Natural England Commissioned Report NECR102

Ecosystem services from Environmental Stewardship that benefit agricultural production

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Foreword

Natural England commission a range of reports from external contractors to provide evidence and advice to assist us in delivering our duties. The views in this report are those of the authors and do not necessarily represent those of Natural England.

Background

Ecosystem services are defined as the benefits society gets from the natural environment. These include cultural services such as the conservation of biodiversity and people's enjoyment of the countryside, regulating services, such as flood protection, clean air and water and provisioning services such as the production of food, timber and other resources. Many of these services are provided by agricultural land. Farmers are rewarded for the provisioning services by the market, but Environmental Stewardship (ES) is a major source of funding that helps farmers maintain and enhance the cultural and regulatory services that their land provides.

The Natural Environment White Paper identified the need to increase food production whilst protecting, enhancing and linking biodiversity and landscapes. To meet this challenge, land managers need to have a better understanding of the complex relationships between the different ecosystem services that farmland can potentially provide. This research was commissioned to identify the ecosystem services which ES (the main agri-environment scheme in England) helps to provide that can:

- Identify the ecosystem services provided by ES that have associated crop production benefits.
- Describe the relationships between ES options and ecosystem services.
- Assess ES options for their contribution to key ecosystem services.
- Map the provision of these services through ES.

The research has confirmed that some of the options under the scheme provide ecosystem services which are important for agricultural production and for retaining a productive capacity. The report does not have all the answers and more research is required into quantifying the ecosystem services provided by Environmental Stewardship and optimising the benefits these services provide to agriculture.

Evidence produced by this project will be disseminated to land managers, farmers and others through various routes, including the production of a Technical Information Note.

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Natural England Project Manager - Mike Green, Natural England, Mail Hub Block B, Whittington Road, Worcester, WR5 2LQ **mike.green@naturalengland.org.uk**

Contractor - Nigel Boatman, Food and Environment Research Agency (FERA), **nigel.boatman@fera.gsi.gov.uk**

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Further information

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SUMMARY

- This report contains a review of the ecosystem services provided by Environmental Stewardship (ES), the main agri-environmental scheme in England. It is particularly concerned with those that are of benefit to agricultural (especially crop) production, thus supporting the Defra departmental priority of supporting British farming and encouraging sustainable food production.
- Ecosystem services can be described as the full range of benefits that people and societies obtain from biological systems, including provisioning, regulating, cultural and supporting services.
- The report identifies ecosystem services associated with crop production benefits that can be provided by ES, describes the relationships between ES options and ecosystem services, scores options for their contribution to key ecosystem services and maps the provision of these services through ES across England.
- Key ecosystem services considered include soil formation, nutrient cycling, carbon sequestration, water regulation and purification, genetic resources, pest regulation and pollination.

SOIL FORMATION, NUTRIENT CYCLING, CARBON SEQUESTRATION, WATER REGULATION AND PURIFICATION

- These services are considered together because of the close relationships between them. As the growing medium for crops and grass, soil is fundamental to agricultural production, as are the nutrients therein. Nutrient cycling, carbon sequestration, water regulation and water purification are all reliant on soil, and there are complex interactions between the different services that provide for, and/or are affected by, agricultural production
- The primary requirement for provision of these services is to maintain the soil in terms of both its quantity and its health/structure by maintaining organic matter content, avoiding compaction and preventing loss through erosion.
- Little research has been done on the effects of Environmental Stewardship options *per se*, but much can be inferred from work on similar types of management. The greatest benefits is likely to be achieved from a selection of strategically located ES options in conjunction with a robustly drawn up and implemented Soil Protection Review, along with required management for Nitrate Vulnerable Zones where applicable.
- Key options are those for winter cover crops, arable reversion, grassland creation, seasonal livestock removal from grassland, especially next to watercourses, maintaining traditional orchards, protecting archaeology under cultivated soils, buffer strips and field corners, nectar mixtures, management of intensive grassland and maize to reduce erosion, and bracken control. Organic farming benefits soil organic matter and the payment for organic production provides support for this.
- Most options that benefit soil, water and nutrient cycling on arable land involve taking land out of cropping, hence the benefits are only available to agriculture if the land is returned to cropping in the future. Exceptions are management of maize crops to reduce erosion, winter cover crops and protecting archaeological features through reduced tillage or direct drilling.
- Taking land out of production or converting to grassland also benefits soil macrofauna including organisms responsible for decomposition, which improves

soil organic matter contents. Options involving the sowing of legumes (e.g. nectar mixtures) increase soil nitrogen and organic matter contents and stimulate the soil biota.

- Location of options can be crucial and only specific field-by-field assessments will realise the full potential of the options. A whole farm approach is needed, with ecosystem service provision considered at a landscape scale.

GENETIC RESOURCES

- Sources of genetic material for use in breeding improved types of plants and animals for agricultural purposes can arise from two main sources: (i) existing traditional varieties or breeds, or (ii) wild relatives of cultivated or domesticated forms.
- Traditional crop varieties are maintained in gene banks, for minority uses such as thatching, and by specialist professional or amateur growers etc. Some farms keep traditional breeds of livestock, either as a tourist attraction or for specific qualities, and their conservation is encouraged by the Rare Breeds Survival Trust.
- There are over 300 taxa that are wild relatives of UK crops, potentially forming a source of genetic diversity for use in plant breeding. Some of these are rare. Conservation ideally takes place in situ, but ex situ measures such as germplasm collections can also be used. It is important to conserve genetic diversity within species as well as the species itself.
- Key options include those for traditional orchards, species-rich grassland and upland meadows, coastal saltmarsh and the native breeds at risk grazing supplement.

PEST REGULATION

- Regulation of pest species by natural enemies can be encouraged through the provision of appropriate habitats and resources, and by reduction in pesticide-induced mortality of natural enemies.
- Resources required by natural enemies include pollen and nectar, shelter habitats, alternative prey (when pests are not available), and an appropriately structured environment. These resources can be provided by a number of options under Environmental Stewardship, especially those for hedgerows and banks, buffer strips on cultivated land (especially if floristically enhanced), wild bird and nectar mixtures, undersown spring cereals and enhanced stubbles, beetle banks, low input and species-rich grasslands and upland meadows.
- There is good evidence that these options contain natural enemies, generally at higher densities and diversities than in the crop, but studies of the impacts of ES options on natural enemy densities in crops or effects on pest levels are few. No studies were found that investigated effects of ES options on crop yields or damage, probably because most options are designed for other purposes. However, there are numerous studies across the world in a range of cropping systems that link habitat creation to improved pest control.
- Farmers are aware of the benefits of encouraging biological control and survey data indicate that it is an important reason for establishing grass or wildflower margins around arable fields. Nevertheless, more information on how to achieve the best impacts is required.

- It is suggested that a 'bundle' of options comprising hedgerow or ditch management, buffer strips, beetle banks and one or more options providing floral resources (nectar mix, conservation headland, uncropped wildlife strip, wild bird seed mix including nectar-bearing plants, wild flower margin) would maximise the potential for encouraging natural enemies of pests.

POLLINATION

- Pollination by insects is important for many crops to promote seed set and fulfil yield potential. In Britain and the rest of Europe, insect pollinators contribute to the production of over 80% of crop species; these include oilseed rape, field beans, orchard fruit (e.g. apple, pear, plum etc.) and soft fruit (e.g. strawberry, raspberry, blackcurrants etc.). Estimates of the economic value of pollination services to UK agriculture range from £186m-567m/annum.
- Bees (including honey, bumble and solitary bees) are the most widely studied pollinators but other groups that also contribute include hoverflies, thrips, beetles, Lepidoptera and other Hymenoptera. Maintenance of bee populations requires the presence of nectar and pollen-producing flowers throughout the flying season, including (for bumble bees) perennial species, suitable nesting habitat (for wild bees), and adequate connectivity of habitats within the landscape. Other pollinators, such as hoverflies, have a wider range of habitat requirements.
- ES options with the potential to provide suitable habitat and resources include hedgerow and ditch management (especially enhanced management), floristically enhanced buffer strips, uncropped cultivated margins and conservation headlands, nectar and wild bird seed mixtures, species-rich grassland and other grassland options that result in flower-rich swards. Organic management favours pollinators such as bumble bees because they depend heavily on rotations involving legumes such as clover. Organic farms area also more likely to contain unimproved grassland, which is ideal habitat for pollinators. Payments for organic management help to maintain the competitiveness of organic farming.
- A bundle of options should include undisturbed ground for nesting cover, in hedge bases, ditch banks, buffer strips and/or beetle banks, a source of early pollen and nectar, such as hedges with early flowering shrubs and trees or traditionally managed orchards, and habitats that provide floral resources throughout the rest of the season, such as nectar mixtures, florally enhanced margins, and species-rich meadows.

OPTION SCORING AND MAPPING

- ES options were scored on a 0-3 scale for each of the key services or groups of services identified. Because direct evidence of the value of ES options for agriculture is not usually available, benefits were inferred based on their known or probable contribution to the relevant ecosystem services.
- The resulting scores were used to construct maps of each type of ecosystem service delivery by ES options in England at a $5km^2$ scale, based on the amount of each option within each agreement multiplied by the score for that option. Options were quantified by monetary value to avoid the problem of different units
- For all ecosystem services mapped, there appeared to be an association between levels of the services and arable and dairy farming. This reflects the types of options that contribute to provision of these services, which tend to be associated with more intensive lowland agriculture.

- As pressure on soils, nutrient cycles and water is greatest in areas of intensive land use, it is appropriate that associated ecosystem service delivery is greatest in these areas. Pest regulation and pollination are most relevant for arable and horticultural producers. The maps indicate that service delivery in some areas important for these sectors is low, suggesting that improved targeting of options could be beneficial. This could include the promotion of 'option bundles' to enhance delivery of specific services where appropriate.
- Due to the widespread and often very local distribution of crop wild relatives, geographical approaches to targeting for genetic conservation are less easy to apply at the regional scale, with the exception of traditional orchards, which are clustered in certain areas where targeting could be applied.

CONCLUSION

- Environmental Stewardship has the potential to enhance a range of ecosystem services of benefit to agricultural production, though relatively few options have been designed specifically with this purpose in mind. Exceptions are options to reduce soil erosion, nectar mixtures targeted at the enhancement of pollination services, and beetle banks (specifically designed to benefit natural enemies of pests and so enhance pest regulation). Many other options also contribute to these services, with multifunctionality frequently exhibited.
- There is scope for further development of options to extend the provision of ecosystem services. In particular, the availability of a wider range of options to provide floral resources for pollinators and pest predators (e.g. hoverflies) and parasitoids in entry level schemes, such as wild flower field margins, would be beneficial. There are no options designed to benefit wild crop relatives and this is an area much in need of further research. In contrast, there has been considerable development in recent years in terms of option provision to protect soils and reduce diffuse pollution of water.
- Although there is a large body of research evidence to show benefits in terms of ecosystem service delivery from ES options or similar management approaches, quantitative evidence of benefits is generally lacking. Further research is required to investigate the impact of ES, ideally at a range of scales, on ecosystem services of direct benefit to agricultural production. This should build on existing work to fill knowledge gaps and provide a more comprehensive understanding of what can be achieved. In particular, research on impacts at a landscape level, and the optimal location and arrangement of options within the landscape, should be a priority.

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The report team were:
FERA
Project Co-ordinator: Nigel Boatman
Carmel Ramwell
Gay Marris
Theo Alnutt

GWCT
John Holland

LIST OF ACRONYMS

Abbreviation	Full title
AES	Agri Environment Scheme
CBC	Conservation Biological Control
CEH	Centre for Ecology and Hydrology
CSS	Countryside Stewardship Scheme
CWR	Crop Wild Relative
DEFRA	Department for Environment, Food and Rural Affairs
ELS	Entry Level Stewardship
ES	Environmental Stewardship
ESA	Environmentally Sensitive Area
ESRC	Economic and Social Research Council
FEG	Floristically Enhanced Grass
GAEC	GAEC Good Agricultural and Environmental Condition
GDP	Gross Domestic Product
GWCT	Game and Wildlife Conservation Trust
HLS	Higher Level Stewardship
IPM	Integrated Pest Management
LUC	Land Use Consultants
MEA	Millennium Ecosystem Assessment
NCA	National Character Area
NERC	Natural Environment Research Council
NE	Natural England
NEA	National Ecosystem Assessment
NGO	Non Governmental Organisation
NVZ	Nitrate Vulnerable Zone
OELS	Organic Entry Level Stewardship
SAFFIE	Sustainable Arable Farming For an Improved Environment
SOM	Soil Organic Matter

Contents

1 INTRODUCTION

1.1 BACKGROUND

This report is concerned with the ecosystem services provided by Environmental Stewardship (ES), the main agri-environmental scheme in England, and particularly those that are of benefit to agricultural production. This complements the review sections of project RP0025 which was concerned with valuing the wildlife and landscape benefits of Environmental Stewardship, though valuation of the ecosystem services considered here is beyond the scope of this project. Supporting and developing British farming, and encouraging sustainable food production, is one of the three departmental priorities laid down in Defra's Structural Reform Plan, along with helping to enhance the environment and biodiversity to improve quality of life, and supporting a strong and sustainable green economy, resilient to climate change.

Environmental Stewardship is primarily concerned with the second of these priorities, aiming to achieve public benefits such as biodiversity conservation, public access, landscape protection etc. on farmland, but also contributes to the first and third priorities. With respect to the first, the management supported by the ES can also provide benefits for the farm business itself and to agricultural production, whilst many of the options will also contribute to climate change adaptation and mitigation.

The challenges of maintaining a sustainable level of food production sufficient to feed a growing human population have been the subject of several recent reports (e.g. Royal Society, 2009; Paillard, 2010; Foresight, 2011) In his forward to the latest of these, Professor Sir John Beddington says "The case for urgent action in the global food system is now compelling" (Foresight, 2011). However, in setting out the case for addressing this issue, the report emphasises that balancing future demand and supply must be achieved sustainably, whilst managing the contribution of the food system to the mitigation of climate change and maintaining biodiversity and ecosystem services. This is a global challenge, and the contexts and appropriate responses will vary in different parts of the world. In some areas 'land sparing' will be a key issue, to avoid further conversion of natural habitats such as rain forest to food production, but in the UK and the EU, the main emphasis is on developing sustainable production methods that will enable the retention and, if possible, enhancement, of biodiversity and ecosystem services on existing farmland, whilst at the same time maintaining or increasing production. Thus management approaches that contribute towards both productivity and environmental objectives are of particular importance for the achievement of current policy goals.

This report aims to:

- identify ecosystem services of benefit to agriculture, especially crop production, that may be enhanced by ES options;
- assemble the evidence for such benefits in relation to farming systems;
- consider interactions between services at a landscape scale and where possible; and
- quantify the relationship between ES and ecosystem services that support agricultural production.

1.1.1 Environmental Stewardship

Environmental Stewardship (ES) is the government's flagship agri-environment scheme for England, administered by Natural England, to provide farmers and land managers with support for managing their land in an environmentally sensitive manner. The scheme is voluntary but the payments offered are intended to cover any 'income foregone' from the loss of productive land and associated management costs in implementing the management options identified in the agreement. Launched in 2005, ES replaced the former Countryside Stewardship Scheme (CSS) and Environmentally Sensitive Areas as the agri-environment scheme for England (Natural England, 2009). It has three strands. Entry Level Stewardship (ELS) is designed to provide a basic ('broad and shallow') level of environmental benefits above those supplied by SPS cross-compliance measures. It is open to all farmers and land managers, who have a free choice from a menu of options, each of which is allocated a number of 'points'. Entry is achieved by reaching a points threshold, and payments are at a standard rate per hectare. Organic Entry Level Stewardship (OELS) provides an equivalent for farmers registered with an organic inspection body. Higher Level Stewardship (HLS) is more similar to the old CSS and provides for a higher level of environmental management on land of greater environmental value. Entry is targeted and award of agreements is dependent on submission of an appropriate application (in conjunction with Natural England advisers) including options that address local targets, which are pre-defined at National Character Area (NCA) level. In contrast to ELS, each HLS option has a separate payment associated with it.

The primary objectives of ES are concerned with wildlife conservation, landscape quality and character, protection of the historic environment, resource protection and promotion of access. There are also secondary objectives concerned with flood protection and conservation of genetic resources. In meeting these objectives, ES also contributes to supporting the adaptation of the natural environment to climate change and to climate change mitigation.

1.1.2 Ecosystem Services

Ecosystem services can be described as the full range of benefits that people and societies obtain from biological systems. The importance of ecological processes to human wellbeing is now widely recognised by both scientists and policymakers. The Millennium Ecosystem Assessment (MEA) (2005) provides four categories that are intended to encompass the range of possible services, although it is acknowledged that there is considerable scope for overlap between them (

Table 1.1). These categories have been widely adopted in subsequent studies that attempt the valuation of biological resources.

- **Provisioning services** are the products obtained from ecosystems and include food, fibre, and fuel. They might also include niche products with higher values, such as pharmaceuticals, biochemicals, genetic resources, and ornamental items.
- **Regulating services** are processes that maintain vital resources. Examples include air quality and climate regulation, protection against soil erosion and extreme weather, control of human diseases and agricultural pests, and crop pollination.
- **Cultural services** are non-material benefits, such as cultural diversity, religious importance, educational values, aesthetic appeal, artistic inspiration, historical importance, recreation, and tourism.
- **Supporting services** are distinguished from provisioning or regulating services by their indirect nature and the long time scales over which benefits are obtained. Soil formation, photosynthesis, and nutrient and water cycling are examples of supporting services.

Table 1.1 Summary of ecosystem services identified in the Millennium Ecosystem Assessment

Provisioning services (products from ecosystems)	**Regulating services (benefits from regulation of ecosystem processes)**	**Cultural services (non-material benefits)**
Food	Climate regulation	Spiritual and religious
Fresh water	Pest & Disease regulation	Recreation and ecotourism
Fuel	Water regulation	Aesthetic
Fibre	Water purification	Inspirational
Biochemicals	Pollination	Educational
Genetic resources		Sense of place
		Cultural heritage
Supporting services (necessary for all others)		
Soil formation	Nutrient cycling	Primary production

Other variants of this classification have been used in different studies, some of which include additional services such as photosynthesis, bioremediation of waste, provision of habitat etc. A summary of ecosystem services considered by recent policy statements and UK-based research is provided in the Annex to Appendix 1 of LUC (2009). The MEA classification is the most widely used and provides the basis for analysis in this report.

The UK National Ecosystem Assessment (NEA)[1] has been running since 2009 and was completed in June 2011. It was proposed following the House of Commons Environmental Audit in 2007 and was commissioned by Defra, the devolved administrations, the Natural Environment Research Council (NERC), and the Economic and Social Research Council (ESRC). It is being conducted by a consortium of government, academic, NGO, and private sector institutions and is coordinated by an independent secretariat provided by the United Nations Environment Programme World Conservation Monitoring Centre (UNEP-WCMC). The project aims to assess the status and trends of ecosystem services in the UK, to identify the drivers of change in those services, to provide plausible future scenarios, and to suggest response options. Key findings for enclosed farmland are summarised in Box 1.

[1] http://uknea.unep-wcmc.org/ (Accessed 26 January 2011)

Box 1. Key findings from the National Ecosystem Assessment relating to enclosed farmland

Enclosed farmland contributes 6 per cent of GDP and 73 per cent of indigenous food (and 60% of all food). Arable land accounts for 19 per cent of the land area of the UK, mostly in eastern England. Improved grassland accounts for a further 21 per cent, the majority in the west. Overall, wheat, milk, and meat yields have increased and the area of land under cultivation has risen since the Second World War. The growth in these provisioning services has not been without costs to other services including regulating services, such as carbon sequestration by peat soils and water purification, and may also have reduced the capacity of agricultural systems to function sustainably in the long term, particularly through impacts on soil structure and function.

1.1.3 Ecosystem services and Environmental Stewardship

Although the objectives of Environmental Stewardship are not couched in terms of ecosystem services, the benefits accruing from the scheme clearly enhance a range of these services. However, few studies to date have attempted to quantify the impact of ES on ecosystem service provision.

Land Use Consultants (LUC) (2009) carried out a study of the provision of ecosystem services through Environmental Stewardship, in which they identified potential positive and negative impacts of ELS and HLS options on ecosystem services (as defined under the Millennium Ecosystem Assessment Framework), and scored the level of impact, using a score of 1 or 2, indicating low or high impact respectively. They also indicated whether the impact was expected to be location specific and the degree of confidence in the impact score (again on a 1, 2 scale). The assessment appears to be based largely on information provided in the scheme handbooks, combined with the knowledge of the authors, with only limited reference to the wider scientific literature. This study has been used as a starting point for more detailed consideration of the link between services provided by ES and agricultural production (see below).

1.2 OBJECTIVES

The objectives of the study were:

- To identify ecosystem services associated with crop production benefits that can be provided or enhanced by Environmental Stewardship and the relevant ES options, building on those identified in the project specification.
- To describe and document the relationships between ES options, services and benefits to agricultural production based on the scientific literature, case studies and ongoing research.
- To allocate the services identified to farm production systems and describe the relationship between them, plus any interactions that may result when considered in a landscape scale.
- Describe as far as possible how ES options could be deployed to maximise ecosystem service benefits.
- Identify and review research that quantifies the relationship between ES option and services that support agricultural production, as far as possible based on the information available.

- To map ecosystem service provision by ES that is of relevance to agricultural production.

1.3 APPROACH

The key ecosystem services that are considered to be of benefit to agriculture are identified in Chapter 2 below, along with the associated Environmental Stewardship options. Each main service is then treated separately in succeeding chapters, including the following elements, depending on the amount and nature of the evidence available in each case).

- Introduction; importance of the service to agriculture.
- Key requirements for service provision (e.g. for natural enemies of pests and pollinators, what habitats/resources do they need to complete their life cycle).
- Relevant options or option groups.
- Evidence for provision of services by options/option groups.
- Quantitative evidence for benefits (where this exists) and marginal impact of ES options on service provision (if it exists). ES options are ranked in terms of their impact on a 0-3 scale (0=no impact, 1=low, 2=medium, 3=high).
- Economic valuation of benefits (where this exists).
- Provision in the landscape (covering importance of spatial location, amount of option and spatial relationships between different options (e.g. nesting and feeing habitats), where relevant evidence exists).

The services are then mapped on the basis of the distribution of ES options at a 5 km^2 scale.

2 KEY ECOSYSTEM SERVICES THAT BENEFIT AGRICULTURE AND RELEVANT ENVIRONMENTAL STEWARDSHIP OPTIONS

2.1 ECOSYSTEM SERVICES OF BENEFIT TO AGRICULTURAL PRODUCTION

This section aims to define which ecosystem services are linked to agricultural production, and how they might benefit from ES agreements. The classification derived from the MEA provides a useful starting point, but any attempt at conceptualising the benefits that ecosystems provide to humans requires drastic simplification of the many underlying processes that are highly inter-related. The MEA uses the term 'soil formation' as the identifier of the importance of soil in ecosystems, identifying nutrient cycling and primary production as separate supporting services, although these latter services are wholly dependent on soil being present in the first place. In the UKNEA, soil formation (and nutrient cycling, decomposition, weathering and others) have been identified as ecosystem *processes*, or intermediate services, highlighting the difficulties in separating and classifying the relevant services. In this study, the service 'soil formation' is considered in the 'spirit' of the MEA to include improvement of soil fertility, and the benefit to humans is deemed to be the presence of the soil, and all it contains, rather than simply the initial formation of the soil. The complexity of the interactions between ecosystem services means that it is difficult to consider one without considering the impacts on other related services. Accordingly, it is convenient to consider some services together, as management that influences one will also influence the others. These interactions are explored in the text that follows.

2.1.1 Supporting and provisioning services

Primary production, soil formation and nutrient cycling are clearly key to agricultural production, the products of which are food, fuel, fibre and biochemicals. Environmental Stewardship options generally involve either taking land out of production or modifying the production system to enhance environmental benefits, thus reducing production. Indeed, payments to farmers for their participation in the scheme are calculated on the basis of ‘profit foregone’ as a result of taking up the options concerned. Thus, although ES options may enhance overall primary production in some cases (e.g. of woodland or hedgerows), they do not generally increase agricultural production. However, they may help to reduce costs of production by reducing use of inputs such as diesel or fertiliser on less productive areas of land.

LUC (2009) note that there may be benefits for food quality, production of traditional foods through the use of traditional breeds and conservation of traditional orchards, and the enhanced production of wild foods such as bilberries, blackberries, wild fungi etc, plus increased yields of honey. In the case of wild foods, there would only be a benefit to humans if the increase were harvested for consumption. The reduction of agricultural intensity may enable the recovery of elements of the system, such as soils, which have been damaged by intensive agricultural usage. This may enable better function for agriculture should these areas be brought back into more intensive agriculture, following an AE scheme.

The benefits arising from such strategic and/or long-term adaptations are not necessarily accrued by the farmer implementing the relevant option(s), but farmers downstream from the place of implementation may be the recipient of any benefits. In this report, options that may give rise to strategic benefits, (such as soil improvement due to a reduction in farming intensity), are considered positively in relation to agricultural production, although it is acknowledged that, in the short term, the farmer implementing the option, may have a reduction in production (hence the ES payment). Options identified as 'strategic' are kept within the main body of the report, but they are written in italics; options that are likely to have benefit to farmers 'downstream' (e.g. options that contribute to a reduction in flooding) are noted to that effect in the text.

Soil formation and nutrient cycling underpin agricultural production and will benefit from any options that retain organic matter and plant nutrients within the soil matrix and reduce losses through erosion, leaching or decomposition. Preparation of a soil protection review and action to address issues raised in the review are mandatory cross-compliance requirements (GAEC 1) for those receiving subsidies under the Single Payment Scheme. LUC (2009) do not consider nutrient cycling separately, but many options that provide resource protection benefits are likely to enhance soil formation and nutrient cycling. Retaining nutrient resources within the field where they are available to agricultural crops thus reduces the amount of bought-in fertiliser required. Increasing organic matter in soils results in carbon sequestration, which will assist climate regulation (a regulating service), and also retains nutrients, reduces drought stress, and improves soil structure, reduces tillage energy (or the need for tillage), as well as providing more energy sources for soil organisms and the functions they carry out. However, the key elements for agricultural production relate to the enhanced fertility of the soil, which is the growing medium for crops and grass. Whilst climate regulation is of benefit in global terms, it can also be considered beneficial to agricultural production in that it may mitigate against unpredictable and highly erratic weather patterns which are associated with flooding and extreme, fluctuating temperatures. Soil organic matter content is a key measure of soil quality and soils that sequester carbon also have good capacity for storage and turnover of N and other plant nutrients, which can result in greater indigenous N supply and a reduction in N fertilizer requirements (Cassman *et al.,* 2002). For convenience, soil formation, nutrient cycling and carbon sequestration are dealt with together, since this is a logical combination in relation to agricultural productivity.

Genetic resources from wild plants, particularly close relatives of crop plants, may provide genetic material for use in breeding programmes to enhance yield, disease resistance or other characters of value in agricultural production. Hopkins & Maxted (2011) note that 75% of global crop genetic diversity has been lost, and that the global value of crop varieties bred from Crop Wild Relatives was estimated in 1997 to be US$115 billion per year. They considered that there is “a strong case for conserving a much wider diversity than those plants which are of the same species as an existing crop plant”. According to Maxted *et al*. (2007), 65% of UK native taxa are wild relatives of crops, with 82% of these being relatives of agricultural and horticultural crops. Maxted *et al* identify 303 taxa as wild relatives of major UK agricultural crops, though their definition is widely drawn and in practice only a proportion of these are likely to be relevant in the context of large scale agricultural production. In addition, there are options to encourage the use of traditional breeds of livestock and the retention and management of traditional orchards, which may provide added value to agricultural products arising if they are marketed appropriately to command premia for traditional and/or local production.

2.1.2 Regulating services

Water regulation is enhanced through increased infiltration which reduces the risk of runoff and flooding whilst allowing for the recharge of groundwater supplies. Conversely, soil compaction increases the risk of runoff and flooding through water retention on the surface. Water runoff increases soil erosion and nutrient loss which will be detrimental to production. Flooding is also detrimental, particularly where it occurs on land under arable crops, and produces methane, a powerful greenhouse gas. Grassland is more resilient, at least during the winter.

Freshwater is crucial for crop growth, and in some parts of the world irrigation is essential but in most of the UK crop production relies on natural rainfall; only certain high value crops (e.g. potatoes) are routinely irrigated. Water purification is linked to water regulation. Management that reduces soil compaction and runoff will help to reduce water pollution. Whilst enhancement of water quality is generally considered to be an externality (benefits the population as a whole but not the farmer), benefits could occur to downstream farmland where water is extracted for irrigation or watering of livestock. Furthermore, farmers are under obligation to comply with various regulations arising from the EU Nitrates Directive, and further restrictions are likely to ensue following the implementation of the Water Framework Directive. If ES options aid compliance they could reduce costs of production even if they do not increase production directly.

A key service that is likely to benefit from ES options is pest regulation. Control of weeds, pests and diseases is generally achieved through the use of pesticides, but restrictions arising from EU legislation are leading to a reduction in the availability of active ingredients, and the sustainability of relying on pesticide use is increasingly questioned. Integrated crop management approaches combine system (e.g. rotations, mixed cropping, etc.) cultural, physical (e.g. mechanical weeding) and biological (e.g. sacrificial crops, pheromone traps, predatory wasps, etc) control methods alongside agrochemical methods, whilst organic agriculture predominantly uses non-agrochemical methods. Furthermore, the activity of soil organisms, whether native or from inoculations, can help control the impact of plant pathogens and pests. Integrated pest management (IPM) is a key component of both conventional and organic farming systems and, aims to enhance control of pest species by their natural enemies in the case of biological controls. This may take the form of invertebrate pests controlled by invertebrate predators and parasitoids, but also weed seeds consumed by invertebrates, small mammals and birds (Westerman *et al*., 2003). If natural enemies are to provide a sufficient level of biocontrol it is necessary to ensure that natural enemies are provided with the appropriate resources to ensure their survival and reproductive capacity is maintained or improved. Many of these resources can be provided through appropriate ES options (Holland, 2007), but the impact may be influenced by the scale of provision and mitigated by the surrounding landscape composition (Bianchi *et al*., 2006).

Another key regulating service for agriculture is pollination. Pollination is required for outbreeding crops, which rely on a range of pollinators to provide this service. In Britain (and the rest of Europe) insect pollinators contribute to the production of over 80% of crop species (Williams, 1994; 2002). In the UK, insect-dependent crops include oil seed rape, orchard fruits and beans (Carreck and Williams, 1998; Gallai *et al*., 2010). A range of species (potentially several thousand) comprise this community of pollinators, including various bees, butterflies, moths and hoverflies as well as honeybees. Some ES options (e.g. pollen and nectar mixtures) are designed specifically to benefit pollinating insects, whilst others such as floristically enhanced grass margins will also benefit these species as well as a wider range of invertebrates.

