drained and cultivated fens in East Anglia, but manipulations were carried out at the mesocosm scale, and would not account for losses to erosion (notably wind erosion) or carbon footprint of mechanised tillage. More generally, a DEFRA commissioned report found that improvements in soil organic carbon from zero or minimum till were small in magnitude, although potentially important at the national scale (Bhogal et al., 2008). For a more detailed review of the impact of tillage practices on soil carbon see section 3.12.4.1 of the carbon sequestration review.

Global, regional & local climate regulation	Above ground carbon sequestration	N
	Below ground carbon sequestration	L*

[TOCB Report-3-6 Carbon **EHAZ-134**] There is little research focusing specifically on the impact of ploughing on net carbon sequestration in agricultural lowland peatland. However, logic chains suggest that minimising disturbance on exposed peat would reduce losses of soil organic carbon to erosion. Taft et al. (2018) found that tillage practices had minor or non-significant impacts on soil carbon emissions or cumulative GHG emissions in drained and cultivated fens in East Anglia, but manipulations were carried out at the mesocosm scale, and would not account for losses to erosion (notably wind erosion) or carbon footprint of mechanised tillage. More generally, a DEFRA commissioned report found that improvements in soil organic carbon from zero or minimum till were small in magnitude, although potentially important at the national scale (Bhogal et al., 2008). Similar results would be expected for ploughing.

Global, regional & local climate regulation	Above ground carbon sequestration	N
	Below ground carbon sequestration	L*

[TOCB Report-3-6 Carbon **ECCM-037**] Expert opinion has identified the use of root crops in agricultural peatlands as an issue of concern for soil carbon, however there is little data about the rate of soil erosion due to the harvesting of root crops in the UK relative to other arable crops. Rates of soil erosion during harvesting have been identified as the largest source of soil erosion associated with sugar beet, but rates of loss vary over an order of magnitude across studies from different European countries (3.5 t ha-1 harvest -1 to 15 t ha-1 harvest -1), and no data are reported for England (Owens et al., 2006). It has been estimated that 2 t ha-1 yr-1 of soil are eroded per year during the harvest of sugar beet and potatoes (Owens et al., 2006). As a result it is logical to assume that minimising soil losses from areas with a high concentration of soil carbon would be reduce losses to erosion. If land is subsequently removed from cultivation, benefits would potentially be larger. This is covered in other sections of the carbon review.

Global, regional & local climate regulation	Above ground carbon sequestration	N
	Below ground carbon sequestration	L*

3.1.21.3 Magnitude

Not assessed

3.1.21.4 Timescale

Not assessed

3.1.21.5 Spatial Issues

Not assessed

3.1.21.6 Displacement

Not assessed

3.1.21.7 Maintenance and Longevity

Not assessed

3.1.21.8 Climate Adaptation or Mitigation

Not assessed

3.1.21.9 Climate factors/constraints

Not assessed

3.1.21.10 Benefits and Trade-offs to Farmer/Land manager

Not assessed

3.1.21.11 Uptake

Not assessed

3.1.21.12 Other Notes

None

4 KEY ACTION GAPS

Three additional actions were added by the Cropland review team:

Arable01	Extended stubble - unharvested crop stubble followed by a one-year fallow
Arable02	Unvegetated, ploughed fallow (natural regeneration) for one year
Arable03	Annually cultivate headlands and leave unsown

These three actions were included in the Cropland evidence review above, and scored for effects on biodiversity as the other actions were. Based on previous Defra-funded research, all three actions are likely to have moderate to strong benefits for rare arable plants and wider biodiversity within cropland agriculture, and to have some benefits for pollinating insects and pollination, and farmland birds.

The other management that is likely to have a benefit for wider biodiversity is leaving arable land fallow for a longer period, e.g. 3-5 years. There is strong evidence this can benefit a range of taxa. However, bringing land back into production after this extended period can be difficult, due to the build-up of undesirable species Pywell et al. 2017). This was not included as a separate action in the review.

5 EVIDENCE GAPS

Many substantial evidence gaps have been identified during this review of actions for Cropland biodiversity. Some of these apparent evidence gaps relate to differences in the specificity of the Defra outcome indicator / ecosystem service. The indicator for pest and disease control is defined as 'Evidence of outbreaks of pests and disease'. Within open arable systems there is very little evidence that integrated pest control (IPM), and actions relating to IPM, will reduce pest populations. As a result, this outcome was scored a maximum of Amber L***. There is substantial evidence that some actions lead to an increase in the abundance or populations of natural predators or parasitoids. In contrast, the pollination service outcome is defined as the proxy of the abundance and richness of pollinating insects, for which there is a relatively strong evidence base. The difference in the indicators for pest and disease control vs. pollination are discussed in the Introduction to the Cropland review above.

The other biodiversity outcome / indicator with very little empirical evidence for Cropland biodiversity is 'Biodiversity adaptation - maintaining / enhancing biodiversity under a changing climate Biodiversity adaptation - maintaining / enhancing biodiversity under a changing climate'. While evidence does exist that some actions (or habitats managed under proposed actions) contribute to daily movements of mobile taxa (e.g. hedgerows used by bats, small mammals and moths), there is very little empirical evidence that AES management will help to maintain or enhance biodiversity (specifically populations of plants and animals) under a changing climate. The lack of empirical evidence makes any assessment of the magnitude of action benefits for biodiversity under climate change difficult. Most actions which might contribute to maintaining biodiversity under a changing climate scored a maximum of Amber L*, due to the lack of empirical evidence.

There was little empirical evidence for specific actions or groups of actions. Surprisingly, the effects on wider biodiversity of reducing fertiliser use on its own has not received much study, with more evidence for reduced input farming more widely, i.e. reducing herbicide or pesticide use in addition to reduced fertiliser use. In other cases, the evidence of reduced inputs was complicated by being wrapped up in wider comparisons between organic and conventional farming systems. This made it challenging to assess the effects of reduced fertiliser use on above-ground biodiversity.

Some of the more specific actions did not have a substantial empirical evidence base, against which to assess effects on biodiversity. For example, little evidence was found for the biodiversity impacts of reduced ploughing specifically on lowland agricultural soils. This and other specific evidence gaps are flagged up within the Cropland review text.

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