2.1.3 Cultural services

Whilst ES options can enhance a number of cultural services, none of these are likely to be of direct benefit to agricultural production and they will not be considered further in this report. It is worth noting however that the production of cultural services helps to create and maintain a favourable attitude to agriculture in the minds of the general public, and may also provide incidental economic benefits to the farming industry, thus helping to support agricultural enterprises.

2.2 ENVIRONMENTAL STEWARDSHIP OPTIONS THAT PROVIDE ECOSYSTEM SERVICES OF BENEFIT TO AGRICULTURAL PRODUCTION

In view of the large number of options available in Environmental Stewardship, many of which will have similar effects in terms of ecosystem service provision, it is convenient to consider them in groups, unless there are specific differences between options within a group in relation to the service being considered. LUC (2009) grouped options for this purpose and these groups are also used in this report unless otherwise stated. The options in each group are listed in Appendix 1.

The LUC findings for the services considered in this report are summarised in Table 2.1. The outcomes of their analysis differ from those presented here in a number of instances. For example, they considered ditch management to have negative impacts for pest regulation, whereas we have considered it likely to have a positive impact. There is insufficient explanation in the LUC report to be able to identify the reasons for their individual scores. However, the LUC report considered service delivery globally, not just in terms of benefiting agriculture, and so took into account a larger range of issues.

Table 2.1: Summary of ES impacts on delivery of ecosystem services of value to agricultural production, as defined by LUC (2009)

Green = positive, red = negative, amber = positive and negative

	Soil, Nutrients, water[2]	Genetic resources	Pest regulation	Pollination
Boundary features				
• Hedgerows	[green]		[amber]	[green]
• Stone-faced hedgebanks	[green]		[amber]	[green]
• Ditches	[green]		[red]	
• Hedges and ditches combined (basic hedge management)	[green]		[amber]	[green]
• Stone walls	[green]			
Trees and woodland				
• In-field trees (general)	[green]			[green]
• Woodland fences	[green]			
• Woodland edges	[green]		[amber]	
• Wood pasture and parkland	[green]			[green]
• Woodland	[green]			[green]
• Scrub	[green]		[amber]	[green]
• Orchards	[green]	[green]	[amber]	[green]
Historic and landscape features				
• Archaeology under grassland	[green]			
• Archaeology under cultivated soils				
• Archaeology and high water levels	[green]		[amber]	
• Designed water bodies	[green]		[red]	

[2] Over all categories. Can separate these if necessary or more convenient

	Soil, Nutrients, water[2]	Genetic resources	Pest regulation	Pollination
• Water meadows				
• Traditional farm buildings				
Buffer strips, field margins and corners				
• Buffer strips (2m & 4m)				
• Enhanced buffer strips (6m)				
• Enhanced buffer strips (without grazing)				
• Enhanced buffer strips (with grazing)				
• Buffer strips beside ponds and streams				
• Uncropped cultivated margins				
• Conservation headlands				
• Conservation headlands (no fertiliser or harvesting)				
• Field corners				
Arable land				
• Seed mixtures sown for birds or insects				
• Fallow plots for ground nesting birds and arable flora				
• Low input cereals				
• Undersown spring cereals				
• Over-wintered stubbles				
• Whole crop silage and over-wintered stubbles				
• Fodder crops and over-wintered stubbles				
• Beetle banks				
Grassland				
• Low input grassland				
• Species rich grassland				

	Soil, Nutrients, water[2]	Genetic resources	Pest regulation	Pollination
• Rough grazing (basic)				
• Rough grazing (enhanced)				
• Rush pastures				
• Wet grassland				
• Mixed stocking				
• Rare breeds (supplement)				
Moorland and heath				
• Moorland				
• Shepherding (supplement)				
• Lowland heathland				
The coast				
• Coastal saltmarsh				
• Sand dunes				
Wetland				
• Ponds				
• Reedbeds				
• Fen				
• Lowland raised bog				
Soils				
• Maize crops and resource protection (without cover crop)				
• Maize crops and resource protection (with cover crop)				
• Arable reversion to grassland (no fertiliser)				
• Arable reversion to grassland (low input)				
• Infield grass areas				

	Soil, Nutrients, water[2]	Genetic resources	Pest regulation	Pollination
• Intensively managed grassland and soils (low input)				
• Seasonal livestock removal on intensive grassland)				
• Watercourses and erosion				
Access and education				
• Open access				
• Linear access				
• Educational access				

3 SOIL FORMATION, NUTRIENT CYCLING, CARBON SEQUESTRATION, WATER REGULATION AND PURIFICATION

3.1 INTRODUCTION AND IMPORTANCE TO AGRICULTURE

Soil formation, nutrient cycling, carbon sequestration, water regulation and water purification are all closely inter-related and so are considered together. For example, carbon sequestration through accumulation of organic matter in soil also contributes to soil formation, nutrient cycling, water regulation and water purification.

The combination of chemicals, water and microbes held within the soil degrade the underlying rock, releasing essential macro and micro nutrients, which, in combination with the decomposition of plant (and animal) material to soil organic matter contributes to **soil formation**.

As the growing medium for crops and grass, soil is fundamental to agricultural production, as are the nutrients therein. Nutrient cycling, carbon sequestration, water regulation and water purification are all reliant on soil, and there are complex interactions between the different services that provide for, and/or are affected by, agricultural production. Some of these interactions are described below to provide background to their importance to agricultural production.

A major route of **carbon sequestration** is plant growth. Sequestered carbon is held within plant material until the plant ceases to grow due to consumption or decomposition, when the carbon will be transferred up the food chain or returned to the soil respectively. The process of decomposition degrades the chemical structure of the plant material into increasingly smaller compounds. Soil organic matter (SOM) is a primary product of this decomposition process and it is within the SOM that carbon (soil organic carbon, SOC) is sequestered within the soil matrix. SOM is further degraded over time, releasing some of the carbon, but also releasing nutrients (and other chemicals) making them available for plant uptake, and so the **(nutrient) cycle** continues. It is the *rate of degradation* that is of importance to agricultural production since this governs the rate of nutrient release. An ideal scenario is one where the supply of nutrients matches plant requirements. SOM acts as a reservoir of carbon and plant nutrients that can be released gradually; moderation of the release of plant nutrients not only ensures the sustained availability of nutrients for crops, but also minimises the contamination of surface and groundwaters by impeding nutrient removal through runoff or leaching during rainfall events.

Decomposition of organic matter is carried out by microorganisms which are regulated by temperature, pH, water and nutrient availability, as is plant growth. This means that greater release of nutrients from degradation of SOM will occur at times when plants are also growing most rapidly. Plants stimulate this effect by providing additional labile energy sources as root exudates, which increases the biological activity in the rhizosphere that will release the nutrients from the SOM.

Soil organic matter not only provides a reservoir of plant nutrients, but once it has been processed into stable humus by soil organisms it also provides physical structure to the soil; notably it encourages the binding of particles into aggregates. Larger soil organisms such as earthworms also process the soil organic matter, moving the soil as well as generating humus. This results in more abundant and better-connected pore spaces which then encourage aerobic conditions and allow water to infiltrate freely (which feeds back to maintain aerobic conditions). A good soil structure allows roots to penetrate easily, maximising the ability to uptake both nutrients and water, and provides an environment for the proliferation of mycorrhizae, and other soil organisms, further enhancing the decomposition of nutrient-containing plant materials, nutrient uptake and water purification.

Soil organic matter has a better water holding capacity than mineral soil materials. The ability of soil to store infiltrated water provides a reservoir of water to crops and soil biota after rainfall has ceased. In doing so it impedes the flow of water to rivers and hence reduces the potential for flooding and soil erosion (**water regulation**) and retains more soluble nutrients in the soil and accessible to plants. The soil therefore not only assists with balancing supply and demand of water quantities, but also storing it *where* it is needed.

Any chemical present in the environment, whether indigenous or extraneous, will undergo degradation and/or transformation in the soil, facilitated by soil microorganisms although the timescale for this will depend on the properties of the chemical and on the soil type and soil conditions. For example, pesticides falling on the soil surface can *chemically* bind to soil particles, particularly clay and organic matter whereas microbes (*biological*) within the soil can utilise the carbon within the pesticide and, in doing so, break down the chemical structure, and so the compound is degraded sequentially into non-toxic components. This exemplifies the **water purification** role of the soil. Carbon sequestration will contribute to **climate regulation**, but there are additional soil functions that can affect this process. During decomposition, greenhouse gases such as nitrous oxide (N_2O), methane and carbon dioxide can be released, with N_2O emissions being related to fertiliser additions. The production of methane is greater under anaerobic conditions, which are more prevalent where waterlogging occurs, while combinations of high nitrate from fertilisers and fluctuations in soil water conditions are linked to higher N_2O emissions. Most soils, especially those that are free-draining, also process methane into less harmful CO_2 Unpredictable weather and the extremes of temperatures can negatively affect agriculture through increased prevalence of crop and animal disease, reduced resistance to disease, flooding, water shortages etc (e.g. Boxall *et al*., 2009; Evans *et al*., 2008).

All of the ecosystem services described above are reliant, in some way, on soil micro-organisms. Whilst some microbes can survive in anaerobic conditions or highly polluted soils, on the whole, microbes proliferate in the moist, aerated conditions that prevail in a well structured soil, high in SOM (e.g. Kasantseva *et al*., 2009), and so the positive feedback continues.

3.2 REQUIREMENTS FOR SERVICE PROVISION

The primary requirement for the provision of soil formation, nutrient cycling, carbon sequestration, water regulation, water purification and climate regulation is to **maintain the soil in terms of both its quantity and its health/structure**; this means preventing its loss through erosion, avoiding compaction, and providing a source and slowing the loss of organic matter. By understanding the land management practices that can adversely impact on soil and hence its related ecosystem services, it is possible to infer the benefits that a change in management may have where the change is induced by ES. Evidence from the literature for the relationships between the soil, ecosystem services and land management practices concerned with agricultural production is provided in the following sections.

Maintenance of a vegetative cover, particularly year-round, can reduce runoff, soil loss and pollutant losses by a combination of factors including stabilising the soil through its root system, reducing the physical impact of rain drops, and utilising both water and nutrients, thus reducing the potential for leaching to ground and surface water; indeed it is for these reasons that cover crops are encouraged on vulnerable soils, and, the vegetative cover can be a crop itself. Supporting evidence of the role of vegetative covers is provided in sections 3.3.3, 3.3.14, 3.3.21and 3.3.22.

Soil compaction can increase soil erosion (and any entrained pollutant) losses and runoff, reduce crop yields and adversely impact on soil biota, and hence processes such as mineralisation and nitrification. Compaction is commonly caused by trafficking, or trampling by livestock on wet soil, and the extent to which compaction occurs can be influenced by

SOM content; compaction may therefore be avoided by careful management and/or making the soil more resilient to compaction. Evidence of the above, is given below.

In the absence of wheel compaction, infiltration can increase by 84 – 400%, with an increase of 6 – 34% in plant available water (Chamen, 2006). Cornane *et al* (2010) noted that suspended sediment losses in runoff were greater from grassland gleys than from better structured soils (Brown and Mellanic soils). Dalgleish & Foster (1996) reported a >50% increase in runoff from compacted soils in laboratory experiments investigating the loss of caesium (used as a tracer in erosion studies); caesium losses were also greater from the compacted soil (2% of the applied) compared to uncompacted (<0.5%). Fullen (1985) monitored loamy sand soils in Shropshire and noted that, on compacted soils, low rainfall intensities (~ 1 mm h^{-1}) could be erosive.

Root length can be restricted by 50% due to compaction (Shierlaw & Alston, 1983; Kristofferssen & Riley, 2005) which can then reduce nutrient uptake (Wolkowski, 1990; Miransari *et al*., 2009). Zhao *et al*., (2007) also demonstrated that compaction significantly increased wheat grain concentrations of arsenic. Douglas & Crawford. (1998) highlighted the complex interactions of soil condition and yield; grassland yields were reduced by around 15% comparing typical compaction and zero compaction, i.e. untrafficked, but, in addition, losses from the system of applied fertiliser nitrogen were greater from the compacted soil – this was attributed to losses in runoff and denitrification in the more anaerobic, compacted soil.

There is also clear evidence that compaction adversely affects crop yield. Sparkes *et al* (1998) reported a 15% decrease in wheat yield which they assigned to soil compaction arising from trafficking. Assaeed *et al*., (1990) reported yield reductions as follows: barley 27-40%, maize 25-33%, peas 14-16%, turnips 13-19%, beans 34% and sugar beet 35%, whereas Hebblethwaite & McGowan (1980) noted larger reductions in sugar beet (45%) and vining peas (50%). Soil compaction reduced the competitiveness of barley and increased the incidence of weeds from 20% to 53% (Reintam *et al*., 2006), thus it could be expected that this would result in yield loss.

Nitrous oxide is largely produced under anaerobic conditions in a fluctuating water table and there is strong evidence for an increase in N_2O release with an increase in water-filled pore space (Gillam *et al*., 2008; Ciarlo *et al*., 2007; Sanchez-Martin, 2008; Ruser *et al*., 2006; van Groeningen *et al*., 2005; Smith *et al*., 1998). It is no coincidence that N_2O release can be increased by soil compaction (Ball *et al*., 1999a; Bhandral *et al*., 2007; Ruser *et a*l., 2006; Yamukil & Jarvis, 2002) although, under some circumstances, N_2O losses can be higher from land that could be expected to be aerated (minimum tilled) compared to conventional tillage (which can cause compaction), (Beheydt *et al*., 2008; Liu *et al*., 2007; Ball *et al*., 1999b), highlighting the fact that management techniques must be tailored appropriately to the land.

Methane sequestration and release is also affected by soil conditions. Compaction reduces the ability of soil to sequester methane (Ruser *et al*., 1998; Teepe *et al*., 2004; Flessa *et al*., 2002), compaction can increase anaerobic microbial processes giving a rise in methane production (Yamukil & Jarvis, 2002), and higher water contents reduce methane oxidation (Li & Kelliher, 2007). Conversely, aerobic soils are an important sink for methane (Powlson *et al*., 1997).

As discussed in section 3.1, soil organic matter is initially formed from plant material, and SOM is essential to crop production. Clearly, harvesting of crops prevents the return to the soil of at least some of the plant material whilst repeated disturbance of the soil by cultivation enhances the rate of decomposition and mineralisation of SOM, thus reducing SOC stores. Bhogal *et al*., (2009) measured an increase in soil organic carbon of around 22% of that applied in the form of crop residues over 23 years. Silgram & Chambers (2002) reported a 20% increase in organic carbon in the surface soil where straw was incorporated rather than burnt. Straw incorporation returned significant amounts of N to the soil (> 500 kg/ha), and nitrate losses were slightly reduced (by 10 kg/ha) from straw-incorporated sites. Other studies in the US have shown that, after 11 years, soil organic carbon was a linear function of residues added (Larson *et al*., 1972), i.e. the more residues added, the higher the soil organic carbon content. Manure is also an important source of organic matter, as well as nutrients that can benefit the long-term fertility of soils (Triberti *et al*., 2009). Crop yields can therefore be higher under integrated cropping systems than continuous cultivation (Tracy & Zhang, 2008).

Mineral soils with high levels of organic matter are less vulnerable to compaction when water levels are raised (O'Sullivan, 1992) and wet mineral soils are more prone to compaction (Hakansson and Reeder, 1994) - conditions that decrease infiltration, encouraging anaerobic conditions and erosion and so the cycle of soil degradation can continue (with the exception of peat soils where drainage and hence the drying out of peats tends to lead to erosion). In addition, the degradation of potential pollutants such as pesticides and polycyclic aromatic hydrocarbons (PAHs) is enhanced when soil organic matter is abundant (Kah *et al*., 2007; Barriuso & Benoit, 2003; Gaultier *et al*., 2008; Vacha *et al*., 2010).

The physical properties of the soil also impact on soil biota, which in themselves underpin processes such as nutrient cycling, decomposition and mineralisation. Beylich et al (2010) reviewed literature relating to the impacts of (agricultural) soil compaction on soil biota and biological processes (e.g. respiration and nitrification). However, they could not formulate any general conclusions on the impact of compaction due to the high variability of experimental conditions, notably with respect to clay content, carbon content and pH values, the degree of compaction (0 - 50% of the initial bulk density), the experimental duration (3 weeks - 9 years), and the climatic and soil conditions throughout the experimental period. Negative and positive effects occurred with both slight and substantial compaction for zoological and microbiological parameters. For example, changes in C-mineralisation (as a % of the control) due to compaction (measured as soil bulk density), for field-measured data, ranged from minus 47% to +51% with a tendency of increasing mineralisation with increasing bulk density, but the data were highly variable. Conversely, there was a negative relationship between effective bulk density and C-mineralisation for laboratory-generated data, and, again the data were highly variable, particularly when bulk density was < 1.7 g/cm^3; the one consistent finding was that above 1.7 g/cm^3 effective bulk density, all data demonstrated a reduction in C-mineralisation compared to the control.

Bouwman and Arts (2000) investigated the impact of compaction on soil nematodes and they observed that, whilst the total number of nematodes did not change significantly, there was shift in faunistic composition from microbivorous species - associated with decomposition/mineralisation - to herbivorous species that are associated with crop damage which, the authors proposed, may have contributed to a reduction in crop yield.

Whilst there is clear evidence of detrimental effects to ecosystem services and crop yield arising from poor soil structure and organic matter content in particular, there is variability in the findings from the literature. This reflects the highly complex interactions between factors such as soil type, moisture content, previous cropping history, fertiliser regime and climate, such that management practices must be tailored to the needs of the land and one solution does not necessarily fit all, although the vast majority of studies do indicate that maintaining soil organic matter is beneficial.

3.3 RELEVANT ES OPTIONS

In the following section, evidence is provided for how the different Environmental Stewardship options contribute to ecosystem services related to soil, water, nutrient cycling and carbon sequestration. For the majority, this relates to how the option protects and/or enhances soil, as it can be inferred from sections 3.1 and 3.2 that this will protect and/or enhance ecosystem services e.g. a reduction in runoff will contribute to both water regulation and nutrient cycling (nutrients could be dissolved in runoff). This will normally also reduce soil loss by erosion, although the percentage reduction in runoff and soil losses by management practices is not necessarily equal.

Where possible, the evidence has been limited to studies from northern Europe or areas with a similar climate (e.g. New Zealand). Data from the US have been included due to the volume of published work, but efforts have been made to exclude agricultural scenarios that are totally irrelevant to the UK.

In some cases, there is no direct evidence of how the actual option influences ecosystem services. In these circumstances the impact of the option is inferred from data where the change in land use is similar to that in the option. For example, taking field corners out of production is akin to reverting to extensive grassland, or a grass buffer. The literature evidence that is detailed for one option can therefore apply equally to another option. In order to avoid unnecessary repetition, the reader is referred to the relevant option where the detailed evidence can be found.

The evidence below relates to how the different environmental stewardship options contribute to soil formation, water regulation, water purification, climate regulation and carbon sequestration either directly, or indirectly though soil protection. It is assumed throughout that taking land out of production will have a direct adverse impact on agricultural production at the field scale.

3.3.1 Option types that have no easily discernable benefits to agriculture via ecosystem services discussed in this section are listed at the end of the chapter. Hedgerows + hedgerow trees

Hedges can reduce both wind and water-driven soil erosion. It is assumed here that a hedgerow tree can be an integral part of a hedge, thus the options for hedgerows and hedgerow trees have been combined. Skinner and Chambers (1996) examined nearly 400 fields for evidence of erosion in lowland England and Wales and they noted that erosion was marginally greater in fields where the hedges had been removed in the last 20 years. Evans (2006) reported on a farm that had been monitored for decades: where field boundaries were removed to create larger fields, erosion was common, but, following a change of ownership, field boundaries of hedges and trees were replanted with the effect that water no longer moved from field to field, and connectivity with the surface water was broken. Fullen (1983) reported that field boundaries resulted in the deposition of the majority of wind-blown sediment from a light sandy soil, although very fine fractions could be deposited beyond the boundary. Owen *et al*., (2007) provide quantitative evidence of the ability of hedges bounded by grass margins to trap sediment (0.07 – 0.19 g/cm^2) although in the same study, a hedge in another field, that contained a rill network, did not trap any sediment. This highlights the importance of preventing the initiation of soil erosion and rills (and the channelling of water down the line of the hedge), as simple mitigation methods such as hedges cannot be used in such circumstances.

The benefit of hedges relates to retaining soil within the farmed land and so it accrues on land down slope or downwind of the hedge, as the hedge will have little effect on preventing the initial removal of the sediment that it is subsequently retaining. Chappel and Warren (2003) noted the accumulation of sediment at field boundaries in fields in East Anglia. They extrapolated measured data to estimate a net loss of 0.6 kg/ha/year (range −32.6 to +37.5 t) over 35 years from an area of approximately 19 km^2 area.

The above described benefits relate to the *presence* of the hedge. Clearly hedgerow planting (HLS capital item PH) will provide these benefits, as will gapping up (HLS capital tem HR). However, the majority of the management requirements under these options relate to the timing, frequency and extent of cutting which in itself will have very limited value to ecosystem services with the exception that these stipulations can prevent over-zealous trimming which can lead to a decline in hedge condition and eventual die-back, and so are likely to ensure that the hedge remains healthy and less prone to gap formation.

Hedges could offer an additional benefit to agricultural production via their ability to sequester carbon and their contribution to soil organic matter from decomposition of fallen leaves, and other parts of the plant (both above and below ground). The UK-based "climate friendly food" organisation (CFFcarboncalculator.co.uk) estimates that 2-m wide hedgerows sequester 440 kg C/100m/year. Follain et al (2007) investigated the contribution of hedges (containing some trees) in France and at the landscape scale (i.e. including hedges that are planted down a slope perpendicular to the contour) the soil organic carbon stock associated with hedges was 13.3 kg C/m2 compared to 16.6 kg C/m2 in the vicinity of the hedge (up to 5m either side). Walter et al (2003), also studying in France, reported that for areas of high hedge density (200 m /ha) hedges could account for 38% of the SOC stock, and 13% where hedge densities were lower (50 m/ha). This was primarily attributed to the accumulation of organic matter in soil upslope of the hedge.

Increases in hedge height resulting from adoption of ES options will result in an increase in carbon sequestration, until the desired height is reached.

3.3.2 Stone-faced hedgebanks, Stone walls & Earthbanks

Quantitative evidence relating to the impact of stone-faced hedgebanks, stone walls and earthbanks was not found. It is assumed that they will have a similar impact to hedges, with the exception of a reduced or non-existent contribution by stone walls to carbon sequestration and/or organic matter accumulation. Maintenance of these structures through ES-supported management will ensure their integrity and continuation of their role as barriers to erosion etc.

3.3.3 Ditches and Hedges & Ditches combined

Ditches are commonly found in low-lying, flat areas such as the Fens that can be susceptible to wind erosion. These options relate to ditches forming boundaries and encourage the growth of bankside vegetation. The vegetation will serve to stabilise the bank, reducing the potential for erosion of farmed land. Grasses are particularly effective at stabilising banks (Laubel *et al*., 2003)) and scour can be reduced by 90% compared to bare soil (Pollen-Bankhead & Simon, 2010). Grasses can also be flattened by water and in doing so they further protect the soil from erosion (Hopkinson & Wynn, 2009). Trees are also beneficial to reducing erosion from stream banks (compared to riparian banks of grazed or arable land) (Langendoen *et al*., 2009; Zaimes *et al*., 2006). In addition, vegetation can trap seeds resulting in a positive feedback mechanism of vegetation growth and sedimentation (Gurnell *et al*., 2006). The tall vegetation could also reduce the effect of wind erosion, although there is no published work to support this assumption that matches the ditch scenario. There is however evidence that hedges can reduce wind erosion (as discussed above) and there is a vast amount of evidence that grasses can reduce wind erosion in susceptible areas (e.g. Li *et al*., 2007; Ravi *et al*., 2010; Bohner *et al*., 2003; Lancaster & Baas, 1998) Returning dredged material from the ditch to land will return nutrients, fine particles and organic matter which are required for soil formation, although the timing of dredging in relation to nutrient applications should be considered to reduce the potential for subsequent contamination of the ditch (Smith & Huang, 2010). There are therefore some benefits to agricultural production from this option.

It is assumed that the impact of "hedges & ditches" will be an amalgamation of the impacts described above.

3.3.4 In-field trees

In-field trees (that are still alive) can substantially contribute to carbon sequestration and soil formation by providing organic matter for decomposition. However, as the option relates to individual trees, the overall impact is likely to be small, although there should be some benefit overall at the national scale. Novak & Crane (2002) calculated that urban trees could store in the order of 9 kg C/m2 cover and sequester 0.3 kg C/m2 cover; urban trees could store larger amounts of C than forest trees due to the larger diameter. Ancient trees will not sequester carbon to the same extent as younger trees. However, this option will prevent the destruction of older trees and so limit the release of stored CO2 into the atmosphere. For ancient trees on cultivated land, the 15m radius grass area around the base of the tree will provide some of the benefits of an in-field buffer (section 3.3.24).

3.3.5 Woodland edges

Woodland edges will provide a year-round cover of vegetation that can sequester carbon, contribute to soil organic matter accumulation and reduce water erosion – any reductions in wind erosion due to the woodland edge option are likely to be negligible compared to the protection afforded by the woodland itself. Evidence provided in Section 3.3.1 could also apply to woodland edges.

3.3.6 Wood pasture and parkland

Wood pasture and parkland puts relatively little pressure on the land and so it is sustainable, assuming that it is managed appropriately. There is a year-round cover of vegetation and the trees can sequester and store relatively large amounts of carbon. Whilst there is no direct evidence from wood pastures, their potential for sequestration and/or contributions to soil fertility can be inferred from data relating to woodland. Poulton *et al* (2003) quantified C and N content of soil in land that was arable for centuries until the late 1800's and has since reverted to woodland. The acidic site (mainly oak) gained 2.00 t C/ha/yr over the 118-year period (0.38 t in litter and soil to a depth of 69 cm, plus an estimated 1.62 t in trees and their roots); there were also gains of nitrogen. Hughes-Clarke & Mason (1992) examined 35 field corner plantations adjacent to arable fields and noted a significant increase in total N and total C under the plantations compared to the arable land. The benefits outlined in section 3.3.4 would also apply here.

Trees can increase the rate of infiltration (Broadmead & Nisbet, 2004) which will assist in water regulation. Work in the Pontbren region in Wales has demonstrated that areas of sheep pasture planted with trees can increase the infiltration rate by up to 60 times after 6 years, although significant increases were observed after only two years (Carroll *et al*., 2004).

However, Olson (2007) studied land farmed for decades in the US and noted that woodland and agricultural landscapes had similar amounts of SOC when the crop rotations included forages, cover crops, conservation tillage, and contour farming, highlighting that it is the combination of many factors that influence ecosystem services.

Creation of wood pasture (HLS option HC14) will have the greatest benefit, but restoration and maintenance options (HC12 and 13) will also have benefits in terms of maintaining the ecosystem services provided by these habitats. However, the benefits to agricultural production will depend on what alternative uses could be considered for the land and how these would affect the services concerned.

3.3.7 Woodland

The role of woodlands in regulating water quantity will be the primary benefit to agricultural production, although the beneficiary may not be the farm implementing the option, but a farm downstream. Managed woodland can be used for the production of wood as well as livestock. Carbon sequestration in conifer and broadleaf woodland is estimated to be in the order of 11 t/ha/year (http://www.cffcarboncalculator.org.uk/node/202).

3.3.8 Scrub

The presence of a vegetative cover can assist in preventing soil erosion and creating a reservoir for beneficial soil biota. Where it is used as a buffer, there will be some benefit to agricultural production due to reduced losses of soil and associated SOM, and a reduced potential for runoff (see sections 3.3.3, 3.3.10 and 3.3.14).

3.3.9 Orchards

These systems, like woodlands and wood pastures, put little pressure on soil resources and can contribute to soil formation and water regulation, as evidenced in sections 3.3.6 and 3.3.6. Option HC21, creation of traditional orchards, will have major ecosystem services benefits if created from more intensively managed land, whilst options HC18, HC18 and HC20, will benefit agricultural production as the orchard will be maintained or restored so that fruit production continues, whilst also providing other ecosystem services.

3.3.10 Archaeology under grassland & moorland

These options require cultivated land to be managed as permanent grassland by grazing and mowing, in some cases after reversion from arable land or removal of scrub. The permanent vegetative cover will contribute to reducing soil loss enhancing carbon sequestration, and consequently enhancing accumulation of SOM and biological nitrogen fixation, especially when converted from arable (ED2/HD7). However, the benefits of scrub in relation to carbon sequestration could be similar to hedgerows and preventing the expansion of scrub (ED4) could therefore reduce the potential for carbon sequestration. Any removal of scrub will result in some loss of accumulated carbon.

Hodgkinson and Withers (2007) reported a decrease in particulate phosphorus (i.e. nutrient loss) when arable land was reverted to grassland. Auerswald *et al*., (2009) used measured data from about 100 studies to predict soil losses in Germany and they calculated that soil losses from grassland were about one-tenth of that from arable. This is comparable to work by others in England where erosion rates from grassland were < 0.1 t/ha/yr (Fullen *et al*., 2006) which compares to tolerable levels from British arable fields of 1 – 2 t/ha/yr (Fullen & Booth, 2006) or 4 t/ha/yr (Chambers & Garwood, 2000).

Disturbance of the soil by conventional tillage increases the rate of mineralisation, reducing SOM and SOC content and SOC is commonly lower in frequently tilled, i.e. arable land (e.g. Johnston et al., 2009; Sun et al., 2011) compared to grassland (and see section 3.3.11 below) with concurrent increases in soil carbon when arable land is reverted to pasture. Guo & Gifford (2002) performed a meta-analysis of 74 (global) publications and found that the conversion of pasture to crop reduced soil C by 59% whereas the conversion of crop to pasture increased soil C by 19%.

Where the loss of arable production is not matched by increased livestock production, there could be a disbenefit to agricultural production in the short term, but with possible strategic benefits if the land reverted to arable in the future. This disbenefit would be expected to be greater on arable-only farms compared to mixed farms, where stock will be present to utilise the grassland. .

3.3.11 Archaeology under cultivated soils

The main theme of these options is reduced-depth, non-inversion cultivation (often referred to as min till) and/or direct-drilling. There is a wealth of evidence that no-till or min-till practices are beneficial to the chemical, physical and biological properties of soil. Practicing min-till will therefore enhance the productivity of soil, and reduce erosion losses. For example, over a 14-year period, McGregor *et al*. (1999) studying soybean, demonstrated that during extreme rainfall events (65 mm/h) runoff from no-till plots was 11 to 35% less than from conventional-till and soil loss 23 to 77% less. The yields from the no-till plots varied with weather conditions, but were greater from no-till land by 800 kg/ha by the end of the study period. Quinton & Catt (2004) demonstrated only a marginal benefit in reducing event soil loss using minimum tillage (245 kg/ha) compared to conventional tillage (278 kg/ha) although across-slope/minimal tillage treatment combination had a significantly smaller ($p<0.05$) event soil loss (67 kg/ha). Yields from the min-till land were normally greater than from the conventional till. Stevens *et al*. (2009) over a 2 year experiment did not observe any benefits of minimum tillage compared to conventional ploughing, but this may partly be due to the very short time scale of the work, and the fact that the benefits of min-till can be site/soil specific. Withers *et al.* (2007) studied a chalk soil, a sandy soil and an under-drained clay and noted that soil cultivation effects were variable and site-specific depending on weather, inherent soil susceptibility to structural degradation and management. They found that the timing of cultivation can be more important than the technique in terms of subsequent erosion losses: late cultivation increased surface runoff up to 5-fold and sediment mobilisation by an order of magnitude compared to early drilling using traditional cultivation techniques on the sandy soil.

Organic carbon and microbial biomass carbon contents in the top 10cm of soil can increase significantly under no-till and min till (Simon *et al*., 2009). Hazarika *et al*., (2009) reported an increase in soil carbon in the top soil of up to 17% for no-till/chisel ploughed soil compared to mouldboard ploughing in soil that was considered unsuitable for no-till (silty clay loam); the authors concluded that the accumulation of carbon in the top soil due to no-till practices would assist in creating a stable soil. Several other workers have reported an increase in soil carbon under reduced tillage (van Groeningen *et al*., 2010; Jacobs *et al*., 2008; Kandeler *et al*., 1999; Ogle *et al*., 2005). Manley *et al*. (2005) conducted a meta-analysis of over 50 studies and found that min-till could have triple benefits (increased carbon, increased yields and reduced soil erosion), but, under some scenarios it could be more costly than conventional tillage and store little carbon. Although the Canadian scenarios are not necessarily relevant to the UK, this study further illustrates the need to match management practices to the soil/crop.

Min-till has the additional benefit of reducing energy consumption and so can contribute to climate mitigation: Knight (2004) reported energy use for conventional tillage as 2826 MJ/ha compared to 1191 MJ/ha for non-inversion tillage and 770 MJ/ha for direct drilling on heavy soils(cited in Morris *et al.*, 2010). In the same study, yields from clay soil were lower under min-till, but on a chalk they were greater compared to conventional tillage, again indicating the need to match management practices to the soil/crop. Min-till can be associated with higher emissions of N_2O compared to conventional till (see section 3.2) but, again, this is case specific.

3.3.12 Archaeology under high water levels

This option is available for land already subject to high water levels. Providing areas of land for floodwater reduces the adverse impact of this water elsewhere in the catchment, e.g. on higher value crops. Evidence relating to flooding is described in section 3.3.31. Maintaining this practice will therefore benefit production beyond the limits of the field to which the option applies. Grassland is resilient to winter floods and the deposition of nutrient-laden sediment could reduce the need for imported fertilisers. Great care is needed to prevent compaction of the wet soil which could ultimately reduce production.

3.3.13 Traditional water meadows

The benefits and impacts outlined in section 3.3.12 and 3.3.31 in relation to flood management will also apply here.

3.3.14 Buffer strips, & enhanced buffer strips

Buffer strips are linear, grassed areas on land that could, in practice, be cultivated (hence this excludes steeply-banked sides). These may be sown to grass, which can include wild flower seed, or they can be established through natural regeneration. Buffers therefore provide a year-round cover of vegetation which will contribute to organic matter accumulation, carbon sequestration and reducing soil erosion. These benefits will largely be applicable to cultivated land. On grassland, the buffers can still be grazed and the main difference between the grassland and the buffer is that fertiliser and manures cannot be applied to the buffer and only a very limited use of herbicides is allowed. In terms of ecosystem services there will be little additional benefit of the non-riparian buffer on grassland, assuming the grassland is managed appropriately.

The options described here are non-riparian, nor are they "in-field" for which there is a separate option (EJ5, discussed in section 3.3.24). It can therefore be inferred that these buffers will be placed around the edge of fields. There is little direct evidence of the benefits of these options to ecosystem services although the benefits can be inferred from other data. For example, the work by Owens et al. (2007) investigated hedges bound by a grass margin which provided quantitative evidence of the ability of the hedge + grass to trap sediment (0.07 – 0.19 g/cm2), but it is impossible to separate the effects. They looked at a range of buffer widths from 2 – 9 m. In one storm, a 6 m buffer with hedge trapped over 10 times more sediment (9.1 g/cm2) than a 9-m buffer with trees, but in a storm several months later, sediment trapped was 0.31 and 0.43 g/cm2 respectively. In this storm, a 2 m stewardship grass strip trapped more sediment (0.59 g/cm2). The investigation was not 'controlled' and the soil types, field slopes, and land management differed, but the findings illustrate buffers can trap sediment, though it is difficult to predict under what circumstances and to what levels this may occur. Moreover, the retention of sediment by a buffer is not just a measure of the efficiency of the buffer; it is also a function of how easily the field upslope is eroded and the relative size of the buffer to the land upslope. But, in all cases, there was no sediment deposited down slope of the buffer, indicating they can be effective.

It is reasonable to assume that the benefits of these options will be similar to the effects of converting arable land to grassland that have been discussed in section 3.3.10.

Soil macrofauna responsible for processes such as decomposition (thus contributing to the accumulation of SOM) can be greater under grass strips than under cultivated land. Smith *et al*., (2008a) recorded significant increases in the abundance and species diversity of soil ingester, litter consumer and predator macrofauna in hedgerow boundaries with a 6-m grass strip compared to hedgerows without the grass strip. Grass strips therefore have the potential to provide reservoirs of beneficial soil fauna for recolonisation of the soil, which could have benefits in the short term, although in the aforementioned study the benefits in adjacent fields were not realised which the authors attributed to the relatively harsh field conditions at the time of the experiment. Smith *et al.*, (2009) further demonstrated that litter decomposition was greater on undisturbed, cut grass, compared to scarified grass margins, i.e. disturbed soil, providing further evidence of processes contributing to the accumulation of SOM and its associated benefits.

3.3.15 Buffer strips beside ponds and streams

The vast majority of research on buffers has been conducted on buffers adjacent to watercourses. These have been shown to reduce the speed of runoff which allows time for infiltration, thus the quantity of runoff can be reduced by 63% (Lowrance & Sheridan, 2005). A recent review by Arora et al., (2010), who examined only field data, reported that 45% of runoff volume was retained within buffers (range of 0-100%). Reducing the rate of flow and encouraging infiltration then increases the time available for sorption, degradation and/or uptake of pollutants in the runoff/soil water, reducing potential contamination of the receiving water body by: nitrates, 50% (Vought et al.,1995), 62-85% (Lee et al., 2003), 90% (Osborne

& Kovacic, 1993); Total N, 27% (Lowrance & Sheridan, 2005), 80 – 94% (Lee et al., 2005); dissolved P, 58 – 80% (Lee et al., 2003, 66 - 90% (Vought et al.,1994). Krutz et al., (2003) reported an increase in atrazine adsorption of nearly 60% under a buffer compared to the cultivated soil and Staddon et al. (2001) measured enhanced sorption coefficients of metalachor in a buffer strip (2.25) compared to cultivated (cotton) field (1.6) which they attributed in part to the higher microbial activity in the soil under the buffer strip. Lin et al. (2005) also indicated the importance of microbial degradation in reducing herbicide concentrations emanating from buffers, although there is evidence that only strongly-sorbed pesticides may be retained within buffers (Reichenberger et al., 2007; Patty et al., 1997), and weakly-sorbed compounds may not (Reichenberger et al., 2007; Lovell & Sullivan, 2006, Arora et al., 2010). Similarly, in under-drained fields, highly soluble compounds can by-pass buffers (Muscutt et al., 1993). The retention of strongly-sorbed compounds can be explained by the fact that reducing water flow also encourages sediment (to which pollutants are commonly attached) to be deposited within the buffer, giving reductions in loss of: 63% sediment-bound P ((Lowrance & Sheridan, 2005), 95% sediment (Lee et al., 2003), ~20 – 50% sediment (Udawatta et al., 2010), 76% sediment (Arora et al., 2010), > 50% average sediment (Yuan et al., 2009).

Much of the work on buffers has been conducted in the US, where both the fields and buffer strips are far larger than in the UK. More relevant scenarios are discussed in some detail below, and they exemplify the variability in the findings. In NE Italy, Borin & Bigon (2002) investigated the buffering effect of a 5-m grass strip (8-yrs old) plus 1-m of deciduous trees/scrub and they observed a 90% reduction in nitrate concentrations; the buffer continued to be effective in winter when nitrate uptake by vegetation is minimal. It was proposed that this may have been due to microbial immobilisation of nitrate as the high organic matter content of the soil under the buffer (2.1% compared to 1.7% in the field) could support a large microbial population.

In the same field study (Borin et al., 2004) herbicide concentration abatement varied between 60 and 90%, depending on the chemical and the time since application, and dissolved P concentrations were reduced by almost 100%. However, a further 4-year study by Borin et al. (2005), at a different location (but also in NE Italy and also using 6-m wide buffers consisting of trees + grass, but newly planted) did not demonstrate a reduction in total N, or nitrate. Conversely nitrate concentrations were greater from land with the buffer strip. However, it was calculated that buffers reduced the total mass of N lost from 17.3 to 4.5 kg/ha. Dissolved P was also unaffected by the buffer whereas total P was reduced by the buffer, which could be expected given that total suspended sediment (TSS) was also reduced by nearly 80%. Vinten et al. (2004) studying buffers strips in Scotland, reported around 50% reductions in total P and sediment, although it was noted that by-passing of the buffer caused variation in the results. Heathwaite et al. (1998) studied grasslands in Devon and reported reductions of 94% and 98% of N and P in surface runoff from plots receiving inorganic N fertiliser, and reductions of 75% (N) and 10% (P) from slurry-treated plots. Leeds-Harrison et al. (1999) could not demonstrate the benefits of buffers in terms of reducing nitrate loads from typical English arable land, although their work was conducted over only 3 years with 'young' buffers and a very dry summer induced macropores, such that by-passing of the buffers could have reduced buffer effectiveness. Conversely, Haycock & Pinnay (1997) reported the retention of nitrate by grass and poplar buffers. They reported retention in the winter months which they also attributed to the prevalence of soil organic carbon augmenting microbial (denitrification) activity; Rotkin-Ellman et al. (2004) demonstrated that denitrification was greater in 'hot-spots' of soil patches enriched with organic carbon.

In addition to the role of water purification, the year-round vegetative cover on buffers and the presence of roots within the soil contributes to carbon sequestration and soil formation – and hence other ecosystem services. Buffers therefore offer protection from in-stream erosion (see also section 3.3.3). Total root area has been shown to be almost double in *grass-buffered areas compared to rotationally grazed pasture and soil carbon contents can be significantly higher under buffers (Kumar et al., 2010). Other authors have reported increases in organic carbon content of soil under buffers by factors of 1.7 (Krutz et al., 2003), 1.24 (Borin & Bogon, 2002), 2 (Staddon et al., 2001), 4 (Dousset et al., 2010)*

There is clear evidence that buffers can be beneficial, but there is variability in the findings and the location of the buffer is crucial in determining its effectiveness. Buffers are not very effective where channelisation of flow in rills etc occurs (e.g. Vinten et al., 2004; Leeds-Harrison et al., 1999). Dosskey et al., (2002) estimated that the potential for the reduction in sediment loss in four buffers was 99%, 67%, 59%, and 41% if the runoff was spread evenly over the buffers, whereas the actual reductions were estimated to be 43%, 15%, 23%, and 34% due to the reduced area of contact. Moreover, buffer strips do not serve to prevent the initiation of soil erosion, and it may be necessary to remove sediment from the buffers in order to maintain their effectiveness (Dosskey et al., 2008). On a farm basis, riparian buffers (i.e. at the down slope edge of the field) are likely to provide less benefit to the farmer than buffers/hedges placed upslope where retaining sediment may be more useful. However, at the catchment scale, the reduction in runoff can regulate water flow and potentially reduce flooding downstream, and so in this situation they could be beneficial to production at the landscape scale.

3.3.16 Uncropped cultivated margins

These options require arable land margins to be cultivated in either spring or autumn, allowing the natural seedbank of the soil to determine the vegetative cover. There is unlikely to be any benefit to agricultural production in terms of soil and water related ecosystem services for these options. There could be some benefit to climate regulation through reduced emissions of N_2O as there is a positive correlation between N fertiliser and N_2O emissions (Bouwman *et al*., 2002). Conversely, there could be disbenefits if plant cover is slow to establish, increasing the risk of erosion from bare ground, although the ELS handbook does stipulate that in areas at risk of erosion, grass buffers should be used instead. Quinton & Catt (2004) noted over a 10 year period that runoff and soil erosion on experimental plots at Woburn were concentrated in periods with sparse vegetation cover, i.e. in winter after the late planting of cereals; in spring after the planting of beets; or when soils were bare after harvest, exemplifying the role of a vegetative cover in reducing erosion.

3.3.17 Conservation headlands

These options will reduce agricultural productivity because fertilisers are prohibited and only certain herbicides can be used (Boatman & Sotherton, 1988, Grundy et al., 1996). However, where they are unharvested (EF10), the year-round vegetative cover of a dense crop could assist with preventing erosion and providing a reservoir for soil biota.

3.3.18 Field corners

Field corner management in arable fields, in essence, is a buffer and the evidence of their benefit to ecosystem services has already been described. Additional evidence can be gleaned from work conducted in relation to set-aside. Soil organic carbon can accumulate on set-aside (9.2 g/kg) compared to the cultivated field (7.9 g/kg) even after only 3 years (Hamer et al., 2008). This compares to a 30% increase in soil organic matter content in the surface of the soil (0-5 cm) from 20 up to 31 g/kg ten years after establishment of ley grass set-aside (Fullen et al., 2006). Erosion rates varied from 0.005 to 0.58 t/ha/year, which compares to previous values of 30 t/ha (Fullen & Brandsma, 1995). A review of data in the US where arable land was set-aside considered 142 sites and, with the exception of a single site, there was significant sequestration of organic carbon with an average of 2.088 (range 0.12 – 37.1) Mg CO2 equivalent/ha/yr (Peinero et al., 2009). N2O emissions from grass set-

aside (0.3 kg/ha) are lower than from winter wheat (2.7 and 3.6 kg/ha) or potatoes (5.7 and 6.9 kg/ha) for fertilisation rates of 50 and 150 kg N/ha/yr respectively (Ruser et al., 2001).

Against these benefits must be set the loss of productivity from the fact that the area is taken out of production, though if it was brought back into production at a later date yields would be expected to be higher as a result of the increased productivity for reasons discussed in section 3.2.

On grassland, grazing is not permitted on the field corner, nor is the use of fertilisers/manures which has the potential for reduced N2O emissions (see 3.3.16) and for the accumulation of SOM.

3.3.19 Seed mixtures sown for birds & insects

These options provide year-round cover of vegetation, protecting soil and sequestering carbon. Whilst there is no direct evidence of their benefit to soil, it is reasonable to assume that the benefits will be similar to reversion to grass (3.3.10) for pollen and nectar mixtures, though probably lower for wild bird seed mixes as pollen and nectar mixes contains legumes that can biological fix atmospheric nitrogen, enhancing the fertility of the soils whilst wild bird seed mixes cannot and are more similar to normal, arable crops. . However, where the cuttings are removed (pollen and nectar mixes), the accumulation of carbon may be reduced in comparison to grass. Also, nitrogen fixation under legumes will aid nutrient cycling and will increase soil fertility for any following crop, but may result in increased nitrate leaching if the area is ploughed. Great care is needed to prevent compaction if the land is grazed in autumn/early winter and the soil is wet – as advised in the ELS handbook – which would otherwise be detrimental to ecosystem services as described in section 3.2.

Clearly while these areas are under seed mixtures they will not be producing crops so in that respect they will be detrimental to agricultural production and any benefit will be accrued if the land is returned to agricultural production.

3.3.20 Fallow plots for ground nesting birds

There is unlikely to be any significant benefit to ecosystem services (described in this section) and subsequently to agricultural production from these options.

3.3.21 Low input cereals & undersown spring cereals

These options require spring cereal crops to be established. This has the potential to be beneficial to soil and the processes therein, as there is a reduced tendency for erosion from spring-sown crops compared to winter-sown crops (Chambers & Garwood, 2000). Erosion potential can be further reduced where crops are undersown with a grass/legume mixture. Chambers & Garwood (2000) reported that a cover crop (50 – 100% cover) on a soil of moderate risk of erosion prevented any erosion occurring on the first winter rainfall event > 10 mm/h, and even a 15% cover reduced erosion. In the same study, but at a different site, erosion was recorded from fields with cover crops as the water was being channelled down tramlines and wheelings.

Shepherd (1999) investigated the use of cover crops in a typical arable rotation. Although there was variability in results, which could be expected due to differences in rainfall between the years, he concluded that a reduction of N losses of 25 kg/ha was a reasonable estimate. Askegaard & Eriksen (2008) recorded reductions in the annual flow-weighted mean nitrate concentrations from 13-16 to 5-8 mg L with the use of cover crops with spring barley. Cover crops can therefore contribute to water purification services.

In addition, cover crops theoretically have the potential for contributing to SOM accumulation and carbon sequestration. Dabney *et al.* (2001) suggest that, whilst cover crops are actively growing they increase the carbon flux into the soil, providing food for soil macro and microorganisms and contribute to soil organic carbon. However, Shepherd (1999) did not detect any measurable differences in soil organic matter after 8 years of nitrate-retentive practices in England which included cover crops. Any benefits of cover crops in relation to soil biota and SOM accumulation is likely to be highly variable due to the many influential factors, as was noted for the other benefits described above.

3.3.22 Overwintered stubbles, including whole crop silage and fodder crops

The physical presence of the stubble can reduce the impact of rain drops, provide stability of the soil due to the root system and provide a source of organic matter; these options also provide a form of crop cover (weeds). This option therefore has the potential to reduce the effects of erosion, and contribute to carbon sequestration, soil organic matter accumulation and the proliferation of soil biota. Robinson & Naghizadeh (1992) conducted rainfall simulation studies in SE England showed that soil losses from stubble plots were consistently lower than from shallow cultivated and ploughed plots (0.1 g/h *cf*. 4.3 and 13 g/h on unwheeled soil and 1.7 g/h *cf*. > 20 g/h on wheeled soil). Turtola *et al*. (2007) reported a 14% reduction in erosion from fields with winter stubble with shallow cultivation compared to autumn mouldboard ploughing, whereas untilled land showed a reduction in erosion of 48%. Puustinen *et al* (2005) reported lower losses of total suspended solids (around half) from uncultivated stubble compared to normal ploughing or winter wheat, and shallow cultivated stubble still gave marginally lower losses than winter wheat or normal ploughing. There were corresponding reduction in particulate phosphorus, but dissolved reactive phosphorus in runoff was higher which was attributed to release during decomposition of the straw material.

3.3.23 Maize crops and resource protection

The benefits of this option are to reduce soil erosion and augment the physical, chemical and biological status of the soil through undersowing. Maize is susceptible to erosion due to the length of time for which soil is left bare and harvesting late in the year when the soil may be wet. Laloy & Bidders (2010) investigated the use of rye and ryegrass on runoff and erosion from maize in Belgium over two-years and recorded a reduction in soil loss of 40 – 90% compared to soil left bare during the intercropping period. A reduction in runoff of 90% was also reported in the Defra-funded study “Soil Erosion Control in Maize”, although this was not apparent at all sites studied and only when drilling occurred across the slope. The study highlighted the fact that a single solution does not always suit all and management practices must be matched to the needs of the land. A meta-analysis of data from the US and Canada showed that a winter cover crop containing legumes increased maize yield by up to 37% - this effect decreased with increasing use of inorganic N fertiliser (Miguez & Bollero, 2005). In addition, there were no disbenefits to yield.

3.3.24 Arable to grassland, including in-field buffers

There is clear evidence that the conversion of arable to grassland will be beneficial to ecosystem services. Grassland provides a year-round cover of vegetation, it allows organic matter to accumulate providing a reservoir for soil biota, and it enhances infiltration reducing the potential for flooding. The use of pesticides is also greatly reduced. The evidence provided in section 3.3.10 and 3.3.14 can also apply here, although it is reiterated that the majority of buffer research has been conducted on riparian buffers whereas this option relates to in-field buffers. The siting of these options within the farmed land, rather than at the edge of the farmed land means that both the farmer implementing these options, and others downstream, will reap the benefits. Additional evidence relating to conversion to grassland and in-field buffers is given below.

Bucur *et al* (2007) estimated from measured data over an 8-year period, that soil losses from maize were 2.57 t/ha compared to only 0.14 t/ha in perennial grass whereas Romkens *et al*., (1999) reported that the organic carbon content of an old maize field in the Netherlands increased from 1.6% to 1.8% after conversion to pasture in just 4 years. Other evidence is provided in section 3.3.10

In semi-arid countries and the US there is evidence to show that in-field grass strips (or contour strips, or grass hedges) are effective at reducing soil loss (e.g. Udawatta *et al*., 2002; Thappa *et al*., 1999), but the cropping scenarios and/or the grasses used are irrelevant to the UK. However there has been at least one study in England which demonstrated a reduction by an order of magnitude in runoff and soil loss from 1-m wide grass plots compared to bare soil (Melville & Morgan, 2001). This was attributed to ponding on the upslope side of the grass strip, and, for the one replicate where ponding was not apparent, runoff and soil losses were greater than for the other grass strips. There is also some evidence from France that a grass cover can enhance the sorption and degradation of pesticides entering from upslope thus contributing to water purification. Benoit *et al*., (1999) reported that sorption rates of isoproturon were 5 L/kg in a grass buffer compared to only 1.8 L/kg in cultivated soil, with corresponding half-lives of 8d and 72d respectively. Although isoproturon is no longer used, the process underlying the sorption and degradation of other pesticides could be expected to be similar. Dousset *et al*., (2010), also studying in France, reported higher sorption in grass inter-rows in a vineyard (4.9, 19.1, 7.4) compared to bare soil (2.2, 10.5, 4.2) for diuron, tebuconazole, and procymidone respectively. They reported higher organic carbon content of top soil in grassed inter-rows in a vineyard (2.7%) compared to cultivated/bare soil (0.8%), although lower than in a buffer strip (3.8%).

There is also evidence that siting in-field buffers on natural drainage areas within a catchment can reduce losses of nitrate (Blackwell *et al*., 1999). When a section of an arable field was managed as permanent fallow (cut grass, but not grazed) within the field, nitrate, dissolved P, soil sediment and total organic carbon concentrations in leachate from the whole field were significantly reduced (Ulen *et al*., (2008)). Interestingly, the field was tile-drained, thus, unlike riparian buffers, the impact of underdrainage may be less important as having the buffers appropriately sited.

There is therefore direct evidence that in-field buffers can contribute to soil formation and water purification. It can also be inferred from the evidence that as they reduce soil loss, they contribute to all soil-related ecosystem services and because the soil is retained within the field, the agricultural benefits may be greater than for field edge buffers.

3.3.25 Intensively managed grasslands and soils

Options included here are ‘Preventing erosion or run-off from intensively managed improved grassland’ (HJ6) and ‘Seasonal livestock removal on grassland with no input restriction’ (HJ7). These options serve to ensure that production is sustainable.

Option HJ6 is for grassland that receives > 200 kg N/ha and where there is evidence of erosion and/or runoff, and works to extensify grazing, alleviate or prevent compaction, and reduce N inputs. Sediment losses from extensively grazed pasture have been shown to be lower than from compacted grassed areas (van Dijk, 1998) and runoff can be halved when overgrazed areas are subsequently only lightly grazed (Heathwaite *et al*., 1990, Defra project BD2304). In the latter, the heavily grazed areas had an 80% lower infiltration capacity – which would have a significant impact on water regulation. Bartley *et al.* (2010) reported a reduction in sediment load of *ca*. 70% when grazing regimes were improved, but, they noted that losses were not reduced where rills were present. The reduction in grazing intensity will also reduce the potential for nitrate leaching (Cuttle *et al.*, 1998) due to a reduction in the deposition of excreta and urine which contains more water-soluble forms of nitrogen. Evidence relating to the disbenefits of compaction is given in detail in 3.2 and it follows that relieving this compaction will be beneficial. Reductions in the usage of inorganic fertiliser and the quantity of urine, can also reduce the production of N_2O (see section 3.3.29; Di & Carmeron, 2006).

3.3.26 Watercourses and erosion

Poaching of land next to watercourses will cause the gradual erosion of the stream bank, reducing the area of land available for production. It will also make the land more susceptible to erosion in times of flood. In the long-term, fencing will maintain a larger area of productive land. Restricting livestock access will also allow enhance vegetation growth effectively creating a buffer - with all the associated benefits. There is increasing evidence of the benefits of riparian fencing in reducing soil erosion, and hence the loss of sediment-associated pollutants.

Collins *et al*., (2010) investigated sediment in spawning gravel in SW England. Although the study used a very limited number of data points, the findings indicate that riparian fencing can reduce sediment in six rivers. Estimates of the overall mean proportion of the interstitial sediment originating from eroding channel banks, pre- and post- fencing were: 97% to 69%; 94% to 91%; 12% to 10%; 92% to 34%; 31% to 16% and 90% to 16%. In Iowa, soil loss from pasture that had been fenced for at least 3 years was 6–61 kg/ha/yr compared to losses of 197-264 t/ha/yr for unfenced continuously grazed pasture (Zaimes *et al*., 2008). In Canada, nutrient and sediment loads were reduced by up to 50% after fencing along water courses, providing alternative water supplies, protecting stream crossings, and providing some stream bank bioengineering (Meals, 2004). Providing off-stream water for a cow-calf herd in Virginia reduced the time cattle spent drinking in the stream by 87% and the time spent in the stream by 51% even in the absence of fencing. Stream bank erosion was reduced by 77%, total phosphate loss was reduced by > 90% and total nitrogen by > 50% (Sheffield *et al*., 1997). Excluding cattle from riparian areas can reduce runoff, total N and improve soil condition (Miller *et al*., 2010). Although Vinten *et al*. (2004) did not demonstrate lower concentrations of sediment in Scottish streams from land that was largely fenced, compared to unfenced, it was proposed that this finding could have been due to overflow of a contaminated sump.

3.3.27 Winter cover crops

See section 3.3.21.

3.3.28 Beetle banks

Beetle banks are a form of in-field buffer and have the potential benefits relating to enhancing the physical, chemical and biological status of the soil as described in sections 3.3.14 and 3.3.15. The limited work that has been conducted on beetle banks in the UK demonstrated a trend towards reduced losses of runoff, sediment and P, but the results were highly variable and the evidence was not conclusive (Stevens *et al*., 2009). It was noted that disruption of tramlines had a far greater impact on reducing sediment and P losses. Any reductions in runoff and sediment will benefit the farmer implementing the option (as well as those downstream) as the option is within field.

3.3.29 Low input grassland

These options are available for permanent grassland, i.e. the land is already grassed. The options will serve to maintain this grass and have the benefits as described elsewhere (3.3.10). The low or no inorganic N inputs will reduce the production of N_2O (Anger *et al*., 2003) and hence contribute to climate regulation A single, short term study in Lithuania comparing unfertilised and low fertilisation rates (60 kg nitrate/ha) on mown grass did not find any significant differences in nitrate leaching, but other studies would be required to draw any firm conclusions. Cuttle *et al*., (1998) compared nitrate leaching losses from grass/clover plots (6 to 34 kg/ha/yr) and from fertilised (200kg N/ha) grass plots (2-46 kg/ha/yr) and concluded that the fertilisation rate did not make a significant difference to the quantity of nitrate leached, but the grazing intensity was of more relevance.

3.3.30 Species rich grassland & rush pastures

The benefits of these options will be similar to low input grassland as they maintain a grass cover (see sections 3.3.10, 3.3.18 and 3.3.29). There will therefore be strategic benefits due to improvement in the physical, chemical and biological status of the soil contributing to a wide range of ecosystem services, but the reduction in nitrous oxide emissions due to a reduction in fertiliser use could have benefits to the farmer due to impacts on climate regulation. Cutting rush pastures will increase the amount of land available for grazing and so may increase productivity.

3.3.31 Wet grassland

Included here are options for wet grassland for breeding waders and wet grassland for wintering waders and wildfowl, plus supplements HK19 (raised water levels) and HQ12 (Wetland grazing supplement).

These options allow for production to continue in a manner that does not excessively degrade the soil and have the potential to provide storage for flood waters and so prevent crop damage further downstream. The evidence for their contribution to water regulation is limited. Acreman *et al*., (2003) used models to predict a reduction in peak flow of about 10–15% through the restoration of floodplains, although Acreman *et al*., (2007) subsequently suggested that the reduced storage capacity could have negative impacts on water regulation. Posthumus *et al*., (2010) investigated the impact on ecosystem services of different land management practices on a lowland floodplain in England, and they also demonstrated that creating flooded areas such as wet grasslands could have both positive and negative impacts on water regulation, depending on the exact land management practices. Sedimentation during flooding will provide nutritive additions (Olde Venterink, *et al*., 2006) and could therefore reduce the need for fertilisers, although Surridge *et al*., (2005) highlighted that the levels of dissolved P released from sediment could be very high and hence a potential contaminant.

3.3.32 Options involving cattle grazing

The benefits of these options relate to the sustainability of production. Included here are mixed stocking (EK5), native breeds at risk supplement (HR2, cattle grazing on upland grassland and moorland (UL18), cattle grazing supplement (HR1) and seasonal livestock removal supplement (HL15). Cattle exert approximately twice as much static pressure on soil (160-192 kPa) than sheep (83 kPa) (Drewery, 2006) thus their potential for compaction is greater. Trampling cattle can potentially damage blanket bog and old *Calluna* (Defra project BD1228). There is therefore the potential for disbenefit to ecosystem services through soil degradation (as described in section 3.2) where cattle replace sheep numbers. However, there are other ecological benefits to cattle grazing, and it may be possible to negate the aforementioned risks by matching the stocking density to the soil condition (which may be lower than in the Handbook). Use of the seasonal livestock removal supplement could reduce pressure on sensitive areas in winter, reducing the potential for soil degradation, thus improving the sustainability of production. There is no indication that rare breeds will be any more detrimental than ‘conventional’ breeds, although current research has only considered one breed (Belted Galloway) (A comparison of mainstream and at risk cattle breeds for the management of the hills and uplands, Defra project LS3408).

3.3.33 Upland meadows & Haymaking supplement

There is unlikely to be any significant benefit to agricultural production arising from ecosystem services (relevant to this chapter) provided by these options.

3.3.34 Upland grassland & moorland

Included here is a range of options for management of upland rough grazing and moorland, plus the supplements for management of heather, gorse and grass by burning, cutting or swiping (HL12), and the moorland re-wetting supplement (HL13). These options serve to maintain enclosed and open moorland and the wetland areas therein. Preventing the reversion of this land to more intense practices and maintaining an appropriate stocking level will prevent soil compaction and soil loss by processes evident elsewhere in this section of the report.

Re-vegetation of eroded peat reduced sediment loads from 112 t/km2/yr in 1962/63 to 44.5 t/km2/yr in 2001/2 (Evans *et al*., 2006). In the same study, sediment loss in 2001/2 for a catchment still subject to erosion was 267 t/km2/yr. Evans & Lindsay (2010) used high resolution mapping and data on peat growth to predict the carbon storage of Bleaklow Plateau in the southern Pennines and they concluded that gully erosion during the last millennium shifted Bleaklow Plateau from being a net sink of carbon (-20.3 g C m2/yr) to a net source (29.4 g C m2/yr). They highlighted that gully erosion not only entails primary removal of particulate carbon from the peatland system but also has secondary effects in that it enhances drainage and lowers water tables, potentially enhancing decomposition of surface peats. Others have reported that restoration of peat areas can almost halve the export of carbon and dissolved organic carbon (Waddington *et al*., 2008; Wallage *et al*., 2006).

There is also evidence that the restoration of vegetation and re-wetting can contribute to water regulation. Wilson *et al*. (2010) blocked drains in the Lake Vrynwy catchment which resulted in an increase in the water table. In turn, this caused an increase in surface water during rain events, but, it did not lead to greater discharge in the streams which they proposed could have been due to reduced connectivity. Grayson *et al*. (2010) used historical data on vegetation cover and stream response and further demonstrated that increasing vegetation cover reduced the flashiness of discharge, i.e. more water was stored within the catchment with greater levels of vegetation. The blocking of drains in the 'Exmoor mires restoration project' has also reduced flooding downstream.

There is some evidence that manganese (Heal *et al*., 2002) and phosphorus (Rupp *et al*., 2004) could be released on re-wetting, (i.e. a change in the equilibrium) but if there is disconnectivity, there should be little impact on water quality, and, over time, it could be expected that an equilibrium will return which will be beneficial in the long term.

Burning will be detrimental to soil formation due to the loss of organic matter. In the long term this will be detrimental to production. No information relating to gorse (relevant to the UK) was found, but there is evidence relating to heather burning. Clutterbuck & Yallop (2010) proposed that burning was responsible for an increase in dissolved organic carbon (DOC) concentrations draining from peat in the Pennines. Farage *et al*. (2009) investigated carbon losses over two seasons and they concluded that net C losses were 34 g/m2/yr compared to a net uptake of 146 g/m2/yr. Tucker (2003) reviewed the impacts of heather burning and excerpts from this review highlight the negative role of burning to the soil and hence ecosystem services:

Charred, non-fibrous humified peat formed crusts which were easily detached (for example by needle ice) and then readily removed by water erosion. Bare peat also broke up into granules, creating a surface that was susceptible to wind and water erosion, and insufficiently stable for plant recolonisation.

Water-repellent compounds may also be deposited within the soil by distillation during prolonged smouldering fires. These may create layers in the soil that interfere with water and root penetration, and may create structural weakness.

As a result of the loss of shading by vegetation, there are greater fluctuations in soil surface temperatures and moisture regimes, with increased temperatures and risks of desiccation in summer.

Infiltration rates on freely drained brown podzolic soils declined by 74% on burnt heather plots compared to unburnt plots.

If the heather is cut and the cuttings are left to decompose, impacts to ecosystem services are lessened as the carbon and nutrients are retained within the ecosystem.

The impacts of bracken control are considered in section 3.3.43.

3.3.35 Shepherding

This option prevents overgrazing occurring, which can ultimately prevent degradation of the soil. This option is therefore beneficial to soil and production. In an experiment on Kinder Scout, shepherding gave an effective reduction in stocking level from 2.5 ewe/ha to 0.18 – 0.43 ewes/ha and vegetation cover increased from 49% to 92% on average over an 8-yr period. On the mineral soil, 90% coverage was gained in 5-yrs whereas on the steeper slopes in the most heavily eroded areas, plant cover only reached 76% (Anderson & Radford, 1994).

3.3.36 Lowland heathland

Burning as a form of a management is detrimental to ecosystem services as discussed in section 0. If burning is <u>not</u> carried out, *maintenance* of lowland heath will be beneficial to ecosystem services if it is assumed that more intensive grazing is the alternative land use option, for the reasons relating to soil erosion etc discussed in previous sections.

The *restoration* of heathland is for sites that have been encroached upon by scrub or other natural vegetation, and/or forestry. Woody vegetation will contain more carbon and there could be a short-term release of this carbon. However, in the long term there is the potential for increasing organic matter accumulation and nutrient sequestration, (Mallik, 1995). Where restoration is from overgrazed heathland, there will also be positive benefits to ecosystem services, for example, as discussed in section 0.

3.3.37 Coastal saltmarsh

The maintenance of saltmarsh may prevent its reversion to more intensive forms of agriculture and hence be beneficial to ecosystem services. The creation of saltmarshes could be beneficial to water regulation as it could alleviate flooding elsewhere, which could include farmed land, thus the benefits will primarily be received by farmers downstream, and/or at a strategic level Wood debris and accumulations of seaweed must be retained and will therefore add to the soil organic matter, stabilising the land and contributing to the positive feedback mechanism of soil formation and ecosystem services. Santin *et al*., (2009) confirmed that organic matter does accumulate in reclaimed saltmarshes, but the organic matter content was still half that of natural saltmarshes even after 40 years. Andrews *et al.*, (2008) working with the Welwick Marsh in the Humber Estuary estimated that the net effect of returning 26 km^2 of reclaimed land to intertidal environments could result in the storage of 40,000 t/yr of sediment, about 800 t/yr organic carbon, 40 t/yr of organic N as well as burying inorganic contaminants. However, work at Freiston Shore in Lincolnshire demonstrated no overall benefit of the “re-aligned” marsh as it was noted that the sediment that was accreting in the new marsh came from other saltmarshes (Rotman *et al*., 2008).

3.3.38 Sand dunes

These options can be used to allow existing sand dunes to encroach inland over arable land, grassland and set-aside. Options allow for extensive grazing or mowing, scrub management, maintenance of existing drainage and seasonal flooding pattern and retaining accumulations of seaweed and wood debris. These options provide for sustainable production and their flood protection role can be beneficial to any adjacent farmed land. Everard *et al*., (2010) reviewed literature relating to the ecosystem services of sand dunes. Their findings (for the services discussed in this section) are given in Table 3.1.

Table 3.1 Ecosystem services provided by sand dunes, from Everard *et al*. (2010)

Ecosystem Service	Importance		Specificity	
	Score	Comment	Score	Comment
Air quality	1	Dune slacks are seasonal wetland – net N fluxes are uncertain; canopy roughness may be significant in particulate fallout and dry gaseous pollutant deposition	1	Dunes are a net sink for gaseous N and particulates – as are most other semi-natural habitats.
Climate	2	C accumulation rate is high as this is early successional habitat, but overall area low. Dune slacks may also be source of GHG.	2	Few habitats with high sequestration rates.
Water	3	Sand dunes form a shallow aquifer	3	Provide a rapid recharge groundwater.
Natural hazard	3	Dunes have significant role in buffering storms & natural events providing a major coastal defence.	3	Can be replaced by engineered structures but costly.
Erosion	0	Not important in the context of soil erosion on slopes.		
Water purification	2	No evidence, but dunes are likely to purify infiltrating water	3	Most other land uses are a nutrient source.
Soil formation	2	Successional habitats, accreting soil in wet & dry habitats.	2	Common to most habitats.
Nutrient cycling	2	Most N & P is retained in the system. There are high rates of biological nitrogen fixation.	2	Common to most habitats.

Importance score at national/international level on a per-unit area basis 0 = not important to 3 = high importance. Specificity – the extent to which a service is provided uniquely by sand dunes, or whether it is better provided by other habitats or land use types; 1 = Sand dunes can provide it but other habitats provide it better, to 3 = sand dunes are amongst the best providers, or only sand dunes can provide this service.

Everard *et al*., (2010) stated that there is no benefit of sand dunes to soil erosion, in terms of soil erosion on slopes. However, dunes do protect soil inland (i.e. natural hazard regulation). It is suggested that the water purification role of sand dunes is lower than that proposed by Everard *et al*. (2010) due to their location (i.e. there is little fresh water downstream) and because the ‘soils’ are inherently sandy (allowing water to rapidly move through the profile, reducing the time available for degradation) and low in organic matter. In addition, there are many habitats, other than sand dunes that provide water purification roles, as discussed in all the previous sections. It is suggested that measures of the benefits of ‘Erosion’ should equal ‘Natural Hazards’ and water purification importance and specificity should both be reduced to ‘1’.

3.3.39 Ponds

These options are for existing ponds. There could be some benefit to water regulation if the options prevent their reversion of the pond back to arable or grassland. The collection of runoff could also prevent erosion downstream of the pond.

3.3.40 Reedbeds, Fens & Lowland raised bogs

These are all further forms of wetland. These options will assist in maintaining the benefits of wetlands as described in sections 3.3.31 and 0. Drainage of peatlands, including fens causes subsidence and degradation, but the rate of subsidence can be reduced or reversed by water management measures (Dawson *et al*., 2010). Reedbeds could have greater role in relation to water purification as they retain nutrients to a greater extent than semi-natural vegetation due to the ability to reduce the flow of water and enhance sediment deposition (Olde Venterink *et al*., 2006). The benefits to agricultural production are to provide a sustainable practice, and there could be benefits from reduced flooding for farmers downstream

3.3.41 Basic payment for organic management

Organic farming relies more heavily on ecosystem services provided by the soil, and nutrients are recycled more within a farm. On the whole, land managed under organic arrangements tends to have higher soil organic carbon content. Mondelaers *et al*. (2009) conducted a meta-analysis of peer-reviewed data from developed countries comparing organic and conventional agriculture. Although there was variability in the soil organic carbon content between different studies, overall it could be concluded that there was significantly more soil organic matter. There was also significantly less nitrate leached from organic farms, but when the nitrate leached was assessed in relation to the mass of product produced (i.e. kg NO_3/kg product/ha) there was no significant difference; nitrate losses tended to increase with increasing productivity. There was a tendency for lower P losses although the results were not significant due to the small dataset and large variance. Greenhouse gas emissions were also highly variable and were confounded by whether comparisons were per unit area, or per unit of production: organic farming tended to have lower inputs, but also lower production. However, GHG were not higher from organic farms compared to conventional farms.

3.3.42 Upland management requirements

These requirements under UELS will be beneficial to ecosystem services as they relate to grazing, retaining scrub, maintaining wetlands, retaining woodland, careful placement of supplementary feeding i.e. avoiding compaction which have all been discussed elsewhere. The options will therefore allow for continued, sustainable production.

3.3.43 Supplements

Options relating to the control of invasive plant species and small fields will have no impact on ecosystem services, but they will be beneficial to production.

Although there is no evidential data, it is possible that the 'Difficult site' option will increase the potential for disbenefits to ecosystem services through soil erosion. The option prescription indicates that abandonment is the likely alternative. Natural vegetation compared to grazing, or other, will be beneficial as there is always greater risk of erosion associated with agricultural activities.

Woodland livestock exclusion specifically relates to land that has been overgrazed, thus this will assist in reversing soil erosion (see sections 3.3.6, 3.3.10, 3.3.24) protecting the long-term productivity of the land.

Bracken is highly invasive and can take land out of production if left unchecked (e.g. Cox *et al*., 2008); it is also highly toxic and can be fatal to livestock if ingested (Evans, 1989; Yamada, 2007). In terms of soil/water interactions, bracken can provide a good source of organic matter and sequester carbon. Removal of bracken in habitat restoration work could potentially lead to a loss of carbon, nitrogen and magnesium (Marrs *et al*., 2007). Smart *et al*. (2007) measured a decrease in organic matter in the surface soil under bracken compared to adjacent moorland, and, from the results of their study, they hypothesised that bracken encroachment could be associated with increased nitrate leaching. Bracken also contains carcinogens (hence their toxicity to grazing livestock) which are highly water soluble which could leach into watercourses (Ramwell *et al*., 2010). The benefits of carbon sequestration could therefore be outweighed by the disbenefits of water 'purification' – i.e. bracken is a source of pollutant. Bracken can also harbour ticks which can lead to infections in both humans and animals, and hence reduce production. Controlling bracken will on balance therefore be highly beneficial in most situations to both ecosystem services and agricultural production.

Livestock inclusion/exclusion on salt marshes allows the introduction of livestock, or the removal of livestock to levels that are not detrimental to the soil. They will therefore be beneficial to ecosystem services and production in the long-term.

Wetland cutting & grazing options are likely to have negligible impact on ecosystem services as long as grazing is managed at the correct level.

3.3.44 Options with no impact

The following option types were considered to provide no benefits for soils, water, nutrient cycling or carbon sequestration:

- woodland fencing,
- designed water bodies,
- maintenance of weatherproof traditional farm buildings,
- Open, linear and educational access.

3.4 SUMMARY AND CONCLUSIONS

This section has considered the impact of individual options on ecosystem services related to soil, water, nutrients and carbon, but in order to achieve optimum outcomes, a holistic approach to sustainable production is ideal:

"Organic residue management, the prevention of compaction, crop rotation and the timing of cultivation must all be considered together, taking into account their impact on pest populations and on the natural enemies of pests and ecosystem engineers." (Roger-Estrade et al., 2010)

"Moreover, because climate and soil type can greatly influence SOC dynamic, to increase CO_2 sequestration in cropland, it is important to optimize the fertilization within an agricultural management that includes all the agronomic practices (e.g. tillage, water management, cover crops, etc.) favouring the organic matter build up in the soil." (Triberti 2009)

The impact of a management practice depends on previous cropping and management histories, soil type, timing, frequency etc. and what may be beneficial to crop production at one site, may be detrimental at another. Only specific field-by-field assessments will realise the full potential of the options. Furthermore, the impacts of the ecosystem services on agricultural production, and the industry as a whole, need to be considered at the landscape scale.

It is important to recognise that, while Environmental Stewardship options can make a valuable contribution to maintaining healthy soils and reducing diffuse water pollution from agriculture, they will do this most effectively within a context of good management practice across the farm (Ramwell & Boatman, 2010). Many ES options relate to non-cropped areas at field margins, such as buffer strips, but it is also important to tackle soil erosion and loss of nutrients at source (as recognised in natural England advice[3]. There are some options for crop management (undersown cereals, management of maize crops, cover crops), but management needs to be considered on a whole-farm basis and this can be achieved through diligent application of the cross-compliance soil Protection Review (SPR) and adherence to the requirements for Nitrate Vulnerable Zones. If the appropriate cross-compliance actions are implemented in conjunction with strategically located ES options, the greatest benefits are likely to be achieved.

Data on the impact of ES options *per se* on soil and water attributes are sparse, as resource protection has only come to the fore as a major objective of ES in recent years. Therefore the potential impacts have to be inferred from research on similar types of land management. Much of the research to date has been in the form of short-term studies (< 5 years), although longer studies do exist. However, the full benefits to crop production of the different options may take many years to materialise due to the relatively slow dynamics of the soil and soil formation.

[3] 'Farming for cleaner water and healthier soil' Natural England advisory leaflet NE230

4 GENETIC RESOURCES

4.1 BACKGROUND: SOURCES OF GENETIC DIVERSITY

Sources of genetic diversity are required to provide new genetic material for use in improving current crop varieties or breeds of domesticated animals. Sources of genetic material for use in breeding improved types of plants and animals used for agricultural purposes can arise from two main sources: (i) existing varieties or breeds that are traditional or primitive and no longer widely utilised, or occur in other countries or regions, and (ii) wild relatives of cultivated or domesticated forms.

Wild plants can also provide sources of medicines (for example, digitalin derived from foxglove *Digitalis purpurea*), and the potential for discovery of new medicines from such sources is another reason for conserving genetic diversity. ES options may also contribute to the conservation of beneficial soil organisms such as Trichoderma, Rhizobia and Azotobacteria, which could provide agricultural benefits.

4.2 LANDRACES OLD CROP VARIETIES AND ANIMAL BREEDS

Landraces are local varieties that have developed through selection processes occurring in farm-saved seed, as opposed to varieties developed through conventional plant breeding. These may be maintained for minority uses such as thatching straw, or deliberately by farmers, gardeners and allotment holders. The conservation of traditional varieties of vegetable and fruit crops has become a popular activity among organic, small-scale or specialist producers and amateur gardeners, encouraged by organisations such as Garden Organic. These enthusiasts are supplied by specialist seed companies who maintain stocks of traditional varieties or are members of seed swapping clubs. (These companies were set up to avoid the effects of EU regulations governing seed sales, which require seed varieties to be certified and on a national list of approved varieties)

Preservation of traditional livestock breeds is also now a popular niche activity on small farms, often connected to provision of tourist attractions. Some larger farms also favour traditional breeds for a number of reasons, including docility, lower susceptibility to disease, hardiness and marketing quality. The conservation of rare breeds of livestock is promoted by the Rare Breeds Survival Trust. This was founded in 1973, since when no UK livestock breeds have become extinct[4].

A number of gene banks also exist where old varieties and landraces are maintained. The most significant of these are listed by Hopkins & Maxted (2011).

4.3 CROP WILD RELATIVES

Recently, the conservation of crop wild relatives has received increased attention in the UK. All modern crop species have originated from domesticated wild progenitors, their natural genetic variation selected over many generations to produce desirable crop traits. However, the process of domestication has led to a reduction or bottleneck of genetic variation. Crop varieties contain far less genetic variation than their wild progenitors and current crop wild relatives (CWRs). In some respects this lack of variation is desirable, in that it helps to give uniform crops but it also means that crop varieties may not possess the same ability as CWRs to adapt to new pests, diseases, or environmental change. In addition to the intra-specific genetic bottleneck of crops arising through domestication, there is also very low species diversity in crops compared to natural environments, and the number of staple crops species has further reduced in recent times.

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[4] http://www.rbst.org.uk/

Plant breeders need a source of genetic variation to find new useful traits. Traditionally this source has been crop germplasm collections containing historical varieties and sometimes a few CWRs. Although they are very important resources, germplasm collections are limited in their capacity. Due to the increasing global pressure for food security there is an increasing and wider interest in using CWRs to provide new alleles for disease and pest resistance and adaptation to environmental change. CWRs tend to live in wider ranges of habitats than their crop counterparts and are therefore more likely to possess genetic adaptations for harsher climates and, being unprotected from pests and diseases, can also carry resistance alleles. In some cases, e.g. wheat, thousands of years of human selective breeding are leading to a genetic load[5] which is preventing further crop improvement using varieties alone. Breeders are therefore turning to natural populations to reinvigorate new varieties. As the conservation of crop wild relatives is a relatively new area of concern in the UK, and is more complex than the conservation of existing varieties, this is the main subject of this chapter.

A comprehensive research report on English CWR resources was recently published (Hopkins & Maxted, 2011). The report contains a detailed review of the occurrence, distribution and conservation status of known English CWRs, which we will not replicate here. This section examines the effect of Environmental Stewardship (ES) schemes on CWRs: which scheme options are likely to be most beneficial to CWR resources? The key points made by Hopkins & Maxted (2011) on the impact of ES and CWR conservation are:

- Many CWRs are common weed species and may grow in or near crops;
- In all CWRs, the genetic diversity *within* species is at least as important as the number of species;
- Advances in biotechnology mean that *any* species' biodiversity can be used for crop improvement through trans- or cis-genics[6]; and
- For the purposes of CWRs as a genetic resource, it does not matter if the species is considered indigenous or not.

Hopkins & Maxted (2011) put the genetic resources of a particular crop and its CWRs into three categories:

- Gene Pool 1 within which 1A is the crop itself and 1B is wild or feral forms of the crop;
- Gene Pool 2 includes less closely related species from which gene transfer is possible using conventional breeding; and
- Gene Pool 3 from which genetic transfer is not possible through conventional methods but can be done using molecular techniques.

With respect to ES and CWRs, we will assume that all scheme options have a potentially beneficial effect on Gene Pool 3, but it is not relatively quantifiable amongst them because we do not know in advance which species could provide important genes for transgenics. We will therefore only consider the impact of ES on Gene Pools 1 and 2.

[5] The reduction in diversity of beneficial alleles due to repeated selection

[6] 'transgenics' being the integration of genes from a different species into a target crop species' genome, and 'cisgenics' being the integration of genes from the same or closely related species using molecular methods.

4.3.1 Types of CWR

Hopkins & Maxted (2007) identified 303 taxa in 50 genera as CWRs of UK agricultural crops, including: grasses, legumes, rose family, brassicas, carrot, onion, poppy, potato, lettuce, flax, beet and hemp. They did not cover in detail the resource of coppice and hedgerow trees, e.g. willow, hazel, hawthorn, which may also be considered CWRs. Willow CWRs, in particular, may be a valuable genetic resource where there is considerable scope for its genetic improvement as a biofuel crop (Bellarby, *et al.*, 2010). It has also been overlooked in previous reviews that some wild UK species could become crops of the future, for example nettles have been investigated as a fibre crop, with favourable results (Horne *et al.,* 2008).

Sugar beet is an example of a UK crop which has benefited from exploitation of CWRs. Sea beet (*Beta vulgaris* subsp. *maritima* L.) is widespread in the UK but restricted to coastal environments such as cliffs and shorelines. It was found to contain resistance genes to the sugar beet pathogen *Rhizomania* and was used to breed resistant varieties in the 1980s (Doney & Whitney, 1990), and it is still used as an important genetic resource for beet breeding (Asher *et al.,* 2009).

4.3.2 Genetic variation and structure

Brassica and related cruciferous genera are particularly well represented as CWRs in the UK (28 taxa), which potentially contain genes that could be used to improve the increasingly important oilseed rape crop, and the large and diverse brassica vegetable crops. Well known examples include wild cabbage, and wild turnip, which have both had their UK range of genetic variation studies (Watson-Jones, *et al.,* 2005). The observed distribution of genetic variation in these two taxa highlights the potential difficulty of preserving CWR variation in general (also summarised in Hopkins & Maxted, 2011). Wild cabbage diversity was found to be homogenous over its range, despite having a restricted, local range, while wild turnip populations were found to be more distinct from each other. Such population genetic structure influences the best conservation approach. Genetically distinct populations or groups can exist due to local adaptation, isolation, or drift. These genetically isolated groups are likely to contain genetic variation which is not found in the rest of the taxon’s distribution and are therefore important to conserve. Hence, prior studies of the population genetic structure can be useful in informing conservation management approaches.

4.4 CONSERVATION APPROACHES

Strategies for the preservation of plant genetic diversity, including CWRs, can be either *in situ* or *ex situ. In situ* approaches are largely encompassed by UK conservation schemes where species, habitats and/or sites are given legal protection, through the Wildlife and Countryside Act 1981, SSSI status, etc.; However some particularly rare and important species may require special *in situ* measures, for example Plymouth pear, which has only two small populations.

Ex situ measures usually take the form of germplasm collections, of which several exist in the UK for crop varieties, and include some CWRs. Although germplasm collections provide very valuable resources for plant breeders and researchers, due to the time and expense required for their maintenance they do not tend to hold large numbers of individual taxa or varieties and may therefore be prone to under-representing intraspecific variation of the kind that is needed for exploitation of CWR’s useful and possibly rare alleles.

Hence, *in situ* conservation of species is usually preferable, and *ex situ* should be viewed as a fall-back or last resort measure for conservation. However a complication to *in situ* measures exists when attempts are made to restore plant populations in degraded sites: a local gene pool may contain unique alleles and may be depleted in numbers; when restoration is attempted without using local genotypes, they can be lost through competition or introgression and drift.

4.5 ENVIRONMENTAL STEWARDSHIP OPTIONS

4.5.1 Traditional breeds and varieties

The conservation of genetic diversity is a secondary rather than a primary objective of Environmental Stewardship. Options are limited but include a rare breeds supplement for livestock in HLS and HLS options for the creation, restoration and maintenance of traditional orchards.

4.5.2 Crop wild relatives

There are no Environmental Stewardship options that specifically target the preservation of CWR diversity, although many will indirectly affect CWRs. Table 1 shows those current options which will impact CWRs and notes on the main CWR groups affected. Several HLS option groups are subdivided into maintenance, restoration and creation. These options can have different implications for CWR diversity, maintenance of existing diversity being the most preferred, followed by restoration and creation. This is because restoration and creation are increasingly likely to either fail to conserve local diversity (or indicate that it is already lost), or to actually dilute it and cause its loss, especially if they are performed without study of the remaining CWR diversity.

We have assessed the relative beneficial impact of ES options on CWRs in terms of preservation or their preferred environment and their genetic diversity. Scores have been assigned based on assessment of the numbers of CWR taxa expected in affected environments and the importance of the CWRs (value of related crop). (see section 7.1 and Appendix).

Among the most beneficial habitats are species-rich meadows (including water meadows), which contain diverse and important CWRs, e.g. wild carrot *Daucus carota* ssp. *carota* and wild parsnip *Pastinaca sativa* ssp. *sylvestris* (Maxted *et al.,* 2007). Options involving their conservation are therefore especially useful. Saltmarsh is the only specifically coastal environment listed in the ES options. It has been given a high score for being an important environment for sea barley *Hordeum marinum*, beet *Beta vulgaris* ssp*. maritima*, wild celery *Apium graveolens* ssp. *Graveolens* and wild leek Allium ampeloprasum among others. However, important coastal CWRs (e.g. wild cabbage *Brassica oleracea,* wild asparagus *Asparagus prostrates*) are not represented in ESS options because they do not include sea cliff conservation or management. Consideration could be given to the creation of a cliff management option in HLS. This would however, have to be carefully drafted and flexible to allow for site specific management plans to be developed to suit the species concerned. As ES is an agri-environment scheme primarily directed at farmers, it would need to be carefully considered whether this was an appropriate mechanism for conservation of these species.

Appropriate management of hedgerows may benefit many taxa, particularly fruit shrubs and trees such as crab apple *Malus sylvestris* and bird cherry *Prunus avium*. If ES options involve a reduction in cutting frequency compared with previous practice, this is likely to be beneficial in terms of the health of the hedgerow shrubs and increasing the opportunities for flowering and seeding. It may also benefit any CWRs in verges, as passage of cutting machinery may damage plants growing there.

Buffer strips may protect CWRs growing in adjacent habitats, but will only provide direct benefits if locally sourced seed is used. Use of non-local genotypes may be detrimental where similar CWRs already exist, as competition with and introgression into local gene pools can result in loss of locally adapted alleles (see above). Similar comments apply to options for field corners.

Pollen and nectar mixtures are likely to be sown with non-local genotypes and therefore be detrimental. This also applies to wild bird seed mixtures, but these may also provide an opportunity for ruderal CWRs such as charlock *Sinapis arvensis* to flower and set seed, as may options involving reduced herbicide use such as conservation headlands, uncropped cultivated strips, reduced herbicide cereal crops followed by a winter stubble, and low input spring cereals.

Grazing of semi-natural habitats such as salt marshes may be detrimental if it damages CWRs and encourages the spread of other more species that are more resistant to grazing. Conversely, grazing may be beneficial where the area has become dominated by a few competitive plant species, by opening up the sward and allowing less competitive species to grow. Selection of livestock species, timing of grazing and stocking rates need to be carefully considered to ensure a positive outcome.

5 PEST REGULATION

5.1 INTRODUCTION

The regulation of pest species by natural enemies can provide a valuable service to agriculture, at the same time reducing the need for pesticide use, and hence has been the subject of a considerable amount of research. The control of crop pests by their natural enemies and the enhancement of this process through actions that preserve or protect natural enemies is termed conservation biological control (Ehler, 1998). There are two key practices: 1) habitat manipulation that improves the resources for natural enemies and 2) a reduction in pesticide-induced mortality of natural enemies. These two actions can potentially also create a positive feedback cycle termed the “IPM Treadmill” (**Error! Reference source not found.**) (Tait, 1987).

Figure 5.1 The Integrated Pest Management treadmill

The aim of habitat manipulation is to increase the provision of resources for natural enemies without also encouraging the pests. This in turn is assumed to diversify the species composition of natural enemies, and increase their abundance and distribution across the landscape both spatially and temporally. A reduction of pesticide inputs can directly benefit natural enemies through a reduction in mortality or sub-lethal effects from insecticides. There may also be indirect benefits such as preservation of alternative prey or increase in weed cover from fewer herbicide inputs that creates improved environmental conditions or plant food sources.

A reduction in pesticide inputs is desirable for many reasons and has far reaching benefits. Natural and social science research highlight the potential negative environmental effects of pesticides on biodiversity and water catchments (e.g. Pretty *et al.,* 2000, Foster & Mourato, 2000; Tilman *et al.,* 2002) and concerns over pesticide residues within the Food Chain (e.g. van Ravenswaay & Hoehn, 1991; Eom, 1994). In addition, certain retailers have set objectives to supply produce completely free from pesticide residues (e.g. Marks & Spencer – Pesticides News 2001). Revisions to EU pesticide regulation (91/414) are leading to withdrawal of many pesticide products currently in use, especially in the horticultural sector and alternative pest control strategies are needed. Finally, conservation biological control (CBC) increases the sustainability of crop production, a key government policy (Anon, 2010). Thus, there exists a real demand for improved CBC from a range of stakeholders across the food chain. CBC also benefits farmers by reducing the incidence of harmful pest outbreaks, and allows them to save money on buying and applying pesticides, thus increasing gross margins and potential profitability.

The current situation for field–grown crops is that all pests are controlled to some extent by their natural enemies and chemical intervention is only needed when pests escape from this natural regulation. Whether sufficient control occurs is determined by many interrelated factors. Theory suggests that the level of CBC will improve with natural enemy diversity and this alone may be a good measure of this ecosystem service, however, this is not always the case.

For example, in a recent study of the effect of landscape, habitat diversity and management on species diversity in cereal systems, Weibull *et al*. (2003) revealed that there was no straightforward relationship between species richness of carabids, rove beetles, and spiders, at either the farm level or in individual cereal fields, and biological control. They concluded that species richness in itself is not as important as a high diversity of different guilds of predators, such as ground and foliage predators, spring and summer breeders, day and night active species, for the overall efficiency of biological control. That is, the key to effective natural control is in maximizing functional complementarity among the natural enemies of pest species.

Unfortunately, our understanding of complementarity and the factors determining the emergent properties of multi-species predator assemblages are limited (Schmidt *et al.,* 2003). While there is evidence that there is significant niche partitioning across microhabitats and functional complementarity among spider species (Sunderland *et al*., 1999), for example, few other studies have shown significant complementarity among natural enemies (Snyder & Wise, 1999). Similarly, whilst examples of synergistic interactions between predators exist (e.g. foliar predators eliciting dropping responses in aphid prey which increases their vulnerability to ground-foraging predators (Losey & Denno, 1998), processes such as intra-guild predation can severely disrupt biological control (Rosenheim *et al.,* 1995; Snyder & Ives, 2001) and overall the process of biological control is highly complex depending not only on species richness, but the relative abundance of different species and guilds whose relationships may change through time. This complicates the process of evaluating the potential of ES options. Data may exist on natural enemy species composition and/or abundance within the habitat but evidence on how this influences levels within the crop will also be needed. Even this information may not be sufficient if it is the ratio of different species/guilds that is important, with further complications arising as these relationships vary through time and for different pests.

A further challenge in evaluating biocontrol relates to effects of scale of adoption. Although it can be shown that the installation and management of semi-natural habitats, such as field margins and beetle banks, can significantly increase the density of insect predators and parasitoids within these habitats, it is not yet known whether these habitats are actually increasing populations of these beneficial insects within the whole ecosystem, or simply affecting their local distribution. If the latter is the case, then it could be hypothesised that the pest management benefits of habitat diversification on arable farms will reduce as the scale of its implementation in the landscape increases. That is, if the initial positive effects of an intervention demonstrated at the single field level (the usual scale in developmental research) derive from local redistribution, then not only might this be at the ‘expense’ of natural pest control in adjacent fields (generally not tested), but the effect will saturate out when the scale of adoption exceeds the ecological scale over which the redistribution occurs. A reverse scenario may also occur whereby the habitats created prove more attractive than the crop to natural enemies so leading to a depletion of biological control. On the other hand, a contrasting scenario is also possible whereby the effectiveness of a technology could increase with increased adoption due to synergistic effects arising in the move from field to farm to landscape scales. Such synergies are most likely if population size is affected, though not necessarily exclusively so.

Finally, the composition of the non-crop habitats in the surrounding landscape can have an impact on the level of CBC. There is evidence that biological control is higher in complex compared to simple landscapes (Thies & Tscharntke, 1999; Ostman *et al.,* 2001). More robust biological control may be expected in complex landscapes as a consequence of species complementarity and niche separation because resources are abundant across a range of scales and a greater range of species are able to exist (Loreau & Hector, 2001). However, this theory is not always supported in practice; the diversity of cereal aphid parasitoids was the same in simple and complex landscapes and it was assumed that the parasitoids could obtain all the necessary resources in simple landscapes (Vollhardt *et al.,* 2008). Levels of biological control may also be mitigated by intra-guild predation of natural enemies (Rosenheim, 1998), while pests may be better able to exploit the resources of the uncropped land and so sway the natural enemy:pest ratio in their favour (Baggen *et al.,* 1999). In contrast, within simple landscapes there may be fewer natural enemies allowing pests to escape their control more frequently and this may explain why levels of biological control improve when more resources for natural enemies are provided through an increase in uncropped land (Thies & Tscharntke, 1999; Tscharntke *et al.,* 2002). Thus the debate continues as to whether the value of extra non-crop habitats is more effective in simple or complex landscapes.

This review focuses on above ground pest control although there may also be biological control occurring within the soil. The soil of AES habitats may be biologically more active than the cropped areas if there is less soil disturbance and return of organic matter (Smith *et al.,* 2008). However, most AES habitats are created along field boundaries or in less productive areas and because soil organisms are relatively immobile, there may be little impact within the field. There may be some exceptions, for example, if pests overwinter in perennial habitats outside of the crop and are subsequently attacked by the local soil dwelling natural enemies and pathogens. The extent that this occurs, and even the overwintering location of some agricultural pests, is poorly understood. If AES habitats are returned to cropping, especially those that were perennial, there may be higher levels of soil antagonists which may create benefits in the following crop or in some cases damage (e.g. frit fly and leatherjackets after grass), but this has not been investigated.

Natural enemies require a number of essential resources if they are to thrive and have significant impacts on pests; these are (Holland & Oakley, 2007):

1) Pollen and nectar: Floral resources are utilised by a broad range of predators and parasitoids because they provide energy and can act as an alternative food source (Wäckers, 2005). For parasitoids, a source of non-host food can influence many facets of their biology that ultimately affect the levels of biocontrol achieved; for example, longevity, mortality rates and fecundity, while locating these food sources adjacent to the crop improves searching efficiency (Olson *et al.,* 2005).

2) Shelter habitats: Predators that overwinter outside the cropped area benefit from the provision of habitats that create the correct environmental conditions and protect them from predation (Griffiths *et al*., 2008). Tussocky grasses associated with field boundaries have been shown to support a range of Coleoptera and Araneae, and hedgerows and woods may also provide suitable conditions for the more widely dispersing species, although this has been less well studied. In addition, such habitats may also allow pests and their parasitoids to survive the winter, ensuring their supply in the following season. A range of important natural enemies including beetle larvae, parasitoids and spiders also overwinter within the soil, along with predators that reside all year round within or on the soil (e.g. centipedes). Intensive tillage can destroy natural enemies; however, the impact will vary according to the vulnerability of life stage present and the timing of cultivations. As the majority of invertebrates will not emerge until April, cultivations that occur before this time are considered potentially damaging.

3) Alternative prey: Pests may not be present throughout the natural enemies' foraging lifetime and therefore a source of alternative prey or hosts is needed to ensure survival and to maximise reproductive potential. These may be present within non-crop habitats or a crop. For soil living natural enemies a source of diverse organic matter is needed on which alternative prey (e.g. bacteria, fungal feeding nematodes) can thrive.

4) Appropriate environment: Invertebrates vary in their occurrence within different habitat types because they have preferences for different environmental conditions (humidity and temperature) or foraging strategies. Web-building spiders need complex structures within which to build webs whilst hunting species (e.g. Lycosidae and some Carabidae) require more open habitats. Pesticides and some other farming operations e.g. tillage, can also directly and indirectly reduce the abundance and diversity of natural enemies (Jepson, 1989) and therefore they require refuges free from disturbance. In addition, the impact on local populations of any disturbance will be governed by the extent of their distribution in relation to the proportion of area affected. Non-crop habitats and untreated cropped land can act as refuges from which treated fields can be repopulated, although repopulation by some soil dwelling organisms that are less mobile is unlikely to occur (Smith *et al.,* 2008).

In this review, the potential impact of ES options on levels of CBC was appraised by examining the level of resource provision provided for natural enemies and measurements of the natural enemy fauna within each habitat, but given the caveats outlined above, further quantitative evidence was sought of changes in natural enemy abundance within the crop (for which some caveats still apply) and an impact on pests.

5.2 APPROACH

The options in ELS, OELS and HLS were grouped according to the type of habitat that was being enhanced or created. For example, all the hedgerow options were grouped. Each habitat type was the given a subjective score according to the level of each of the five essential resources that they provide. If there was some uncertainty then this was highlighted. Options for arable and grassland are combined because some natural enemies are highly mobile and may potentially move between arable, mixed or livestock only farms.

In view of the large amount of published literature available on this topic, a semi-systematic approach was adopted. The following Web of Knowledge databases were searched using the search terms detailed below:

- Web of Science 1970-present
- CABI 1973-present
- Biosis Previews 1969-2008
- Current Contents Connect 1998-present

Searches were carried out using the terms: (biological control OR biocontrol OR natural enemies OR integrated pest management) NOT (disease OR medic* OR vetin*) and each of the following separately: (grass margins), (wild bird seed OR wild bird cover), (wildflower OR floristically enhanced), (beetle banks), (conservation headlands OR unsprayed headlands OR cereal headlands), (low input) AND (cereal OR arable), ((hedge OR hedgerow OR ditch), ((fallow OR set-aside), (winter cover crops), (grassland AND invertebrates).

The searches were restricted to references with addresses for UK or France or Germany or Netherlands or Holland or Denmark or Sweden or Norway or Switzerland, however, only information for the UK is used if available as habitats created under agri-environment schemes in other European countries differ to those in the UK as does some of the invertebrate fauna. In addition, the Defra science base of research projects was similarly searched along with references databases held by GWCT, compiled by Dr JM Holland and Dr KD Sunderland.

These terms were found to select the majority of appropriate references because not only were studies on the invertebrate fauna of these habitats selected, but also studies of their abundance in adjacent crops and impact on pests.

5.3 RESULTS

The options within ELS and HLS were grouped according to the type of habitat that was being preserved, enhanced or created. The category “shrubby vegetation” encompassed those options that were targeted at the woody vegetation and included all the hedge management options or those designed to allow scrub to develop. The category “Protection/creation of uncultivated ground flora” comprised those options that encouraged a perennial, grass dominated ground flora to develop and included all the buffer zone options. The remaining categories are self explanatory. For some categories no published evidence could be found that the resources were being provided and in these cases the scoring was based upon the flora present and what it would be expected to provide using expert opinion. Despite the large amount of research that has been carried out on biocontrol, overall there was a dearth of information pertaining to the use of the resources provided by ES options by natural enemies and even less on their impact on both natural enemies or pests within the adjacent crops.

For each habitat type, the level of each of the four main resources enumerated above (floral resources, shelter, alternative prey and appropriate environment) was determined, although in some cases the levels are based upon expert opinion as no published evidence was available (Table 5.1). Overall the more complex habitats would be expected to provide the broadest range of resources.

The numbers of natural enemy species in each family likely to occur in arable crops was determined by Holland & Oakley (2007). Whether these taxa also occur within each habitat category was also determined and the key references provided (Annex 5.1). However, the absence of a taxon does not necessarily mean it is not present, because it may not have been recorded. The sampling approach and invertebrates selected for identification varied in each study, biasing what was reported. Consequently it is not possible to compare habitat categories according to their natural enemy diversity or guild richness, which is an important factor determining the effectiveness and robustness of pest control (see above).

5.3.1 Hedgerows and shrubby vegetation

This habitat is one of only three which would be expected to provide all of the four key resources for invertebrates (Table 5.1). They are considered to harbour an enormous diversity of invertebrate species, 1500 species according to the Hedgerow Biodiversity Action plan (Anon., 2011) and from 70 families (Pollard & Holland, 2006). Areas that become scrub will comprise hedgerow species, but they would be expected to be less floristically diverse and therefore contain an impoverished fauna compared to a hedgerow, although this has not been specifically investigated.

5.3.1.1 Evidence that habitat supports natural enemies

The ES options for hedgerows, through cutting every other year, will allow the woody perennial component to produce flowers that would not otherwise flourish with annual cutting. However, annual cutting encouraged more vegetative growth and had a positive effect on herbivorous insects (Maudsley *et al.,* 2000) that may then act as alternative prey for natural enemies. Greater invertebrate diversity was found in cut compared to uncut hedges, but the proportion of predatory invertebrates was similar (28%). In remnant hedges that have suffered from poor management, the predatory fauna only formed 15% of the total (Sotherton, 1981). Cutting was found to increase berry production of non-woody species (e.g. brambles) (Maudsley *et al.,* 2000), and presumably flower production although this was not measured.

In contrast, more mobile invertebrates (Hymenoptera and Diptera) were less abundant in early summer when hedges were cut annually, either because fewer flowers from woody plants were available or because there was less wind shelter. The flowering species typically found within a hedgerow flower throughout the year, but are a particularly valuable source of early and late flowering species, so extending the period over which pollen and nectar is available for natural enemies. However, the extent to which these floral resources are utilised by natural enemies is not well understood, though considered important for Syrphidae (Cowgill *et al.,* 1993a; van Rijn & Smit, 2007), Anthocoridae (Sigsgaard & Kollmann, 2007) and lacewings (Bowden & Dean, 1977). They are also considered to attract parasitic wasps (van Emden, 1963), however most species were observed foraging predominantly on Umbelliferae growing alongside the hedge (Jervis *et al.,* 1993).

The value of the shrubby component of the hedge as an overwintering habitat is not well documented. In winter, hedgerows were found to contain spiders (Maudsley *et al.,* 2002) and Coccinelidae (van Emden 1965). When the emergence of overwintering invertebrates was measured using pitfalls located at the hedge base in completely enclosed hedge sections, a greater range of taxa was collected, but invertebrates may have overwintered in the hedge base (Griffiths, 2003; Griffiths *et al.*, 2007). This part of the hedgerow is known to harbour high densities of natural pest enemies, provided that the distance from the centre of the hedge is no more than 2 m it will be protected from agricultural inputs under cross compliance regulations (GAEC 14) and is not considered here. The presence of a well established hedge base or ditch can however lead to a greater invertebrate diversity within the hedge (Pollard, 1968; Maudsley *et al.,* 1997). Similarly, the presence of mature trees along a hedgerow also added structural diversity and a specialised habitat for some invertebrates, for example Diptera (Peng *et al.,* 1992).

5.3.1.2 Evidence of impact on natural enemies in the adjacent crop

Little information could be found showing that the presence of a woody hedgerow had an impact on the invertebrates within the adjacent field, and none of the studies identified had investigated whether changes in hedgerow management had an impact either on the predators or levels of pest control in adjacent fields for the UK. The effect of hedgerows on natural enemies in orchards has been investigated in several European countries and was reviewed by Simon *et al*. (2010). Natural enemies were more abundant in trees nearest the hedge and a gradient of density from the hedgerow towards the orchard was found for some species e.g. lacewings. However, such gradients are not always found, nor was there a correlated impact on pests and some pests were able to utilise the resources provided by the hedge. Likewise, grain aphids in arable crops originated from adjacent hedgerows in some years (Vialatte *et al.,* 2007).

In a spatially explicit model, the impact of shape, area, and fragmentation of non-crop landscape elements on overwintering of the coccinelid, *Coccinella septempunctata* and thereby aphid control in arable crops was examined (Bianchi & van der Werf, 2003). Landscapes with 9 and 16% non-crop habitat supported enough *C. Septempunctata* to control aphid infestations and this was best when small hedgerow elements were evenly distributed across the landscape.

Table 5.1 Resources provided for natural enemies by each Environmental Stewardship category

ES Option	Floral resources	Shelter	Alternative prey	Appropriate environment
Shrubby vegetation: EB1-3, EB8-10, EC4; HB11-12,HC15-17,HC11	*** ?	***	***	***
Trees: EC1-2, EC23; HC5-6, HC12-14, HC7-8, HC9-10, HC18, HC20-21	***?	***	***	**
Protection/creation of uncultivated ground flora (predominantly grassy): EB6-7, EB8-10, EC3, EC24, EC25, ED5, EE1-10, EF1, EJ5, EJ9, EJ11, EK1,EL1; HB14, HD7, HJ3-4, HJ6, HE11,	*	***	***	**
Wild bird seed mixture: EF2; HF12	* ?	* ?	***	**
Flower rich habitats: EC24,EF4;HE10,HK18	***	**	***	***
Overwintered stubbles: EF6,EF15,EG4,	N	**	*	*
Beetle banks: EF7	N	***	***	**
Cereal with reduced herbicide inputs and no fertiliser: EF9, EF15; HF14, HG7	*	N	***	***
Undersown spring cereals: EG1	N	***	**	**
Uncropped, annually cultivated margins: EF11; HF20	**	N	**	***
Non-inversion tillage: ED3, EF22;HD6	N	***	**	N
Low input grassland: EK2-3, EL2, EL2-3, HK6-8, HK15-17, HK11	**	**?	***	**

NOTE: (*** = high benefit, *** = moderate benefit, * = some benefit, N = no benefit,? = resource expected to occur but no published evidence)

5.3.2 Protection/creation of uncultivated ground flora (predominantly grassy)

These habitats provide shelter and a source of alternative prey (Table 5.1). In addition, the perennial nature of these habitats creates stable soil conditions and will allow organic matter to increase, supporting more soil dwelling organisms than the adjacent crop (Smith *et al*., 2008). This would be most noticeable at the base of hedgerows. Floral resources would not be expected as discussed below. When established as a buffer zone, there may be recipients of some agricultural inputs via drift, with narrow strips having a greater proportion of the area affected.

Many options within ES aim to protect the ground flora either adjacent to habitat features (e.g. hedge or ditch) through creation of a buffer zone or on features such as an ancient monuments, although the area occupied by the latter is small and therefore less significant at a landscape scale. In addition, field corners may be taken out of production and allowed to naturally regenerate or sown with an appropriate mixture. The flora of such habitats is determined by their method of establishment and consequently dictates the invertebrate fauna (Thomas & Marshall, 1999). If created by sowing with a simple grass mix e.g. a "Countryside Stewardship" mix, then the resulting flora will eventually comprise predominantly tussock-forming grasses. Even when fine grass species are included in the seed mix, they tend to become dominated by the more aggressive tussock-forming species such as cocksfoot (*Dactylis glomerata*) (Critchley *et al.,* 2006). If established through natural regeneration then the flora will reflect the local seed bank, but is often more diverse than strips sown with only grasses (Critchley *et al.,* 2006) and develops greater diversity over decades (Gibson & Brown, 1992). Over time, the margins originally sown with just grasses did not develop floristic diversity but if forbs were included in the original seed mix then these were maintained through annual cutting (Critchley *et al.,* 2006). All options which are created either by sowing grass mixes or through natural regeneration are included in this section.

5.3.2.1 Evidence that habitat supports natural enemies

A considerable amount of research has been carried out on the benefits of grassy field margins for natural enemies. The primary benefit of grass dominated field margins is as overwintering sites for beetles and spiders. Tussock-forming grasses (e.g. *Dactylis glomerata* and *Holcus lanatus*) provide appropriate and relatively stable conditions during the winter (Luff, 1966) and resulted in greater invertebrate survival compared to other plants structures (D'Hulster & Desender, 1982). In autumn and spring, grass margins that were either sown or established through natural regeneration were found to contain predatory beetles (Carabidae, Cantharidae, Coccinelidae and Staphylinidae), Opiliones, Araneae (Lycosidae & Linyphiidae) and Heteroptera (Anthochoridae) (Meek et al, 2002). In winter a diverse range of carabid and staphylinid species and spiders from the families Lycosidae, Linyphiidae, Tetragnathidae and Clubionidae were found (Pywell *et al.,* 2005) and other beneficial species including Isopoda, Coleoptera and Lumbricidae (Smith *et al*., 2008. Grass margins also support a diverse range of alternative prey including phytophagous invertebrates (Woodcock *et al.,* 2008) and the hosts of parasitic wasps (Powell & Pickett, 2003).

The abundance of natural enemies in grass margins, in comparison to some of the other ES habitats, was examined in several studies (Thomas & Marshall, 1999; Kirkham *et al.,* 1999; Arable Stewardship Pilot Scheme; Meek *et al.,* 2002; Pywell *et al.,* 2005; BD1624: Buzz Project; LK0926: SAFFIE project; LK0971: Farm4bio project).

In a comparison of rye grass (*Lolium perenne*) strips, floristically enhanced grass (FEG), natural regeneration and the crop, no difference was found in the numbers of four carabid species and overall carabid diversity captured by pitfall trapping (Thomas & Marshall, 1999). The abundance and diversity of a range of natural enemies collected by suction sampling in summer was generally highest in the hedge base, next highest in the margins left to natural regeneration and least in grass margins sown with rye grass and the crop. The abundance of overwintering natural enemies in the grass margins was generally lower than the hedgerow but higher than the crop.

Carabidae, Staphylinidae and Araneae abundance and diversity were measured using pitfall trapping and turf samples in a basic grass mixture, tussocky grass, diverse grass, diverse grass plus wildflowers and natural regeneration (Kirkham *et al.,* 1999). As with all studies using pitfall traps, any comparison of abundances between habitats with different vegetation structures must be treated with caution because of the reliance on activity for capture, which is influenced by vegetation density (Thomas & Marshall, 1999). The technique is more robust with respect to comparing diversity. Comparing the data from the turf and pitfall samples confirmed that the sward density was affecting the results for the pitfall trapping and consequently the abundances are not considered. The turf sampling revealed a positive relationship between carabid abundance and plant diversity. The grass mixes contained few Carabidae compared to the wildflower mixes, but there was no difference between the habitats for Staphylinidae and Araneae.

In the ecological evaluation of the arable stewardship pilot scheme, the abundance and diversity of carabid beetles was measured using pitfall trapping in a range of the options including grass margins in comparison to a winter wheat margin (control) (Gardner *et al.,* 2001). Sampling was started in October/November to measure use by overwintering beetles and continued into the following year (samples taken in May and July). As expected, the abundance of carabid adults and larvae and species richness were no higher in the grass margins compared to the control on any sampling occasion. This was expected because the margins were less than one year old at the time of sampling and had not yet developed tussocks. There was some variation in species composition between grass margins and controls attributed to the differences in vegetation composition and environmental conditions. Meek et al. (2002) also used pitfall traps operated in spring and autumn to measure invertebrates in 6m grass margins established by natural regeneration, sown with a tussock-forming seed mix, enhanced with wildflowers, split with half tussock-forming grasses and half grass and wildflowers and a crop. There was no difference in the abundance of Carabidae and spiders or species richness of Carabidae between the grassy habitats but all were better than the crop. Sweep netting revealed that Coccinelidae were higher in the grassy habitats compared to the crop but two other predators, *Cantharis nigricans* (Cantharidae) and *Anthocoris nemorum* (Anthochoridae), were similar across all habitats.

The overwintering densities of Coleoptera and Araneae was measured using soil coring in a mature field grass margin, 3-4 year old sown tussocky grass margin, mature hedge base and newly planted hedge base (2-5 years) (Pywell *et al.,* 2005). The abundance or richness of carabid beetles and spiders did not differ between the habitat types or with their age. The abundance and cumulative richness of staphylinid beetles was higher in the hedgerows compared to field margins. There was no effect of habitat age on abundance or diversity of Staphylinidae. Likewise, the age of a sown grass margin (2-6 years old) had no effect on the abundance of overwintering Carabidae, Staphylinidae or Araneae collected using a Vortis suction sampler, however, all these taxa and total predatory invertebrates were more abundant in the hedge base compared to the grass margin (Figure 5.2) (Holland *et al.,* 2009; Birkett, unpublished).

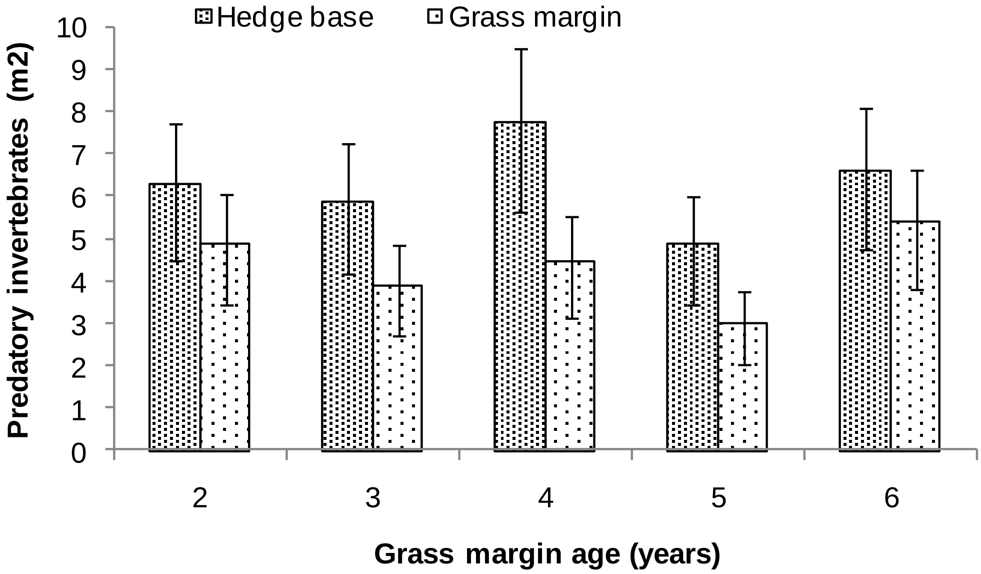

Figure 5.2 Density of predatory invertebrates in grass margins of different age and the adjacent hedge base

In the Buzz project (BD1624), the density from soil cores of overwintering Carabidae, Staphylinidae and Araneae was highest in tussocky margins compared to Conservation Headlands, margins established through natural regeneration, pollen and nectar or wildflower margins (Pywell *et al*., 2007). However, taking the mean value over five years from pitfall trapping in spring revealed that the species richness of predatory invertebrates in tussocky grass margins was lower than natural regeneration and was no better than the other treatments. They also had the lowest seed predator species richness. As discussed above, the use of abundance data from pitfall traps should be treated with caution. The autumn pitfall trapping showed that the tussocky grass margins had the lowest diversity and abundance of invertebrate predators and seed predators, but this could have been a result of reduced activity. There was no difference between the tussocky grass margins and the other margin types for predator and parasitoid species richness nor parasitoid abundance (Final report BD1624).

In the SAFFIE project (LK0926) the invertebrates present within three margin habitats (grass only, tussocky grasses and forbs, fine grasses and forbs) were measured in summer using a suction sampler. The abundance of predatory beetles was similar in grass-only (became dominated by tussocky grasses) compared to a mix of tussocky grasses and forbs, and higher than margins with a combination of fine grasses and forbs (Woodcock *et al.,* 2008). There was no effect on the phytophagous beetles.

In the Farm4bio project (LK0971) the invertebrates present within four project managed habitats (natural regeneration, wild bird seed mixture, insect rich cover and floristically enhanced grassland) and a range of other habitats commonly created on farmland were measured in summer using a suction sampler. At present only data for the four project managed habitats, grass margins and game cover has been analysed for the three treatment years. In addition, transect walks to determine pollinator abundance were conducted during June and late July and these included an assessment of hoverfly numbers. In the suction samples taken in July the abundance of predatory natural enemies was 29% higher (Figure 5.3) and parasitoids 23% lower in the grass margins compared to the mean value for the other five habitats (Figure 5.4). In grass margins during June, hoverflies were 18% lower than in FEG but twice as abundant as in the other habitats. By July, however, numbers in grass margins were less than half those in all the other habitats (Figure 5.5).

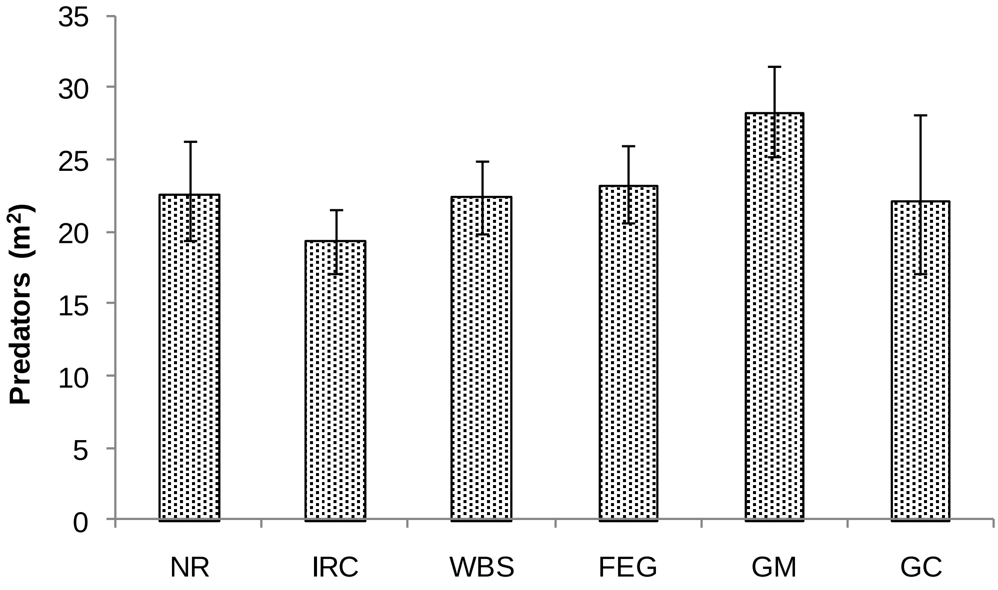

Figure 5.3 Density of predatory invertebrates in six different habitats. Source farm4bio project (NR=natural regeneration, IRC=Insect Rich Cover, WBC=Wild bird Seed mixture, FEG=Floristically Enhanced Grassland, GM=Grass Margins, GC=Game Cover)

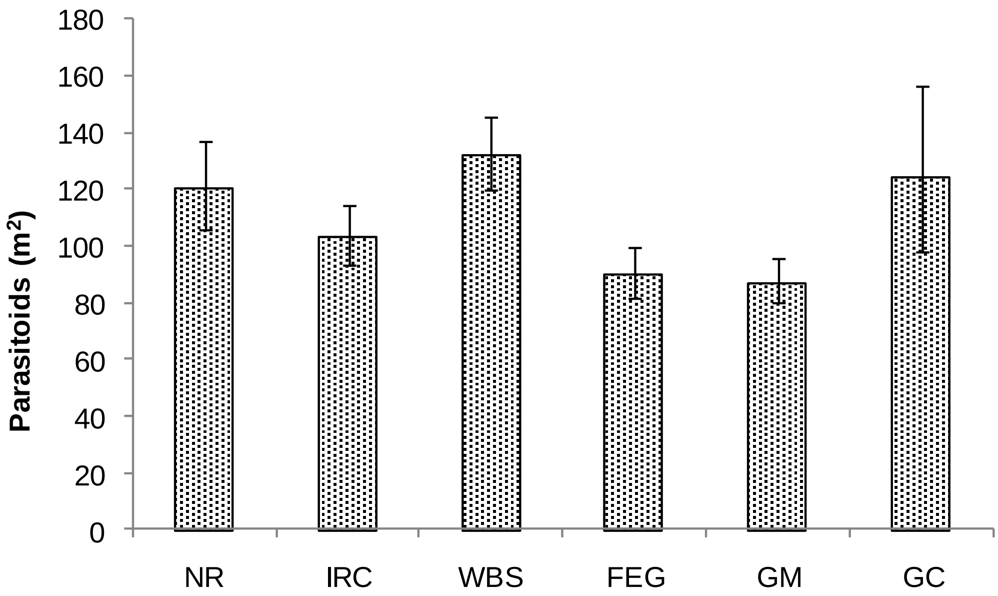

Figure 5.4 Density of parasitoids in six different habitats. Source Farm4bio project (see fig. 3 for notation)

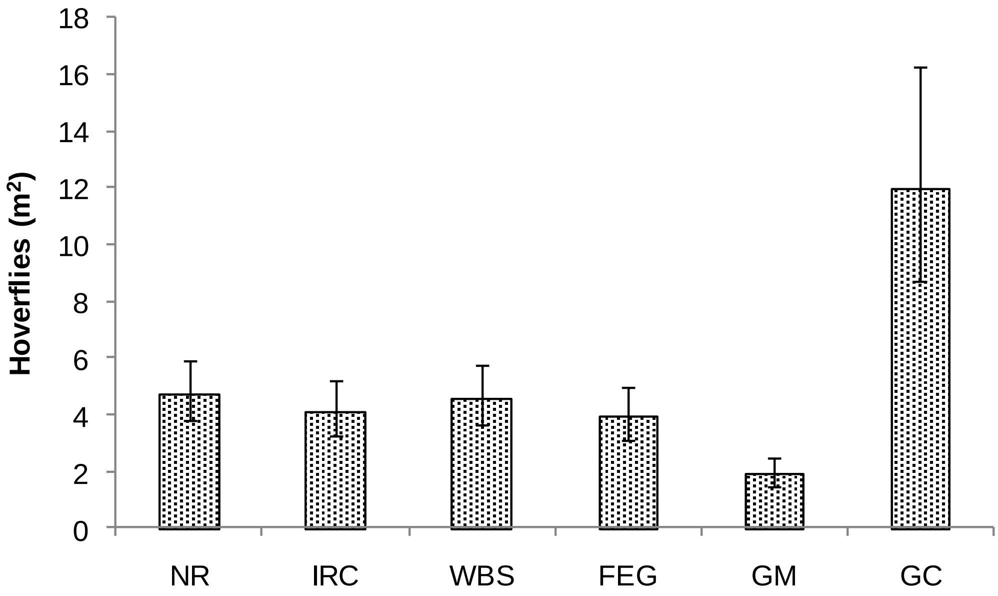

Figure 5.5 Density of adult hoverflies in six different habitats. Source Farm4bio project (see fig. 3 for notation)

5.3.2.2 Evidence of impact on natural enemies in the adjacent crop

The impact of two margin types (tussocky grasses and forbs, fine grasses and forbs) on invertebrates within the adjacent winter wheat crop was examined in the SAFFIE project (Cook *et al.,* 2007). There was no significant effect of the sown margins on the invertebrate groups collected using pitfall traps, suction sampler or sweep net, either along transects extending from the margins or when only samples taken mid-field were considered. Of all the invertebrate groups, the numbers of boundary overwintering Carabidae and Staphylinidae in the adjacent crop, as measured using pitfall traps, would be most expected to respond to the additional overwintering habitat provided by the sown margins. The lack of any effect may have resulted from the experimental design: a) only half the margins were sown with tussocky grasses, the remainder were sown with fine grasses that may be less suitable for overwintering; b) beetles remaining within the margins; (in another study, approximately a third of the Carabidae and half the Staphylinidae measured during the winter remained within field boundaries during the summer; Thomas *et al*., 2000); c) beetles redistributed by the time of sampling and mixed with those originating from areas beyond the field, (species capable of flight can achieve rapid coverage across the whole field; Coombes & Sotherton, 1986; Kromp & Nitzlader, 1995), masking any margin effects; d) margins supported too few invertebrates to have any impact on field populations (Holland *et al.,* 2006).

In a study encompassing forty two fields, half sown with 6 m grass margins, the abundance and species richness of Araneae and the weight of Carabidae mid-field collected by pitfall trapping was not affected by the presence of a grass margin (Marshall *et al.,* 2006). Of the Araneae, the more mobile Linyphiidae that disperse by ballooning were unaffected by the 6m margins, however, the Lycosidae that disperse by walking, showed a response that varied with field size. They were more abundant in small compared to large fields with 6m margins, indicating that some enhancement was occurring.

The extent to which landscape features and especially sown grass margins influenced the abundance of flying natural enemies was examined as part of the

RELU funded project ‘Re-bugging the system’ (Bailey et al., 2009). The distribution of flying aphid predators was examined within twelve winter wheat fields using sticky traps (Oaten *et al*., 2008; Oaten, 2011). In addition, all uncropped land within 1000 m radius, in increments of 50, 100, 250, 500 and 750 m, of each field was measured and entered into a GIS and the impact on aphid predators (specifically Cantharidae, predaceous *Tachyporus spp.* (comprising *T. hypnorum, T. chrysomelinus* and *T. obtusus*), Empididae and Linyphiidae) was assessed. This included determining whether proximity to the nearest field margin was a factor influencing the abundance of aphid predators. The abundance of Cantharidae was negatively correlated with the proportion of field margin within 100 and 250 m, indicating that the margins could be ‘pulling in’ these predators from the fields. In contrast, predaceous *Tachyporus spp.* were positively correlated with field margin density for 500-1000 m, showing that fields were acting as a source.

5.3.2.3 Evidence of impact on pests

Whether grass margins enhanced cereal aphid control was also tested in the ‘Re-bugging the system’ project (Bailey *et al.,* 2009). Exclusion cages of different types were used to quantify predation and identify which guilds of predators were responsible (ground-dispersing or flying). Levels of cereal aphid control were positively related to the proportion of linear grass margins within a 250-750m radius of the study areas. Control was attributed to flying natural enemies, which were largely composed of predatory Diptera and Linyphiidae (Araneae) (Holland *et al.,* in prep). However, the same fields were used as in the study by Oaten (2011) and for which neither Linyphiidae nor Empididae (Diptera) exhibited a response to the proportion of field margins. Whether the rate of aphid predation was affected by the proportion of field margins in the surrounding area was tested using container-grown aphid infested plants located within the same fields. No effect was detected of field margins on the rate of aphid predation. Thus there is some evidence that field margins affect levels of pest control but further research is needed to identify the natural enemies responsible.

5.3.3 Flower-rich habitats

Two options, nectar flower mixture (WM2) and floristically enhanced grass (FEG) can provide floral resources, alternative prey and an appropriate environment for many natural enemies. In addition, FEG seed mixes also sometimes include tussock-forming grasses which would increase their value as an overwintering habitat, but owing to competition these would be to the detriment of the flowering species in the long-term. Nectar flower mixes are typically composed of agronomic varieties of legumes (red clover, sainfoin, vetch and birdsfoot trefoil) and in the past some fine grasses (e.g. crested dogstail, fescues and smooth stalked meadow grass), although more recently they have become available without the grasses. Because of the structural complexity of these flowers, the floral resources are not available to all natural enemies. In contrast, FEG is usually composed of a broader range of herbaceous species and fine grasses, and importantly herbaceous plants with open floral structures e.g. yarrow *Achillea millefolium*, that are utilised by a broad range of natural enemies. The larger Umbelliferae (wild carrot *Daucus carota*, common hogweed *Heracleum sphondylium*, hemlock water-dropwort *Oenanthe crocata* and wild angelica *Angelica sylvestris*) were the species preferred by the most individuals and greatest range of parasitic wasp species (Jervis *et al.,* 1992). The most preferred foraging plants for hoverflies were also identified as those with umbelliferous or umbel-like flowers (yarrow, cow parsley *Anthriscus sylvestris* and hogweed) and white campion *Silene latifolia*. The second most preferred were a group consisting of three members of the daisy family with similar flower structures (cornflower

Centaurea cyanus, common knapweed *C. nigra* and rough hawkbit *Leontodon hispidus*).

The effectiveness of these two approaches must however still be carefully considered. Conservation biological control theory would suggest that creating habitats with greater floral diversity will increase the diversity of resources for natural enemies leading to an increase in biological control (Tschartke *et al.,* 2005). However, even in more complex habitats, plant species that allow the key natural enemies access to their floral resources are not always present (Olson & Wäckers, 2007); instead adding plants that have known uses for natural enemies may be more beneficial (Baggen *et al.,* 1999; Wäckers *et al.,* 1996). Furthermore, pest species may also be able to utilise these additional resources, altering the balance between natural enemies and subsequently changing the overall level of biological control, something about which little is known (Baggen & Gurr*,* 1998).

5.3.3.1 Evidence that habitat supports natural enemies

The natural enemies present within nectar flower mixture mixtures were examined in the Buzz project (BD1624). The density from soil cores of overwintering Carabidae, Staphylinidae and Araneae was not significantly different, although values were always lower, compared to the tussocky margins. The species richness of predators (14.3) and parasitoids (5.4) was no different from the other ES habitats but was higher than in the crop (predators 12.1, parasitoids 3.4). Predator abundance was significantly lower than in the tussocky grass and wildflower mix, but was higher than in the crop. Parasitoid species richness did not differ between habitats.

The natural enemies present within a wildflower mix were also measured in the Buzz project (BD1624). The density from soil cores of overwintering Carabidae, Staphylinidae and Araneae was not significantly different from the other habitats but higher than in the crop (Final report for BD1624). The abundance and species richness of ground-dwelling beetles sampled by pitfall trapping was similar in the FEG compared to other sown habitats (pollen and nectar, tussocky grass), but lower than the more open habitats (natural regeneration, conservation headland, crop) in spring and autumn (Pywell *et al*., 2007). Spiders were most abundant in the non-crop habitats compared to crop and conservation headland. Predator abundance was significantly higher than in the other habitats. In contrast predator and parasitoid species richness measured by suction sampling was higher in the wildflower and pollen and nectar mixes than in the crop or conservation headland, but no different to the other habitats.

The abundance of natural enemies in FEG margins was examined in several studies, in comparison to some of the other ES habitats (Thomas & Marshall, 1999; Kirkham *et al.,* 1999; Meek *et al.,* 2002; BD1624: Buzz Project; LK0926: SAFFIE project; LK0971: Farm4bio project).

In summer FEG did not support any greater number of four carabid species captured by pitfall trapping than the grassy habitats (Thomas & Marshall, 1999). The abundance and diversity of a range of natural enemies collected by suction sampling was generally highest in the hedge base, next highest in a grass and wildflower mixture and least in grass margins sown with rye grass (*Lolium perenne*). The abundance of overwintering natural enemies in the FEG was generally lower than the hedgerow but higher than cereal field margins plots.

In the study by Kirkham *et al*. (1999, see above for treatments) the grass and wildflower mix harboured 74% and 44% of the total catch of Carabidae at the two sites respectively compared to the grass mixes. In contrast, there was no difference between grass and wildflower mix compared to grass only mixes for Carabidae and Araneae abundance and diversity when sampled using pitfall traps (Meek *et al.,* 2002). Sampling using sweep netting revealed that the abundance of Araneae, Soldier beetles (Cantharidae), Coccinelidae and predatory bugs (Anthochoridae) was highest in grass and wildflower habitats compared to grassy habitats or the crop.

The highest numbers of Carabidae and Araneae (Lycosidae and Linyphiidae) were caught in FEG margins compared to the grassy habitats but numbers in the FEG margins were only significantly higher than those in the crop (Meek *et al.,* 2002). The species richness of Carabidae was also higher than in the crop. No differences were found in the autumn.

In the SAFFIE project (LK0926) the abundance of predatory beetles collected using a suction sampler was similar in grass-only compared to FEG margins when tussocky grasses were present (Woodcock *et al.,* 2008). More intensive soil sampling at one study site found no difference in the overwintering predatory fauna between grass-only and FEG margins, but some beneficial invertebrates were only found in the margins (e.g. woodlice) or the margins supported higher densities and diversity (e.g. beetles) than the crop (Smith *et al*., 2008).

In the Farm4bio project (LK0971) numbers of predatory natural enemies in the FEG was similar to the other project managed habitats and game cover (Figure 5.3). The abundance of parasitoids was similar to grass margins but lower than game cover or the wild bird seed mixture (Figure 5.4). In June, the FEG supported the most hoverflies although by July the game cover also had the highest (Figure 5.5).

When the value of wildflower habitats across Europe was reviewed, it was concluded that sown wildflower strips support higher invertebrate densities and diversity than cropped habitats (Haaland *et al*., 2011) and grass margins, but less than pollen and nectar mixes. However, ground dwelling beetles were considered to prefer cropped habitats as they prefer a more open vegetation structure.

5.3.3.2 Evidence of impact on natural enemies in the adjacent crop

As part of the ‘Re-bugging the system’ project, the distribution of flying aphid predators around a nectar flower strip was examined using a grid of 77 sticky traps that extended up to 360 m from the 0.5 ha strip (Oaten, 2011). In addition, the nectar flower strip was sprayed with a trace element so that utilisation of the floral resources could be tracked in the dispersing hoverflies. Cereal aphids were lower around the field edges suggesting predation was higher in these areas. Predatory flies (Empididae) were more abundant close to the nectar flower strip and hedgerows, which indicates that they were using the floral resources or alternative prey present in these habitats. Syrphidae were also heterogeneously distributed but patches were not located next to the nectar flower strip and only 1.5% contained the trace element. Several explanations for the lack of utilisation of this floral resource are given.

In the 3DF project (Powell *et al.,* 2003, 2004) the abundance of hoverflies and cereal aphids within and at 10m, 30m and 100m of the FEG margins was compared to that of un-enhanced field margins. There was no evidence that the numbers of adult hoverflies, adult parasitoids or carabid beetles was enhanced in the fields with flower rich margins, however, numbers of cereal aphids were significantly reduced in seven site-years out of twelve.

The spatial and temporal variations in aphidophagous syrphid abundance were measured over two seasons across FEG patches of different sizes sown in a winter barley crop and associated field margins (Sutherland *et al.,* 2001). Syrphid abundance and diversity was higher in the field margin than the FEG patches and crop, despite the former having a greater abundance of flowers. The FEG patches did not encourage a greater spread of Syrphidae across the 8.4 ha field but this could be expected given their high mobility. One of the commonest species, *Episyrphus balteatus*, always remained closely associated with the margin.

The distribution of flying natural enemies was measured using sticky traps and suction sampling in fields with and without FEG margins ('Re-bugging the system' project; Oaten *et al.,* 2007; Oaten, 2011). Some natural enemy taxa (Empididae, Syrphidae, Staphylinidae and Linyphiidae) were higher within fields with FEG margins but only early in the season (May), which was attributed to their use of the FEG as an overwintering site. Cutting of the margins in summer increased the abundance of some taxa in the adjacent crop.

5.3.3.3 Evidence of impact on pests

In the study by Oaten (2011), the distribution of cereal aphids was assessed at the same sampling locations as the natural enemies and associations between aphids and the most abundant predatory Diptera (Syrphidae, Empididae and Dolichopodidae) were investigated. There was strong evidence that Empididae and to a lesser extent Dolichopodidae and Syrphidae were able to locate aphid patches and contribute to aphid control.

Exclusion cages were used to measure levels of aphid predation in fields with and without FEG margins, with transects of cages at 20 and 80 m from the margin (Holland *et al.,* 2008). Flying natural enemies provided >90% aphid control. The FEG margins were considered to have no benefit for biocontrol because flying predatory natural enemies capable of moving between fields were primarily responsible or the amount of uncropped land suitable for natural enemies was not a limiting factor in the landscape.

5.3.4 Conservation headlands

Conservation headlands were originally devised as a way of providing more insects food for grey partridge chicks (Rands, 1985), and this option can encourage a diverse weed flora which provides some floral resources, alternative prey and an appropriate environment for many natural enemies. When first introduced, conservation headlands (CH) received a restricted herbicides regime and no insecticides in summer, but fertiliser was allowed. The prescription was revised in 2008, and fertiliser is no longer permitted under ES guidelines, which produces a thinner crop permitting more weeds to survive and thrive.

5.3.4.1 Evidence that habitat supports natural enemies

A number of studies were conducted to determine the abundance of insects important in the diet of grey partridge chicks, which also include some natural enemies. A meta-analysis was conducted that examined whether invertebrates were higher within the unsprayed crop headlands and whether this affected their abundance within the adjacent sprayed crop (Frampton & Dorne, 2007). Eighteen of the thirty studies were conducted in the UK and the remainder in Netherlands, Scandinavia and Germany. Positive effects of pesticide exclusion were greatest for phytophagous invertebrates and consequently alternative prey for natural enemies would be higher than in fully sprayed crops. For Carabidae, only 3 of 16 studies showed a positive impact of pesticide exclusion, increasing abundance 1.1-1.8 times. Likewise no increase was found in the Arable Stewardship Pilot Scheme (Gardner *et al.,* 2001). For Staphylinidae 3 out of 7 showed a positive impact with an increase of 1.2-1.4 times. Coccinelidae were higher with pesticide exclusion in 2 out of 5 studies. There was also an indication that Neuroptera and Diptera increased with pesticide exclusion, although Diptera include many non-predatory species. Araneae showed no overall response to pesticide exclusion. In addition, in one of the two years, the aphid-specific syrphid *Episyrphus balteatus* was higher in the CH compared to fully sprayed crop but this did not lead to an increase in the ratio of syrphid eggs to aphids (Cowgill *et al.,* 1993b). Carabidae were found to be better fed in CH (Chiverton & Sotherton, 1991). The meta-analysis by Frampton & Dorne (2007) did not consider fertiliser exclusion, which is now an obligatory requirement for this option. It could be expected that this would further encourage a more abundant and diverse weed flora and thereby natural enemies, although this remains to be tested.

A more recent study (BD1624) found that the abundance of predators collected using pitfall traps in spring was similar to levels found in the crop and higher than the perennial habitats (Final report for BD1624; Pywell *et al.*, 2007). The density and diversity of predators collected using suction sampling was the same in conservation headlands as in the crop, and lower than the perennial habitats, however parasitoid abundance was higher.

5.3.4.2 Evidence of impact on natural enemies in the adjacent crop

Frampton & Dorne (2007) found no overall evidence that CH or unsprayed headlands had any impact on invertebrates within the adjacent crop, although there are examples of individual studies in which there was a positive effect on natural enemy abundance (Cardwell *et al.,* 1994).

5.3.4.3 Evidence of impact on pests

Oviposition by hoverflies was not increased in the adjacent crop (Cowgill *et al.,* 1993b). However, fewer aphids were found at 8 m from CH compared to fully sprayed or uncropped headlands (Hawthorne & Hassall, 1994). In contrast, cereal aphids in three wheat fields (including the one from the above study) at distances between 3 and 64 m were also assessed by Hawthorne (1994) for the same treatments listed above, but there was no consistent evidence of a difference between CH and fully sprayed headlands.

5.3.5 Beetle banks

This is the only option designed to encourage natural enemies and originated from studies that identified high numbers of natural enemies (Carabidae, Staphylinidae, Araneae) overwintering within the ground vegetation of hedgerows (Sotherton, 1984, 1985). Beetle banks provide shelter, alternative prey and an appropriate environment for some natural enemies.

5.3.5.1 Evidence that habitat supports natural enemies

The creation of "island habitats" across fields was devised as a way to replace the loss of hedgerows with a habitat that was simple to manage and would provide overwintering cover and encourage a more extensive and earlier coverage of the field with generalist predators (Thomas *et al.,* 1991). The first studies confirmed that the banks were quickly colonised by very high densities of beetles over winter; peak numbers of predators reached 1500 $^{m-2}$ with maximum numbers being reached within three years (Thomas *et al.,* 1992). However, other studies did not find such high densities and the mean value was 585 $^{m-2}$ (Table 5.2), although these densities were maintained for up to 10 years and were comparable to or even higher than field margins (Macleod *et al*., 2004; Collins *et al.,* 2003; Thomas, 2001). The abundance of boundary overwintering species increased with bank age (Thomas, 2001). Considerable variation was found between years and study sites, which was attributed to differences in overall farm densities that reflected the many different inherent influences (e.g. soil type and landscape composition) and anthropogenic impacts (e.g. crop management practices) occurring in adjacent fields. Overall the invertebrates found within the banks included Carabidae, Staphylinidae (mostly Tachyporus species) and Araneae (mostly Linyphiidae). In the summer, the abundance of Carabidae, Staphylinidae, Coccinelidae, Linyphiidae and Opiliones was not significantly different from the field margin, but Cantharidae, Heteroptera (probably predominantly phytophagous species) and other Araneae were significantly lower (Thomas *et al.,* 2001).

Table 5.2 Densities of overwintering predatory natural enemies within beetle banks in three studies

		Densities (m^2)			
Reference		**Carabidae**	**Staphylinidae**	**Araneae**	**Total predators**
Macleod *et al*., 2004	1987	10.6	1.2	6.1	17.9
	1988	110.4	44.4	22.3	177.1
	1989	19.7	39.3	26.3	85.3
	1990	13.8	27.7	43.1	84.6
	1991	52.5	84.4	48.3	185.2
	1992	71.8	125.4	45.4	242.6
	1993	45	91.3	24.6	160.9
Collins *et al*., 2003b	1994	80	377	136	593
	1995	301	857	89	1247
	1996	423	1550	207	2180
	1997	79	351	84	514
Thomas, 2001	1997	200	340	380	920
	1998	250	480	470	1200
	Mean				**585.2**

5.3.5.2 Evidence of impact on natural enemies in the adjacent crop

A brief wave of emigration of generalist predators from the banks was detected in April or May (Thomas *et al.,* 1991; Thomas *et al.,* 2000; Collins *et al.,* 2002) followed by a period in which there was an even spread of boundary-overwintering predators across the adjacent field (Thomas *et al.,* 2000). Measurements of their densities within banks during the winter, spring and summer revealed that the density of Carabidae decreased by two-thirds between winter and spring with a slight increase in summer compared to spring (Thomas, 2001). Densities of Staphylinidae declined by three-quarters and Araneae by a half between winter and spring indicating a similar emigration from the beetle banks but with a proportion remaining within the banks. Some losses may be ascribed to overwinter mortality rather than emigration.

5.3.5.3 Evidence of impact on pests

Two studies were conducted to determine whether the beetle banks were leading to more even predation across fields. When artificial prey were located across fields up to 60 m from the beetle bank, predation rates were even at all locations, although predation was highest on the bank itself (Thomas, 1990). The impact on naturally occurring aphid infestations was evaluated within barriered plots that excluded ground-dispersing predators. These were established at 8, 33, 58 and 83 m from a beetle bank (Collins *et al.,* 2002). The mean number of aphids and aphid peak was reduced up to 58 m from the beetle banks, but reductions were greatest at 8 m.

5.3.6 Natural regeneration

A number of options may allow natural regeneration to occur. In some cases there is an annual cultivation at some point during the winter (fallow plots for ground nesting birds and uncropped cultivated margins) for others natural regeneration is used as a means of establishing the habitat (buffer strips and field corners) and so the vegetation will develop over time. The former are discussed below and the latter were considered in the previous section on uncultivated ground flora (see 5.3.2). The resources provided for natural enemies will be very much dependent on the plant species composition and vegetation structure that develops, however, some alternative prey and floral resources will be available.

5.3.6.1 Evidence that habitat supports natural enemies

In the Buzz project (BD1624) pitfall trapping indicated that abundance of predators was higher in natural regeneration than any other habitat, although species richness was similar (final report for BD1624). Suction sampling showed that in natural regeneration predator diversity was higher than in the crop, but less than in perennial habitats, although abundances were similar to the latter. Parasitoid species richness was similar to the perennial habitats but they were more abundant than in the crop or perennial habitats.

In the Farm4bio project, natural regeneration was allowed in annually cultivated strips (typically 6m wide) next to the field boundaries, i.e. where uncropped cultivated margins would be located. The abundance of predatory natural enemies was similar to the other options (Figure 5.3) whilst parasitoids were more abundant than in grass margins or FEG (Figure 5.4). In June and July, hoverfly numbers were similar to other annual habitats which would have a similar weed spectrum, with the exception of game cover (Figure 5.5).

5.3.7 Wild bird seed mixtures (a.k.a. wild bird cover, WM1)

A wide range of seed-bearing species are sown, with a minimum of at least three types under scheme rules, and includes both monocots and dicots. The plants may produce flowers that are attractive to natural enemies and also support phytophagous invertebrates, some of which may be crop pests. A rich understorey of weeds can also develop, providing floral resources, alternative prey and hosts for parasitoids. Consequently, the natural enemy fauna may vary hugely because of the variation in plant species composition.

5.3.7.1 Evidence that habitat supports natural enemies

In the PEBIL project, there was no difference in the abundance or total species richness (but species composition differed) of beetles or spiders between wild bird seed mixtures and grass plots managed for silage cutting when the study area was located in grass fields (Final report to Defra: BD1444).

In the Farm4bio project, wild bird seed mixtures supported similar densities of predators (Figure 5.3), but high densities of parasitoids compared to the other annual habitats (Figure 5.4). This was also confirmed in an on-going Defra funded project (IFO126: J. Pell, pers. Comm.) in which the same four Farm4bio habitats were sampled more intensively. Hoverfly numbers in wild bird seed mix were similar to the other annual habitats in June but by July were higher than the perennial habitats in one region. They were high in the game cover which comprised similar plant types, although sometimes included maize. Where high hoverfly numbers were found this was attributed to high levels of arable weeds (J Holland, H Martin: pers. observ.).

5.3.7.2 Evidence of impact on natural enemies in the adjacent crop

In the 3D Farming project, the abundance of cereal and pea aphids and their natural enemies was assessed in fields with and without a 24 m strip of wild bird seed mixture. In one year, cereal aphids on wheat were higher at 10 and 30 m from the strips compared to the field boundary, indicating that strips were encouraging biological control (Powell *et al*., 2004). The strips contained a high proportion of flowering plants at this time, including sown species such as *Phacelia tanacetifolia* that may not normally be sown as part of a wild bird seed mix, and flowering weeds, and thus may have boosted numbers of hoverflies and parasitic wasps leading to higher levels of aphid predation or parasitism. However in the second year the reverse effect on aphids was found, but some key natural enemy groups (parasitoids and hoverflies) were not appraised and there was some evidence that the strips were acting as a sink habitat for Staphylinidae. In the pea fields the set-aside strips had no effect on the abundance of pea aphids, but there was some evidence that the strips were acting as a sink for Staphylinidae.

In the Defra project IFO126 natural enemies and crop pest levels were measured in the fields of the Farm4bio study. At study sites with the four project managed habitats, the abundance of parasitoids was higher and cereal aphids lower compared to farmer managed sites where the predominant uncropped land was grassy field margins (J. Pell pers. comm.). The percentage of uncropped land and semi-natural habitat had a positive impact on parasitoid abundance.

5.3.8 Undersown spring cereals (EG1)

This option should improve the survival of those natural enemies overwintering in the soil because the soil remains undisturbed from drilling until 15 July the following year. The emergence of Carabidae was twice as high in undersown barley compared to barley (Vickerman, 1978). Likewise in Sweden, the emergence rates of carabid beetles was increased by an average of 50% and by up to 100% for *Bembidion* species (Carabidae) in spring cereals undersown with clover or ryegrass (Helenius *et al.,* 1995). The increase was attributed to preferential selection of the undersown crop or improved larval survival. The undersown vegetation may also create different environmental conditions and host alternative prey for natural enemies if a sufficient sward develops. Indeed, the abundance of Araneae and Opiliones, Hymenoptera, Coleoptera and Diptera was higher in undersown barley compared to barley that was not undersown (Vickerman, 1978). In the ASPS there was no difference in the abundance or diversity of Carabidae between undersown and conventional crops during this period, however, pitfall trapping was used and differences in vegetation density may have masked any effect (Gardner *et al.,* 2001).

5.3.8.1 Evidence that habitat supports natural enemies

In two of the three study years 60% more cereal aphids were found in barley compared to undersown barley, and this was attributed to increased predation in the undersown crop (Vickerman, 1978). Undersown fields may act as either a sink or source of natural enemies in the landscape.

5.3.9 Uncropped, cultivated areas for ground-nesting birds (EF13)

No studies have been published on the natural enemies that occur in such areas. However, their management is similar to that of rotational set-aside, with annual cultivation, although the areas may remain in the same location allowing weeds to build up so making them more attractive to natural enemies. They may allow ground overwintering natural enemies to survive as they receive only shallow cultivations. Set-aside plots supported similar numbers of carabid and staphylinid beetles compared to cropped areas, although the numbers of spiders was twice as high in early summer (Hopper & Doberski, 1992).There were significantly fewer parasitic wasps and highly ranked predatory natural enemies within set-aside fields than the adjacent field boundary, whilst aphid-specific predators were very low and showed no difference (Moreby, 2007). These findings would suggest that this option is of little value in pest regulation.

5.3.10 Overwintered stubble (EF6, EF15, EF22)

The overwintered stubbles in options EF6, EF11, EF13, EF15, EG4, EJ10, EJ13 and HG5 would have no benefit for natural enemies overwintering in the soil because the soil can be cultivated in February.

The larvae of some numerical important carabid and staphylinid larvae overwinter in the soil with up to 1.57 million per hectare (Holland *et al.,* 2007). However, emergence does not start to occur until late March, peaking in June but still occurring to some extent by July (Holland & Reynolds, 2003; Holland *et al.,* 2007). The parasitoids of some important oilseed rape pests (pollen beetle, stem weevils and flea beetles) also overwinter within the soil of the oilseed rape field (Walters *et al*., 2003). In the ASPS there was an increase in the abundance of carabid larvae in spring attributed to improved overwinter survival (Gardner *et al.,* 2001). Cultivations are known to reduce survival of beetles (Holland & Luff, 2000; Holland & Reynolds, 2003) and especially oilseed rape parasitoids, which only overwinter at a depth of 1-3 cm (Hokkanen, 1989). Cultivations are permitted from 15 February in EF6 & EF15 therefore these options are not expected to increase survival of natural enemies. There is a possibility that EF15 may preferentially attract beetles in the autumn where they may overwinter and consequently it may act as a sink habitat, damaging beetle populations. On the other hand, the new option EF22 (extended overwintered stubble) may increase overwinter survival of beetles, spiders and parasitoids. If the improved overwinter survival of oilseed rape pests is to be best utilised, the oilseed rape stubble field should be adjacent to a new crop to increase the chance of them locating the new crop, because some parasitoids are poor dispersers (Hokkanen, 1989).

5.3.11 Grassland

A range of grassland options are available which aim through a reduction in inputs (fertiliser, pesticides, grazing) to increase plant diversity and vegetation structure and thereby, it is assumed, invertebrate abundance and diversity. This management may increase provision of all four key resources, however, grassland is a complex ecosystem and relationships are not always consistent or as expected. For this reason, and because there are many options for grassland habitats but no studies of natural enemies within each option, only general principles are discussed.

Experimental investigations of plants and invertebrates confirm that taller vegetation supports more invertebrate species and individuals than short swards, especially herbivorous insects, however, the response by natural enemies varies between species and functional groups, with some (e.g. carabid beetles) preferring short swards. Overall predatory and parasitic species show a weaker relationship to vegetation structure and species composition than their herbivorous prey (Pöyry *et al.,* 2006), but those dependent on structure for shelter may show a stronger relationship (Morris, 2000). Likewise the response to plant diversity and species composition may be species and functional group specific, for example parasitoids showed no relationship to plant diversity, the activity of predators declined with increasing plant diversity, but the response may be influenced by the sampling method creating conflicting conclusions (Koricheva *et al.,* 2000).

5.3.11.1 Evidence that habitat supports natural enemies

No studies of the individual ES options were found, however, there have been studies examining the impact of pasture improvement on invertebrates. Of the predators, Araneae show the strongest relationship to vegetation structure with spider diversity increasing as grazing pressure is reduced and structural diversity develops (Gibson *et al.,* 1992). This is the expected response for other predatory groups (Morris, 2000). In contrast, on calcareous grassland, sward height was negatively correlated with predator species richness. Higher numbers of predatory beetles were found in shorter swards in trials conducted along grass field margins (Woodcock *et al.,* 2007) and likewise an increase in grazing increased predator mass (Woodcock & Pywell, 2010). However, in this second study grazing occurred before the main growth period and was influencing plant species composition, the selected plants then providing a full spectrum of refuges. When different grazing regimes were compared for lowland calcareous grassland, the abundance of predatory beetles was higher with lower grazing intensity because this allowed grassy tussocks to develop (Woodcock *et al.,* 2005). In the uplands, beetle community composition was determined by the grazing regime with the majority of arthropods occurring in the grass tussocks where reduced grazing pressure permitted these to develop (Dennis *et al.,* 1998).

The majority of the natural enemy biomass only disperses short distances (within farm) with the exception of some notable examples (linyphiid spiders and hoverflies), therefore even if low input grassland management increases pest natural enemies the impact will be restricted on crops because of the polarisation of farming with eastern England dominated by arable farms and western areas by livestock. On mixed farms or those surrounded by semi-natural habitats (e.g. downland) there is the possibility of some exchange between habitats, but this has not been examined. For the highly dispersive linyphiid spiders, a landscape-scale individual-based-model was developed and used to test the impact of refuge habitats (permanent grassland) in the landscape on spider populations (Thorbek & Topping, 2005). Increasing the proportion of grassland above 2% had a dramatic positive impact on spider populations. However, if prey availability decreased in the permanent pasture this reduced spiders in the landscape suggesting a relationship between grazing intensity, vegetation structure and spider populations.

The influence of grassland management on natural enemy control of herbivores within grass fields and consequently levels of herbivory is complex and beyond the scope of this review.

5.3.12 Options not considered

5.3.12.1 Skylark plots (EF8)

The area occupied by skylark plots is a minimum of 0.32% of the arable field. The resources provided by such a small area of natural regeneration would not be expected to have any impact on the population of natural enemies within a field.

For all other options no information on natural enemies was available.

5.4 DISCUSSION

There is clear evidence that a broad range of ES options contain natural enemies and these are often at higher densities and in greater diversity than within the crop. However, there are considerable gaps in knowledge even for the most popular options (e.g. hedgerow management) and for some options only information on broadly similar habitats was obtainable as the specific options have not been evaluated. The exceptions are those options monitored in the Arable Stewardship Pilot Scheme, but even in those studies the only natural enemy taxa measured were Carabidae, and these only form a proportion of the natural enemy fauna. Few studies have specifically examined the impact of specific ES options on the levels of natural enemies in the adjacent crop and even fewer have measured levels of crop pests or other suitable indicators such as natural enemy:pest ratios. No studies were found which had investigated the effect of ES options on crop yields or damage. This is not surprising because all the options with the exception of beetle banks, for which there are some studies, were designed for other purposes.

If farmers are to be convinced of the pest regulation services provided by ES then they will also need information on the financial implications. Only one example was found where the economic value of the habitat in reducing insecticide use was estimated. The economic benefits of beetle banks were estimated based upon the cost of establishment and income foregone for the land occupied by the bank and did not include any measure of reductions in insecticide use or subsequent yield gain. In 2002, the establishment costs were £975 ha^{-1} with subsequent costs of £2 ha^{-1} for income foregone from the land occupied (Collins *et al*., 2002). Thus the agri-environment scheme payments of £600 ha^{-1} would cover these costs within two years and be more profitable in following years. The cost of an insecticide was £3-12 ha^{-1} without application costs, but aphicides are typically added to a fungicide programme. Without the AES payments beetle banks are not therefore economically advantageous.

The use of habitats to improve pest control, termed "conservation biological control", has been examined across the world in a variety of cropping systems. The approach taken and the success of 51 studies published between 1990 and 1999 was reviewed by Gurr *et al*. (2000). Nineteen studies investigated the impact on natural enemies in the target crop with most reporting an increase. Pest levels were recorded in 22 studies with 19 reporting a reduction of the pest. Of the 22 studies, 15 demonstrated that the higher levels of natural enemies were responsible for improved pest control. Only one showed that the habitat was acting as a sink, attracting natural enemies away from the crop. Ten studies looked at damage levels, with 6 showing a benefit.

There is an extensive literature on the theories behind conservation biocontrol and ways to achieve success (Gurr & Wratten, Eds. 2000; Gurr *et al*., Eds. 2004; Wäckers *et al.,* Eds. 2005), but relatively little research demonstrating its success in the UK. Despite this, farmers would appear to be adopting some of the approaches. In a farmer survey conducted as part of the 'Rebugging the system' project, 68% of respondents stated that they were improving field margins and a further 13% considering this action (Bailey *et al*., 2009). However, in many cases this is likely to be the establishment of grass margins, given their popularity in ES. Twenty-eight percent of those questioned were using flower strips to encourage natural enemies and a further 40% were considering this option. Beetle banks were used by 21% and almost 40% were considering them, yet within ELS uptake is only 1.4%. The high awareness amongst farmers of these approaches indicates that they are considering conservation biocontrol and there is scope to encourage this process, but more information on how to achieve the best impact is still needed. This would entail identifying the most appropriate habitats; specific seed mixtures may be required that increase the natural enemies without benefitting pests. The amount and configuration of such habitats requires further investigation both at farm and landscape scales. In addition, the role of existing habitats that already form a large proportion of the uncropped land (e.g. hedgerows, woodland, unimproved grassland) needs investigation as it is currently poorly understood.

Of all the options in ES, those providing floral resources or overwintering habitat have been most intensively investigated and further research is underway (Horticulture LINK project: HL0192). These options may sometimes have measurable impacts on natural enemies yet many of the other options may also provide a contribution. However, because biocontrol often involves a high diversity of invertebrates within a complex environment it is the interplay of a diverse array of influencing factors (e.g. crop management, crop growth, soils, climate, landscape composition) that ultimately determines the levels of pests and the control that occurs. Consequently it is difficult to quantify the impact of individual options and as a consequence the judgements provided in Annex 5.1 and Appendix are largely subjective. Even comparisons of scheme and non-scheme farms would be strongly influenced by the extraneous factors and further confounded by movement of natural enemies across the landscape.

5.4.1 References to projects quoted in the text

BD1624: Comparison of new and existing Agri-environment Scheme options for biodiversity enhancement on arable land (2003-07) Defra.

HL0192: Perennial field margins with combined ecological and agronomical benefits for vegetable rotation schemes (2008-13) Horticulture LINK.

LK0926: The Sustainable Arable Farming For an Improved Environment (SAFFIE) (2002-07) Sustainable Arable LINK.

LK0971: Managing uncropped land in order to enhance biodiversity benefits of the arable farmed landscape (Farm4bio) (2005-11). Sustainable Arable LINK.

Other references may be found in the main reference list (see page 106).

Annex 5.1 Number of natural enemy species within each taxon and the key references for each habitat type

Invertebrate taxa	Common name	Habitat type and key references											
		Number species (important/abundant)	Shrubby vegetation	Uncultivated ground flora (grass)	Flower rich habitats	Cereal headlands	Beetle banks	Uncropped, annually cultivated margins	Wild bird seed mixture	Undersown spring cereals	Uncropped, annually cultivated margins	Uncropped, cultivated areas for ground-nesting birds	Low input grassland
Coleoptera										15			
Cantharidae	Soldier beetles	5 (3)	1	4	4,5		14	5			5		18
Carabidae	Ground beetles	20-30 (5-10)	1	3,4,5,6	4,5,7,8	9,11,12	13,14	5	5		5	16	17, 18
Coccinelidae	Ladybirds	5	1	3,4,5	4,5,7	11	14	5	5		5		17
Staphylinidae	Rove beetles	40-50 (5-10)	1	3,5,6	5,7	9,11	13,14	5	5		5	16	17, 18
Diptera				6			14			15			
Asilidae	Robber flies	2	1										
Dolichopodidae	Long-legged flies	6	1	5	5			5	5		5		
Empididae		6	1	5	5			5	5		5		
Hybotidae	Dance flies	3											
Muscidae	Muscid flies	6	1	5	5			5			5		
Rhagionidae	Snipe flies	3											
Syrphidae	Hoverflies	6 (2)	1	5	5	11		5	5		5		
Therevidae	Stiletto flies	2											

Heteroptera					8		14			15			
Anthorochoridae	Flower (pirate) bugs	1	1	4,5	4,5	9,10		5	5		5		
Geocoridae		2											
Microphysidae		2	1										
Miridae		12	1	4	4								18
Nabidae		2	1	5	5	10		5	5		5		18
Pentomidae		3	1										
Reduviidae		2	1										
Saldidae		1											
Neuroptera				5		11			5				
Chrysopidae	Lacewings	3 (1)	1										
Hemerobiidae			1										
Arachnida			2	6	8	11				15		16	
Linyphiidae	Money spiders	40-50 (10)		4,5	4,5		13,14	5	5		5		18
Lycosidae	Wolf spiders	12 (2)		4,5	4,5		13,14	5	5		5		18
Opiliones	Harvestmen	3		4,5	4,5		14	5			5		18
Phytoseiidae	Predatory mites												
Tetragnathidae	Long-jawed spiders	4											
Therididae	House spiders	6											18
Thomisidae	Crab spiders	4		5	5				5				18
Hymenoptera				6									
Parasitica				5	5	11			5				
Brachonidae			1										

Ichneumonidae	1	
Pompilidae	1	

1-Joyce, 1998 (summer); 2-Maudsley et al., 2002 (winter); 3-Woodcock et al., 2005 (summer); 4-Meek et al., 2002; 5-Farm4bio (summer); 7-BD1624 (summer); 6-BD1624 (winter); 7-Woodcock et al., 2008 (summer); 8-BD1614; 9-Moreby & Southway, 1999; 10-Moreby 1994; 11-Frampton 2003; 12-Hassall et al., 1992; 13-Macleod et al., 2004 (winter); 14-Thomas et al., 2001 (summer); 15-Vickerman, 1978; 16-Hopper & Doberski, 1992; 17-Woodcock et al., 2005; 18-Dennis et al., 1998.

6 POLLINATION

6.1 THE IMPORTANCE OF POLLINATION TO AGRICULTURE

6.1.1 Definition: biotic pollinators

Pollination is the transfer of pollen from the male parts (anthers) of a flower to the female part (stigma) of the same or different flower. If the pollen is compatible, and the ovule is fertilised, this results in fruit and seed formation. In some self-pollinated species, reproduction takes place passively using the plant's own pollen, without the need for it to be transferred by any agent. In others pollination is achieved actively by abiotic means, when pollen travels between flowers for example on wind currents or in water. However, many plants require their pollen to be carried by an animal pollinator. In order to evaluate the contribution of biotic pollinators to agricultural production in the UK it is necessary to consider the range of species providing pollination services, the crops that are important in agricultural production, their relative dependencies on biotic pollination, and the economic values of these crops.

6.1.2 The range of species providing pollination services in UK agricultural production

The most comprehensive and up to date evaluation of biotic crop pollination in world agriculture is that of Klein *et al.* (2007). Although this global review refers to "animal" pollinators, in fact the authors found that in all but a very few cases the only reliably demonstrated pollinators were insects; exceptions being vertebrate pollinators of commodity crops that are not of relevance to UK agriculture (for examples see Hennessy, 1991; Free, 1993; Degenhard *et al*., 2001 and references cited in Klein *et al.,* 2007). Insects are thus the key contributors to the ecosystem service of pollination in the UK.

In spite of the fundamental and well-appreciated relationship between insect pollination and yield, we are "remarkably ignorant" (Goulson, 2003a) of the pollinating fauna for the majority of crops. Given the diversity of crops grown for agricultural purposes, and the concomitant variations that exist in the form, degree of self-compatibility and sexuality of their flowers, it follows that the community of insect pollinators comprises a diversity of species (McGregor, 1976; Free, 1993; Williams, 1994; 1995; 2002; Delaplane & Mayer, 2000; Klein *et al*., 2007). Although any given crop may be visited by a very wide array of insects (for example, more than 300 species from 71 families have been recorded on carrot flowers (Hawthorn *et al*., 1956; Bohart & Nye, 1960; Bohart *et al*., 1970; in McGregor, 1976)), it does not follow that all, or even any, of these provide a significant contribution to ultimate productivity. For example, honey bees, carpenter bees and the solitary bee *Eucera pulveracea*, all visit broad bean flowers but of these, only *Eucera* is a reliable pollinator; the other two species being "nectar robbers" gaining access through holes made by the bumble bees at the base of the corolla (Aouar-sadli *et al*., 2008). Managed honey bees are commonly used to enhance crop yield (Delaplane & Mayer, 2000), but recognition of the important role that wild pollinators may play in agricultural production is growing (e.g. Westerkamp & Gottsberger, 2000; Goulson, 2003a; CGRFA, 2007; Kremen & Chaplin-Kramer, 2007). In fact, it is likely that in most environments, both wild and managed pollinators will exploit flowers of crop species (Degrandi-Hoffmann & Watkins 2000; Greenleaf & Kremen 2006a; 2006b; Klein *et al*., 2007); moreover, these may act synergistically to increase crop yields (Geenleaf & Kremen, 2006a; Klein *et al*., 2007; Elmquist & Maltby, 2009; James *et al*., 2009; POST, 2010): Strawberry flowers visited by both wild and honey bees are more likely to be completely developed, in contrast to flowers that are visited by only one type of pollinator, which tend to have misshapen fruits (Chagnon *et al*. 1993). Fields of rape grown near uncultivated areas produce significantly higher yields due to greater pollination services from a more diverse and abundant wild bee community (Morandin & Winston, 2005; 2006). Effects such as this have rarely been looked for, but may prove to be widespread (Klein *et al.*, 2007).

The relationships that exist between an insect-pollinated crop and the various species visiting it are thus highly complex, and there has been no systematic, crop-by-crop assessment of the relative contributions of different insect groups to agricultural pollination in UK. However, based on a detailed review of available empirical evidence and the results of direct testing studies that distinguish between flower visitors and true pollinators (Klein *et al*., 2007), it is believed that in the majority of important global crops, 85% of insect pollinators are bees (honey bees, stingless bees, bumble bees and solitary bees). Other insect groups are hoverflies and other Diptera (5% of species), beetles (4% of species), thrips (4% of species), and wasps (2%). The ALARM project has also identified broadly the same insect groups as the key functional pollinators in the EU (Luig *et al*., 2005).

In the UK the native European honey bee (*Apis mellifera* L.) is widely recognised as the key crop pollinator (Corbet *et al*., 1991; Williams, 1994; 2002; Delaplane & Mayer, 2000; Klein *et al*., 2007;). Honey bees are a practical solution to pollinating many intensively farmed crops, as they can be reliably managed and moved to be locally common when crops are in bloom (Free, 1993; Delaplane & Mayer, 2000; Allsopp *et al.,* 2008; van Engelsdorp & Meixner, 2010; POST, 2010). There are currently over one hundred thousand managed colonies in England, Scotland, Wales, owned by registered beekeepers (BeeBase, 2011), but the total number of colonies in the UK (including unregistered colonies and colonies in Northern Ireland) is estimated to be 250,000 (*pers. comm*. Giles Budge, Research coordinator, National Bee Unit, 2011). Feral colonies of *A. mellifera* are also present in the UK, and studies are in progress to record their abundance and distribution (Thompson *et al*., 2010). Honey bees are generalists (polytropic (Free, 1993)), visiting a wide assortment of flowering crops (McGregor; 1976; Free, 1993; Delaplane & Mayer, 2002; Klein *et al*., 2007). Many flower species are visited for both nectar and pollen, but some are visited mostly for nectar, and a few are visited only for pollen (Free, 1993). Although polytropic, compared to other insect pollinators honey bees are comparatively “constant”, keeping to one flower species during a single foraging flight, making them reliable cross-pollinators (Free, 1993; Williams, 2002). Honey bees prefer to forage within a short radius of their hives, but if necessary will cover large distances (>12km) in search of resources (Ratnieks, 2000; Beekman & Ratnieks, 2000). By virtue of their sociality, successful foragers rapidly recruit co-workers from their colony to utilise a local food source, thus greatly enhancing their efficiency as crop pollinators.

There are 22 species of wild bumble bees (*Bombus*) present in the UK, each of which may play some role in crop pollination. At least of six of these are widespread and ubiquitous in Europe: *B. terrestris*, *B. pascuorum, B. lapidarius, B. pratorum, B. hortorum* and *B. lucorum*) (Williams, 1982; Goulson *et al*., 2006; Goulson, 2010), and with the possible exception of the long-tongued *B. hortorum*, these are known to have broad diets (Williams 2005; Goulson *et al.*, 2005). Although bumble bees are often generalists, for certain crop species they are superior pollinators compared to other bee genera (McGregor, 1976; Corbet *et al*., 1991; Free, 1993; Osborne & Williams, 1996; Delaplane & Mayer, 2000; Williams, 2002). Long-tongued *Bombus* (*B. hortorum*, *B. pascuorum*) are effective pollinators of crops with deep corollas such as field bean (Delaplane & Mayer, 2000; Williams, 2002). Some flowers only release their pollen when they are sonicated by “buzz pollinators” (McGregor, 1976; Free, 1993; Delaplane & Mayer, 2000), and as such bumble bees are better pollinators than honey bees of crops such as raspberry and tomato (Goulson, 2010). Bumble bees are comparatively tolerant of poor weather conditions, foraging in cooler, wetter and windier conditions than other genera (Delaplane & Mayer, 2000; Williams, 2002; Goulson, 2010). Compared to honey bees, when foraging in raspberry, bumble bees visit a higher proportion of pollen-bearing flowers, visit flowers earlier in the morning when pollen is most abundant, visit more flowers per minute, carry more pollen on their bodies, and deposit more pollen onto raspberry stigmas (Willmer *et al*., 1994).

There are several hundred species of solitary bee native to the UK (O'Toole & Raw, 1991). Studies suggest they are effective pollinators, particularly of fruit trees and other early-blooming crops (McGregor, 1976; Corbet *et al*., 1991; Delaplane & Mayer, 2000; Klein *et al*., 2007; Bosch *et al*., 2008; Pitts-Singer & James, 2008), but in the UK their respective contributions to crop pollination are still poorly understood (Williams, 1996; 2002). They are not usually as numerous on crops as honey bees or bumble bees, with their abundance being limited by availability of local nesting sites. When other bees are scarce, species of *Andrena*, *Osmia* and *Anthopora* may contribute to the productivity of early flowering fruit, and *Megachile* are important pollinators of legumes (Williams, 2002). In apple orchards, 600 solitary bees can provide a level of pollination equivalent to two managed *A. mellifera* colonies (30,000 honey bees) (Delaplane & Mayer, 2000).

Hoverflies are widespread in the UK (Ball & Morris, 2000), with numerous species listed by the UK's Hoverfly Recording Scheme (www.hoverfly.org.uk). Hoverflies are frequently implicated as important (and possibly declining) crop pollinators (Biesmeijer *et al*., 2006; Klein *et al*., 2007). For example, they certainly carry pollen between blackberry flowers (Gyan & Woodell, 1987), and are active pollinators of raspberry (Prodorutti & Frilli, 2008). However, as with other non-Hymenopteran members of insect pollinator community (beetles, wasps, and various Lepidoptera (McGregor, 1976; Free, 1993; Klein *et al*., 2007), their contributions to agricultural productivity have yet to be confirmed and quantified.

6.1.3 Degrees of crop dependence on insect pollination

The morphology and arrangement of flowers on any given plant species, as well as the plant's level of self-infertility (Acquaah, 2007) dictate the degree to which it requires a living vector to actively transfer pollen between inflorescences (Delaplane & Mayer, 2000). Species that have separate male and female flowers, irrespective of whether these occur on the same or different plants (monoecious or dioecious species respectively), have a comparatively high dependence on pollinator species. Plants with flowers that have both male and female sexual parts are comparatively more likely to be self-pollinating, but this may still be optimised when pollen vectors are present (Delaplane & Mayer, 2000).

In Britain (and the rest of Europe) insect pollinators contribute to the production of over 80% of crop species (Williams, 1994; 2002). Various authors have compiled lists of crops grown within the EC where seed set is enhanced by insect (bee) pollination (Corbet *et al*., 1991), and have attempted to weight the degree to which they depend on this service (McGregor, 1976; Borneck & Merle, 1989; Robinson *et al*., 1989a; 1989b; Corbet *et al*., 1991; Southwick & Southwick, 1992; Morse & Calderone, 2000). However, more recent reviewers (Klein *et al*., 2007), have questioned the reliability of such coefficients of dependence due to their derivation from uncited data sources. To properly understand the degree to which agricultural production requires insect pollination it is necessary to compare fruit or seed set in crops that have been grown with or without the services of specific insect pollinators and, in some cases, with or without supplementary hand pollination. Although Klein (*et al*., 2007) provide examples (Canto-Aguilar & Parra-Tabla, 2000; Javorek *et al*. 2002; Cane &

Schiffhauer 2003; Klein *et al*. 2003*a*,*b*; Greenleaf & Kremen 2006a; 2006b; Blanche *et al.,* 2006), studies of this kind are comparatively rare; for the vast majority of crops grown in the UK (or elsewhere) their relative dependency on insect pollination has not been quantified.

Klein and her co-workers took into account plant breeding systems, the community of insects visiting flowers, and the level of production increase arising as a result of insect pollination activities, to assess crop dependency on biotic pollinators; crucially, their conclusions are well supported by experimental evidence (Kevan & Phillips, 2001). Using FAO data from 200 countries, Klein *et al*. (2007) conclude that fruit, vegetable or seed production from 87 of the leading global food crops is increased by animal (insect) pollination. This equates to 68% of the 57 leading single crops and 72% of the 67 leading global commodities. However, they point out that the actual amount of agricultural productivity attributable to insects is likely to be lower than these figures suggest, as certain crops are not solely reliant on animal pollination (e.g. hermaphrodite, self-compatible species in which pollination may be supplemented by the wind). Klein *et al*. looked at available data from experiments comparing measures of pollination (e.g. fruit set, number of seeds, fruit or seed weight, or pollen deposition) at the level of flowers, inflorescences or whole plants, with and without access to pollinators. Where sufficient literature was available to allow adequate assessment, this information was used to place one of five relative levels of dependence on insect pollination for each of 108 crops, these levels being: (i) Essential (production reduced by at least 90% in absence of pollinator(s)); (ii) Great (production reduced by 40-90%); (iii) Modest (production reduced by 10-40%); (iv) Little (production reduced by up to 10%); (v) No reduction in productivity without pollinator(s). On this basis, they found empirical evidence for increased productivity with insect pollinators in 85% of the selected crops. This need for insect-mediated pollination was found to be essential in 14% of crops, high in 33%, modest in 29%, and little or nothing in 23%.

While the overall figures presented by Klein *et al*. (2007) provide a valuable insight into the global dependency of crops on insect pollination, when considering pollination requirements on a national scale it is important to remember that Klein *et al.*'s figures are derived from a portfolio that includes many crops which, although they are of global significance, are not grown in the UK: for example, stimulant crops such as coffee and cocoa, fruit crops such as citrus and several types of nut. The main crops relevant to UK agriculture, as defined by land coverage, and the impact of insect pollination on their respective productivities, are presented in Table 6.1. Unless otherwise stated, crop statistics used in Table 6.1 are based on available figures obtained from the 2009 annual June Survey (Defra, 2010a). Impacts of pollination are the coefficients of dependency provided by Klein *et al*. (2007). Vegetables and salads for human consumption, grown in the open, are not included in Table 6.1, although in total these cover 126,000 hectares (Defra, 2010a). This is because, due to the small areas grown, not all UK countries collect data on individual crops in this category (Defra, 2010a), thus insufficient breakdown statistics are available to allow further evaluation (see Table 6.2, below). Even though protected crops such as tomato and cucumber are known to have 'Little' or 'Great' needs for insect pollination (Klein *et al*., 2007), these are excluded from Table 6.1 as they are not accessed by native pollinators likely to be influenced by Environmental Stewardship. Each year the UK currently imports approximately 60,000 units[7] of commercially-reared bumble bees for the purposes of pollinating horticultural crops

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[7] 1 unit = 1 pollination box, which will typically contain 1 queen, 350-400 workers and brood (pupae, larvae and eggs

grown inside enclosed greenhouses or polytunnels (*pers. comm*., Selwyn Wilkins, National Bee Unit (2011)). In the UK, arable crops cover 4.4 million hectares (Defra, 2010a). The majority of this land is used to grow cereal crops (~3 million hectares) and oilseed crops (rape and linseed) (0.7 million hectares). However, although these, along with potatoes, and other non-horticultural crops (sugar beet, field beans root crops for fodder etc.) together account for 74% of the UK's total croppable area, their dependencies on insect pollination are, with the exception of field beans, generally low or negligible (Table 6.1). Field beans generally achieve variable levels of passive self pollination but honey bees and bumble bees also make modest contributions to their pollination (Free, 1966; 1993; Le Guen *et al*., 1993; Suso *et al*., 1996; Bond & Kirby, 1999; Pierre *et al*., 1999; Somerville, 1999; Goulson, 2010). However, in wheat, barley and oats pollination is passive without the need for flowers to open (cliestogamy), cross pollination being achieved with wind borne pollen (Allan, 1980; Brown, 1980; Starling, 1980; Acquaah, 2007; references cited in Klein *et al*., 2007). Cross-pollination in rye also relies on wind-borne pollen (Morey & Barnett, 1980; Acquaah, 2007). Although visited by honey bees, bumble bees, solitary bees and hoverflies, in oilseed rape and linseed self pollination is generally passive self-pollination, and/or by the wind (Free, 1993; Adegas & Noqueira Couto, 1992; Abel & Wilson, 1999; Manning & Boland, 2000; Abel *et al*., 2003; Morandin & Winston, 2005; Hoyle *et al*., 2007; Cresswell, 2008). Potatoes show an increase in seed production in response to pollinator activity (Plaisted, 1980; Free, 1993), but production of tubers (i.e. parts for human consumption) is vegetative and has no requirement for pollination. Sugar beet is self-fertile (Archimowitsch, 1949; Smith, 1980; Bosemark, 2006); cross-pollination is achieved on air currents, with insects (honey bees, bees and thrips) only providing a minimal contribution to pollen movements (Free *et al*., 1975). Field peas self-pollinate passively (Free, 1993; Franklin *et al*., 2000; McPhee, 2003). Although maize is visited by carpenter bees it too is wind-pollinated (Russell & Hallauer, 1980; Delaplane & Mayer, 2002; Bannert & Stamp, 2007).

Regarding orchard produce, soft fruits and vegetables and salads grown outdoors for human consumption, these make up make up just 3% of coverage (the remainder being temporary grass and uncropped arable land) (Defra, 2010a). However, their dependencies on insect pollination are much higher than those of the arable crops listed in Table 6.1. According to the coefficients allocated by Klein *et al*., 2007, their dependencies on insects are either modest (up to 40% reduction in crop production in absence of pollinators) or great (between 40-90% reduction in productivity). Apples, pears plums and cherries are all mainly self-incompatible, and have a great requirement for biotic vectors for their pollen. A large body of literature is available about their pollination requirements compared to most other crops (Crane, 1991; Free, 1993; Sekita & Amada, 1993; Fourez, 1995; Batra, 1998; Calzoni & Speranza, 1998; Delapane & Mayer, 2000; Westercamp & Gottsberger, 2000; Vicens & Bosch, 2000; Frève *et al*., 2001; Kron *et al*., 2001; Sekita, 2001; Stern *et al*., 2001; Thomson & Goodell, 2001; Wei *et al*., 2002; Maccagnani *et al*., 2003; Nyéki & Soltész, 2003; Soltész, 2003; Szábo, 2003; Ladurner *et al*., 2004; Monzón *et al*., 2004; Sharma *et al*., 2004; Stern et al., 2004; in Klein *et al*., 2007). Honey bees, bumble bees, solitary bees and hover flies are all recorded as true pollinators of orchard fruits, managed honey bees being the primary pollinator in most commercial scenarios in the UK (Delaplane & Mayer, 2000). Raspberries are hermaphrodite and self-compatible; in the absence of insect pollinators, passive self-pollination yields inferior fruits (Yeboah Gyan & Woodell, 1987a; Chagnon *et al*., 1991; Free, 1993; Willmer *et al*., 1994; Pinzauti *et al*., 1997; Cane, 2005). Most varieties of strawberries are hermaphrodite and are self-compatible. In the absence of insect visitors, pollination is passive or (less often) by wind, but in the UK insects likely to make a (modest) contribution are honey bees, bumble bees, solitary bees and hoverflies (Maeta *et al*., 1992; Chagnon *et al*., 1993; Free, 1993; Kakutani *et al*., 1993; Zebrowska, 1998; Delaplane & Mayer, 2000; Malagodi-Braga & Kleinert, 2004). Currants self-pollinate passively, with honey bees, bumble bees and solitary bees making modest contributions (Free, 1993; Koltowski *et al*., 1997; 1999; Soltész *et al*., 2003).

Table 6.1 Areas covered by the main agricultural crops grown outdoors in the UK and the impact of insect pollination (IP) on productivity

Crop Type Crop name	**Area** (10^3 ha)	**Impact of IP** (after Klein *et al*., 2007)
Arable		
Cereals		
Wheat	1,814	None
Barley	1,160	None
Oats	131	None
Other (Rye)	28	None
Oilseeds		
Oilseed rape	581	Modest
Linseed	29	Little
Potatoes	149	None
Other non-horticultural crops		
Sugar beet	116	None
Field beans	190	Modest
Peas for harvesting dry	43	None
Maize	166	None
Fruit grown in the open		
Orchard fruit		
Apple	13.6*	Great
Pear	1.7*	Great
Other (Plum, Cherry)	1.5*	Great
Soft fruit		
Strawberries	} Total =18	Modest
Raspberries		Great
Other (Blackcurrants, blackberries, gooseberries, grapes)		Modest

Note: Great = production reduced by 40-90% without IP; Modest = 10-40% reduction; Little = up to 10% reduction; None = no reduction

*Orchard Fruit survey data (Defra, 2010b). This is collected on the tree areas of each variety, rather than the field size. For this reason, results are not directly comparable to those in the June survey of agriculture and horticulture (Defra, 2010a; 2010c) which states total area of orchard fruit as 28,000ha in 2009.

6.1.4 Economic evaluation of insect pollination in agriculture

A number of studies have placed estimates on the economic value of insect pollination in agriculture. However, the majority have concentrated on the contribution made by honey bees to this service. Valuations vary widely, and have been variously based on a summation of the value of those commodities believed to be dependent on insect (generally honey bee) pollination (Robinson *et al*., 1989; Morse & Calderone, 2000), or the financial loss to society likely to be incurred should managed honey bees be unavailable for cropping systems (Southwick & Southwick, 1992). Evaluations have been completed for many countries (Gill, 1989; Carreck & Williams, 1998; Gordon & Davis, 2003; Allsopp, 2008), including the EU (Borneck & Bricout, 1984; Borneck & Merle, 1989). Gallai *et al*. (2009; 2010) placed an estimate of approximately €153 billion on the annual value of insect pollination globally (equivalent to £127 billion), and calculate that the (2005) value for the contribution of pollinators to crop production used directly for food in Europe is over €14.2 billion, a figure equivalent to 10% of the total value of human food production Europe-wide each year. Borneck and Merle (1989) calculated that insect pollinators contributed 5 billion ecus to the annual market value of 30 selected crops. Regarding studies specific to the UK, based on insect pollination dependency levels produced by Williams (1994), Carreck and Williams (1998) used market values of arable, tree, soft fruit and seed crops which utilise managed honey bee colonies to place a value of £172 million/year on insect pollination in UK agriculture. Based on experimental data, Temple *et al*. (2001) estimated the value of honey bee pollination to agricultural and horticultural crops in England was £117 million/year. Interestingly, this ADAS study also undertook a survey of 800 growers whose crops (according to Carreck & Williams 1998) most benefited from pollination (e.g. soft fruit, top fruit), and found that these growers placed an annual value of just £54 million on honey bee pollination for the same year.

Applying different approaches to evaluating the financial worth of insect pollination in the UK, Mwebaze *et al*. (2010), used the contingent valuation method to calculate the public's willingness to pay for a theoretical pollinator protection policy is equivalent to £1.77 billion/year. Using the Replacement Cost method, Marris *et al*. (2009) showed that in the absence of any insect pollinators, the cost of the average UK dessert apple would double. Other recent studies have variously estimated the annual value of honey bee pollination in the UK as £191 million (NAO, 2009), £230 million or between £159 and £475 million (Hughes *et al*., 2010 pers. comm.). Using the methods of Gallai *et al.* (2009), the production function value of biotic pollination as a contribution to crop market value in 2007 was £430 million, which is approximately 8% of the total value of the market (Defra 2008b; 2009; BHS, 2008). An unpublished study values total insect pollination in the UK at £440 million/year or 12% of UK agricultural revenue, and estimates that replacing insects with hand pollination in the UK would cost about £1,500 million/year (Potts, cited in POST, 2010). These figures were based on the value of the ecosystem service provided by the entire community of biotic pollinators (both managed and wild); evaluations of the relative economic contributions made by wild pollinators (as opposed to managed honey bees or bumble bees) to agriculture are rare, and the extent to which they contribute to wildflower pollination is also unknown (UK NEA, 2011 and references cited therein). However, their contributions are likely to be high. Unmanaged insect species constitute the majority of visitors in plant pollinator webs (Memmott, 1999), and there is evidence that many forage plants that depend on unmanaged (bumble bee) pollination services have declined in numbers (Biesmeijer *et al*., 2006; Carvell *et al*., 2007); Indeed, it has been suggested that given the estimated numbers of managed pollinators (honey bee colonies) known to be available to service known areas of certain insect-dependent crops, as much as two thirds of pollination services for these plants must be provided by wild species (Free, 1993; UK NEA, 2011). Using crop dependency data from Morse and Calderone (2000), Losey and Vaughan (2006) generated an estimate that native insects (almost exclusively wild bees) are worth $3 billion to US crop pollination.

In the present study, we have used the most up to date market values currently available for the main agricultural crops grown in the UK (Defra, 2010c), and corresponding pollinator dependence values given by Klein *et al*. (2007), to calculate the annual economic contribution of insect pollination (Table 6.2). On these bases, we estimate that, in total, insect pollination contributes between £186 million and £567 million each year for outdoor-grown crops.

Regarding the reliability of this evaluation, Table 6.1 and Table 6.2 are not comprehensive, and certain crops currently grown in the UK are not included. In some cases, crops are omitted because no breakdown statistics are available regarding their individual productivity values in the UK. Notable omissions of this type are pumpkin, marrow and courgette, which are known to be very heavily reliant on insect pollination (Free, 1993; Nepi & Paccini, 1993; Delaplane & Mayer, 2000; Canto-Aguilar & Para Tabla; Ashworth & Galetto, 2001; Cardoso, 2003). According to the dependencies allocated by Klein *et al*. (2007), insect pollinators are essential for these crops, and their productivities will drop by at least 90% without this service. The British pumpkin market alone is reported as worth about £25 million each year (Anon, 2004), but specific Defra productivity data were not found. Agricultural statistics for production of the minor seed crops grown in the UK that gain a modest benefit from insect pollination (dependency between 0.1 and 0.4 (Klein *et al*., 2007)), such as mustard, are also unavailable, and these are likewise comparatively high value crops. Borage covers between 1,000 and 3,000 hectares of arable land in the UK (Defra, 2010a), and is pollinated by bees (Montaner *et al*., 2001), but this crop is not listed by Klein *et al*. (i.e. the degree to which it depends on insects is unknown) and no annual productivity value is given by Defra (2010a; 2010c). Although in many crops (like potato) insect pollination is not required to produce those parts required for human consumption, this service is however necessary for their propogative seed production (i.e. in this way insect pollination may make at least some contribution to economic value, albeit unmeasured). Examples of other crops of this type excluded from Table 6.1 and Table 6.2 are onions, asparagus, cabbage, cauliflower and carrots (Crane, 1991; Free, 1993; Schittenhelm *et al*., 1997; Delaplane & Mayer, 2000; Witter & Blochtein, 2003; Slaa, 2006). Unspecified vegetables and salad grown in the open for human consumption in the UK have a combined value of £776 million/year (Defra, 2010c). If we conservatively estimate that, collectively, these have only a little dependency on insect pollinators (between zero and 0.1, according to Klein *et al*., 2007), this equates to a further contribution of £77.6 million to agricultural productivity in the UK each year. In the light of these considerations, the overall range of insect pollination values presented in Table 6.2 is likely to be an under- rather than an over-estimate of the worth of this service to UK agriculture.

6.2 RESOURCE REQUIREMENTS FOR THE POLLINATOR COMMUNITY

The community of biotic pollinators of significance to agricultural production in the UK is comprised of a diverse array of insects (see Section 6.1.2), but primary service providers are honey bees, bumble bees, and solitary bees. Hoverflies, thrips, beetles, Lepidoptera and other Hymenoptera provide further (but unmeasured) contributions. In order to implement effective ES Options that will conserve or promote insect populations at/to levels that will support agricultural pollination services, it is necessary to understand the ecological needs of these pollinator groups. This section focuses on the resource requirements of bees, and how these requirements may be met through a suite of ES Options. This is not only because bees are widely identified as the key crop pollinators, but also because their respective biologies are disproportionately well-documented in the current literature. However, other insect groups, notably hoverflies, are taken into account where sufficient data are available to allow informed comment.

Table 6.2 The economic contribution of Insect Pollination in the UK, using market values for the UK's main outdoor agricultural crops, and dependency values from Klein *et al*. (2007)

Crop Type Crop name	**Value** (£m)	**Dependence on Insect Pollination**		**Insect Pollination value** (£m)	
		Min	Max	Min	Max
Arable					
Cereals					
Wheat	1,590	0	0	0	0
Barley	687	0	0	0	0
Oats	73	0	0	0	0
Other (Rye)	3	0	0	0	0
Oilseeds					
Oilseed rape	478	0.1	0.4	47.8	191.2
Linseed	18	0	0.1	0	1.8
Potatoes	690	0	0	0	0
Other non-horticultural crops					
Sugar beet	241	0	0	0	0
Field beans	86	0.1	0.4	8.6	34.4
Peas for harvesting dry	17	0	0	0	0
Maize	No data	0	0	0	0
Fruit grown in the open					
Orchard fruit					
Apple	107	0.4	0.9	42.8	96.3
Pear	12	0.4	0.9	4.8	10.8
Other (Plum, Cherry)	27	0.4	0.9	10.8	24.3
Soft fruit					
Strawberries	231	0.1	0.4	23.1	92.4
Raspberries	110	0.4	0.9	44.0	99.0
Other - Blackcurrants, blackberries etc.	43	0.1	0.4	4.3	17.2
			Total	**186.2**	**567.4**

Note: (Great (0.4-0.9); Modest (0.1-0.4); Little (0-0.1); No impact (0)

Honey bees (managed or feral *A. mellifera*) are long-tongued. They are excellent generalist foragers; apart from the well-documented lists of commercial crop plants visited (McGregor, 1976; Free, 1993; Klein *et al*., 2007), they will utilise a very wide variety of flora in natural, semi-natural and comparatively urban landscapes (Howes, 1979; Hooper & Taylor, 1988; Delaplane & Mayer, 2000). The foraging behaviours and food requirements of honey bees are detailed in Free (1993). Some flower species are visited for nectar only, some are visited for pollen only, and others are utilised as good sources of both. At any one time, honey bees tend to forage from just a few species (Free, 1993), but recent research suggests that diversity of diet is important: honey bees fed with a polyfloral pollen mix have increased levels of immunocompetence compared with those fed on pollen from just one plant species (Alaux *et al*., 2010).

There has been a great deal of research into the flower-types favoured by bumble bees (*Bombus*) (Goulson, 2003a; 2010; Goulson *et al*., 2005; CEH 2001; Defra, 2008a and references cited therein). Table 6.3 lists the tongue lengths (and nesting characteristics) of British bumble bees in relation to their foraging habitats. Medium and long-tongued species visit deep flowers (e.g. Asteraceae, Fabaceae and Lamiaceae), whereas short-tongued species are more generalised but still have preferences (e.g. Asteraceae). All bumble bee species use a broader range of plants for nectar collection than they do for pollen, but longer-tongued species have a comparatively narrow diet breadth when collecting nectar (Defra, 2008a). Bumble bee species with short colony cycles, which require a high quality food supply, may thus be more specialised in their flower requirements (Goulson & Darvill, 2004).

Table 6.3 Characteristics of British bumble bees (after Williams, 1986; Edwards & Jenner, 2005; Defra, 2008a)

Species	Tongue length	Nest location	Habitat type
B. hortorum*	Long	Below ground	A B C D E
B. humilis***	Medium	On surface	D E
B. jonellus**	Short	Below ground	A D E F
B. lapidaries*	Short	Below ground	A B C D
B. lucorum*	Short	Below ground	A B C D E F G
B. magnus**	Short	Below ground	F
B. monticola**	Short	Below ground	F
B. muscorum**	Medium	On surface	B D E G
B. pascuorum*	Medium	On surface	A B C D E F
B. pratorum*	Short	Below ground	A B C
B.ruderarius***	Medium	On surface	A B D
B. ruderatus***	Long	Below ground	A B D G
B. soroeensis**	Short	Below ground	C D E F
B. sylvarum***	Medium	Below ground	B D G
B. terrestris*	Short	Below ground	A B C D E

* Common species throughout England
** Predominantly found in North West of England
*** Restricted to Southern England
Habitat types: A – gardens; B – farmland; C – woodland glades and edges; D – grassland; E – heathland; F – uplands; G – marshes and bogs.

6.2.1 Importance of season-long of bloom

The value of a floral landscape to local bee populations is greatest where there is a season-long succession of bloom (Delaplane & Mayer, 2000). Any wild bee colony only has a limited window of opportunity to start a nest (with a single mated queen), rear a sufficiently large population of workers to sustain the colony, and to collect enough food to produce new queens and males. The number of queens a colony can produce depends on the number of workers in the weeks preceding the queen production period (Heinrich, 1979) which, in turn, depends on season-long availability of pollen and nectar food, for example as provided by meadows with rich flower densities (Bowers, 1986). Honey bees (wild or managed) store large surpluses of food, and are thus able to cope with periods during which food supply is interrupted (Delaplane & Mayer, 2000).

Moreover, in managed apiaries the beekeeper mitigates forage shortages by supplementing the colony's food reserves, and/or by moving hives to areas with alternative food plants. However, wild bee species that do not keep big reserves depend on a continuity of available food resources in their surrounding environment (Shelly *et al*., 1991; Williams & Christian, 1991; Defra, 2008a). For this reason bumble bees, which store enough nectar for only a few days, are particularly vulnerable to dearths of nectar that can occur in the mid-summer. Worker bumble bees that are deprived of nectar for just one day alter their behaviour and cease incubating brood, such that the survival of the whole colony is jeopardised by a even a short interruption in food supply food (Cartar & Dill, 1991). Bumble bees require a succession of flowers from April to August (Fussell & Corbet, 1991; Defra, 2008a; Goulson *et al.*, 2008). The best situations for this floristic succession are usually found in perennial semi-natural habitats (Corbet, 1995). Many studies have demonstrated positive relationships between the floral diversity of an area and the number of bee species found (Banaszak 1983; Kells *et al*, 2001; Bäckman & Tiainen, 2002; Chapman *et al*. 2003; Kells & Goulson, 2003; Defra, 2008a).

6.2.2 Importance of perennial versus annual planting

Many different bee species (and other insect pollinators) take advantage of annual plants, especially mass flowering crops like oilseed rape, because they provide rapid and locally extremely abundant forage (McGregor, 1976; Free, 1993; Delaplane & Mayer, 2000; Westphal *et al*. 2003; Defra, 2008a). However, although such annual crops can have benefits for generalist foragers, as they only flower for a short period, they do not provide the succession required by certain pollinator species (see above). Perennial herbs and shrubs generally offer superior and more reliable forage (Fussell & Corbet, 1992; Dramstad & Fry, 1995; Petanidou & Smets, 1995). They are comparatively richer in nectar, due to their ability to store and secrete sugars from the previous season, and can provide bees with a "more-or-less dependable food source year after year" (Delaplane & Mayer, 2000). For these reasons, (bumble) bees tend to utilise perennials and biennials over annuals. However, different species do show preferences: longer tongued bumble bees prefer perennial mixes rich in *Trifolium pratense*; shorter tongued species make more visits to *Borago officinalis* in an annual mix (Carvell *et al*., 2006). Goulson *et al*. (2005) found that almost one third of bumble bee pollen-collecting visits were to *T. pratense*, and over 60% of visits were to Fabaceae as a whole. The presence of perennial species also encourages repeated bee nesting in the area, which may at least in part account for observed correlations between the rising numbers of pollinator species and rising numbers of plant species over time in undisturbed meadows (Delaplane & Mayer, 2000).

6.2.2.1 Nesting resources

Managed honey bees nest in hives provided by the beekeeper. Unmanaged *A. mellifera* (Thompson, 2010) and all other wild bees must obtain nesting materials/sites (mud, leaves, leaves, soil, resin, dead wood, etc) in their surrounding habitats (Delaplane & Mayer, 2000; Roulston & Godell, 2011). Requirements may be complex and species-specific. For example, a shortage of mud could be a limiting factor with *Osmia sp.*, and these mason bees also use arial cavities and hollow stems as nesting sites (Free & Williams, 1970; Delapane & Mayer, 2000). Unequivocal demonstration that lack of nesting resources limits pollinator populations (and that provision through ES would increase pollinator numbers) is proving challenging for current researchers, due to the correlation of nesting sites with local vegetation structure and thus floral resources (Roulston & Goodell, 2011). However, numerous positive relationships have been noted between nesting densities and/or abundance of wild bees (from various groups), and environmental variables such as availability of wide cavities, abandoned rodent nests, soil moisture/composition, ground cover, slope and aspect (Potts *et al*., 2005; Kim *et al*., 2006; McFrederick & LeBuhn, 2006; Roulston & Goodell, 2011). Many ground-nesting bee species construct their nests less than 30cm below ground-surface (O'Toole & Raw, 1991; Roulston & Goodell, 2011). Clearly, ground disturbances of any kind, particularly agricultural tillage, are likely to be very destructive to such pollinators. However, to date precise levels of mortality are not believed to have been recorded for any UK species. Bumble bees prefer undisturbed habitats characterised by coarse vegetation for nesting, which takes place in leaf litter or small mammal burrows (Goulson, 2003a; 2003b). In agricultural landscapes, potential nesting sites for bumble bees are found in perennial semi-natural habitats, fence lines, hedgerows and forest margins (Kells & Goulson, 2003; Osborne *et al*., 2008a). Bumble bee forager density has been positively associated with rodent hole density (McFrederick & LeBuhn, 2006). Lower populations of these mammals in the agricultural environment have led to a reduction in potential nest sites for both above and below-ground nesting bumble bee species (Goulson *et al.*, 2008).

6.2.2.2 Importance of landscape

6.2.2.2.1 Fragmentation

The diversity of pollinator (bee) species is highest in large, continuously-connected areas of suitable habitat (Delaplane & Mayer, 2000). Spreading urbanisation coupled with modern farming practices effectively break up the landscape, resulting in comparatively small "ecological islands" of pollinator-friendly habitat, separated by much larger tracts of less inhospitable land. Although generally reported as deleterious to insect pollinators (Rathcke & Jues, 1993; Buchmann & Nabhan, 1996; Steffan-Dewenter & Tscharntke, 1999; see Cane, 2001), the relative impact of such fragmentation on different bee species will vary, and depends on the bees' body sizes, their abilities to commute between dissociated nest sites and forage patches, their nest sizes and required home-range area, and the dispersal capabilities of their sexual stages (Cane, 2001; Osborne *et al*., 2007; Defra, 2008a; Darvill *et al*., 2010; Goulson *et al*., 2011).

Irrespective of species, the foraging range of a worker bee determines the area which a nest can exploit for food resources, those with longer ranges being better able to cope with more patchy food availability (Delaplane & Mayer, 2000; Osborne *et al*., 2008b). There is evidence that solitary bees have relatively small foraging ranges (Gathmann & Tscharntke, 2002): long foraging distances impose high costs on offspring production, such that suitable nesting and foraging habitats need to be in relatively close proximity for population persistence (Zurbuchen *et al*., 2010). By contrast, larger (social) bees, including honey bees, are able to commute large distances to find food (Roubik & Aluja, 1983; Delapane & Mayer, 2000; see also earlier citations in Section 6.1.2); Cane (2001) suggests an average home-range radius for larger bee species of 2.8 km (median 1.5 km). Where a sufficient number of habitat fragments of sufficient size persist in agricultural landscapes, as long as they are within foraging range of nearby crops, these may serve as pollinator "reserves" in an otherwise impoverished landscape (Ricketts, 2003).

Although bumble bees tend to be area constant (Saville *et al*, 1997; Osborne & Williams, 2001), workers will travel long distances (several hundred to a few thousand metres) from their nests to forage (Walther-Hellwig & Frankl, 2000; Osborne *et al*., 1999; 2008b; Chapman *et al.,* 2003; Defra, 2008a). Distances covered appear to depend on nest size. Those with large nest sizes such as *B. terrestris* and *B. lapidarius* forage further than those with smaller nest sizes such as *B. pascuorum*, *B. sylvarum* and *B. ruderarius* (Walther & Frankl, 2000; Darvill *et al*. 2004; Knight *et al*. 2005). Bumble bee flight times are short compared to the amounts of time spent gathering food within patches of flowers, so that a distant site does not have to be much more rewarding than nearer food resources to be the better option (Cresswell *et al*., 2000): mass flowering crops can act as attractants for foraging and common bumble bee species will make use of these over a foraging range of up to 3 km (Westphal *et al.,* 2003). Indeed, there is evidence that their foraging range may be even larger as marked bumblebees have returned home after being released 9.8 km away (Goulson & Stout, 2001).

Recent studies have demonstrated that the social nature of bumble bees renders them particularly sensitive to habitat fragmentation (Goulson *et al*., 2011). Since each nest contains only one mated breeding female and the sperm she has stored from a (single) haploid male, their effective population size is just c.1·5 times the number of successful nests (Goulson, 2003a; Goulson *et al*., 2011). Although some species remain widespread and hence have large populations, others can only thrive in areas large and continuous enough to support high densities of their preferred forage plants. Edwards (1998) suggests that a healthy bumble bee population may need a minimum of 10 km^2 (Defra, 2008a), and bumble bee richness at the 10 km^2 scales has been positively correlated with land use heterogeneity, as well as the proportion of grassland and the abundance and diversity of dicotyledonous flowers (Pywell *et al*., 2006). Most nature reserves in the UK might only support a handful of nests of the rarer bumblebee species, and are thus far too small to support viable populations. Small populations are inherently more vulnerable to local extinctions, and only where these form part of a larger metapopulation can losses be rebalanced by repopulation (Ellis *et al*., 2006 Goulson *et al*., 2008; 2011). If habitat fragmentation is very severe it can thus lead to isolation without the possibility of repopulation and subsequent loss of genetic cohesion, with the attendant danger of genetic inbreeding (Goulson *et al*., 2008). The dispersal ranges of the sexual stages of bumble bees also vary markedly between species; some groups having relatively high dispersal abilities, while others are more sedentary (Darvill *et al*., 2010). This will also dictate the scale of habitat fragmentation that an individual species can withstand, those that are least able to disperse being the most vulnerable.

6.2.2.2.2 Linear features

Linear landscape features, such as fence lines and hedgerows have been associated with increased bee numbers and diversity (Fussell & Corbet, 1992; Kells & Goulson, 2003; Öckinger & Smith, 2007; Osborne *et al*., 2008a; Menz *et al*., 2011). Osborne and her co-workers (2008a) found significantly more bumble bee nests in linear than in non-linear habitats, and more nest-searching queens (of all species encountered) have been recorded near the boundaries of grassland (near hedges or woodland) than in the centres of grassland areas (Svensson *et al*., 2000). Such observations may simply reflect that bees concentrate in linear features because they are confined to these limited areas in otherwise heavily cultivated landscapes (Öckinger & Smith, 2007). Equally, boundaries may be attractive because certain types of nesting sites, such as burrows vacated by bank voles, are more frequent in such features (Tattersall *et al*., 2002). Moreover, hedgerows are, in their own right, valuable sources of insect forage (Pollard *et al*., 1974; Stechmann *et al*., 1981). In a case study of pollination services in the US, Menz *et al*. (2011) have devised and implemented a planting palette for the restoration of hedgerows, and are currently monitoring pollinator communities on an annual basis. Initial findings from restored hedgerows, and from older hedgerows with a directly comparable but established floral composition, are that local bee diversity is increased. In addition, both managed honey bees and wild bee species prefer foraging on native hedgerow shrubs relative to exotic weeds co-flowering at these sites (Menz *et al*., 2011). However, there is evidence that linear features may also be utilised just because of their "straight line" linearity: bumble bees use linear hedgerows to guide their foraging activity (Cranmer, 2004); queen bumble bees may use linear landmarks to facilitate homing (Osborne *et al*., 2008a); managed honey bees prefer to work up and down rows of apple trees than across them in orchard fruit pollination, and use landscape features to navigate between their nests and foraging areas (references in Free, 1993; also in Delaplane & Mayer, 2000).

6.2.3 Resource requirements for other insect pollinators

Unlike the bee families (in which the needs of adults and immature stages are met with the same (floral) food sources), for most if not all other insect pollinator groups (such as Syrphid flies and Lepidoptera), the respective food requirements of adults and larvae differ. Syrphid adults (hoverflies, also known as flower flies) use flowers for pollen and nectar, but the requirements of their larvae are extremely disparate. In the UK there are about 270 Syrphid species. Some of their larvae feed externally on plants, or they may be internal feeders, attacking bulbs and roots. Some are saprotrophic, feeding on decaying plant and animal matter in the soil, or in ponds and streams. In other hoverfly species, larvae are insectivorous and prey on aphids, thrips and other plant-sucking insects. Differences between adult and larval food requirements mean that hoverflies are a particularly important group in the context of insects beneficial to agriculture as the ecosystem services they provide are twofold. Not only are their adults recognised as important pollinators of a variety of crops (McGregor, 1976; see Section 6.1.2); their larvae are often natural enemies of herbivorous arthropods that can be agricultural pests (see chapter 5) (Ankersmit *et al*., 1986; Heimpel & Jervis, 2005; Tooker *et al*., 2006; Ghahari *et al*., 2008; Ssymank *et al*., 2008; Sajjad & Saeed, 2010). However, these differences also mean that provision of ES Options to meet the needs of both adults and larvae is potentially complex. Recent research has shown that hoverfly species richness is affected not just by availability of adult resources, but also the availability of the diverse habitats required by their larvae (Meyer *et al*., 2009).

By feeding on floral resources, adult hoverflies enhance their longevity and fecundity (Shahjhan, 1968; Faegri & Pijl, 1979). There has been a certain amount of research into their particular dietary needs (Cowgill, 1991; Cowgill *et al*., 1993a; 1993b; Jervis & Kidd, 1996; Branquart & Hemptinne, 2000; Sajjad & Saeed, 2010). Several flowering plants have been evaluated as "insectary plants" (likely to encourage hoverflies as biological pest control agents) (Lovei *et al*., 1993; Colley & Luna, 2000; Tooker *et al*., 2006; see Sajjad & Saeed, 2010), but given the diversity of the group, a complete understanding of Syrphid-plant associations in the UK is lacking. The relative attractiveness of any flower to an adult hoverfly may depend on several factors, including form and colour, as well as the availability of its nectar and pollen

(Sutherland *et al*., 1999). Studies suggest that when hoverflies are foraging in a mixed plant community they are very flower-constant (Goulson & Wright, 1998). A few species are known to be highly selective when foraging (Lovie *et al*., 1993; Lunau & Wacht, 1994), but many others are true generalists, and much more ubiquitous in terms of flower usage (Haslett, 1989; Branquart & Hemptinne, 2000). Dietary specialisation is important in hoverflies (as well as in bees and other pollinator groups), with both adult and larval diets being strongly associated with changes in hoverfly occurrence (Biesmeijer *et al*., 2006). Hoverfly species with narrow habitat requirements in terms of flora are most vulnerable to declines. In the UK, hoverfly declines have been shown to be greatest in species that are comparatively specialised, that have just one generation year, and/or which are less mobile in terms of their ability to disperse (Biesmeijer *et al*., 2006). Hoverflies may favour wild flowers that have large inflorescences and flat corollae (e.g. Apiaceae, Asteraceae, Ranunculaceae and Rosaceae), however adults will usually visit the most abundant and rewarding flowers they can find in any given area (Branquart & Hemptinne, 2000). Hoverfly numbers have been positively linked with flower abundance in unsprayed conservation headland plots, in which they forage on non-crop plants (Cowgill, 1991; Cowgill *et al*., 1993b).

6.3 ES OPTIONS THAT MEET POLLINATOR RESOURCE REQUIREMENTS

Irrespective of insect group, insect pollinators in general will benefit from landscapes that provide a range of appropriate food plants as sources of pollen and nectar. Floral diversity is important to many species, and so are succession and permanency (perennial v. annual). Provision of nesting resources is equally crucial, and there is a strong requirement for undisturbed ground. Conserved habitats need to be large enough and/or close enough to each other that negative effects of fragmentation are mitigated. Studies on insect communities consistently link high pollinator diversity with large, undisturbed, florally-rich, long-blooming habitats (Delaplane & Mayer, 2000). In the case of non-bee pollinators (not just Syrphid flies, but also Lepidoptera and Coleoptera etc.), the needs of immature stages may be quite different from those of adults and these must also be taken into account in habitat provision. There is a wide variety of ES Options that, to greater or lesser extents, address these resource requirements. These are listed in section 6.4 and Appendix, with their respective impact ranking (see also CEH, 2001; Defra, 2008a).

Any ES Options that remove land from intensive arable production and restore a more diverse “natural” flora will be of benefit to a wide range of insect pollinators, and are thus likely to have a high positive impact on pollination services. Natural regeneration of field margins should be the preferred option for increasing floral diversity (CEH, 2001). Six metre wide uncropped field margins that have been allowed to regenerate naturally support approximately six times as many flowering plant species, ten times as many flowers, and ten times as many foraging bumble bees as cropped margins (Kells *et al*., 2001). However, where rapid restoration is required, where pernicious weeds may become a problem, or where local flora is impoverished (and rare arable plants are not at risk), sowing seed mixtures can provide a good variety of pollen and nectar sources (Smith *et al*., 1993; 1999; Carvell, 2004; Defra, 2008a). As long as they provide the required succession of bloom from spring to autumn, extension of arable field margins by sowing perennial grasses can make significant contributions to conservation of bumble bees (and other insects) on arable farmland (Fussell & Corbet, 1991; Carreck & Williams, 1999; Kells *et al*., 2001; Meek *et al*., 2001; 2002; CEH, 2001; Defra, 2008a). However, a comparison of different ES Options for field margins on arable land has shown uncropped margins sown with mixtures of nectar and pollen-producing plants offer better (bumble bee) forage than margins with a grass mix (Carvell *et al*., 2007). This is supported by the findings of Carvell *et al*. (2004), who showed that pollen and nectar grass and wildflower mixtures have the highest bumble bee abundance, and by Pywell *et al*. (2006), who showed that bumble bee abundance is significantly higher on pollen and nectar margins compared to wildflower margins, mature grass margins and recently sown grass margins. Nevertheless, pollen and nectar mixtures may lack resources early in the year and may have limited persistence, so inclusion of a florally enhanced margin option in ELS (currently only available in HLS) would extend choice for those farmers not in HLS.

Sowing with low cost mixtures that include agricultural varieties of legumes creates high quality foraging habitats for bumble bees (Pywell *et al*. 2005; 2006), and the impact of such measures is greatest where the proportion of arable land (i.e. intensity of crop production) is highest (Heard *et al*., 2007). Fertile ex-arable soils are not ideal growing media, preventing certain wild flower species from establishing or persisting, hence the recommended use of agricultural varieties (Pywell *et al*., 2003; Defra, 2008a). CEH (2001) has used bumble bee forage plant preference scores and indices of plant performance, to produce a series of recommended seed mixtures suitable for sowing on arable field margins. These are designed to provide a continuous succession of flowers suitable for long and short-tongued bumble bee species, whilst also providing habitats and food resources for other invertebrates. Syrphids and Lepidoptera will benefit from management practices that promote floral biodiversity and also succession (Biesmeijer *et al*., 2006; Albrecht *et al*., 2007). Hoverfly numbers have been positively linked with wild flower abundance conservation headland plots and field margins (Cowgill, 1991; Cowgill *et al*., 1993a; 1993b). The species richness and abundance of hoverflies and butterflies are significantly higher in meadows managed as prescribed by recent European ecological conservation areas (Albrecht *et al*., 2007). ES Options that offer permanency tend to promote insect pollinators in the environment (Defra, 2008a). For ground nesting insect pollinators, the undisturbed nature of the habitat is paramount, as found in permanent uncropped field margins (and beetle banks). Many ground-nesting bee species construct their nests less than 30cm below the surface (O'Toole & Raw, 1991; Roulston & Goodell, 2011). Clearly, ground disturbances of any kind, particularly agricultural tillage, are likely to be very destructive to such pollinators. However, to date precise levels of mortality are not believed to have been recorded for any UK species.

Hedgerows, which are known to be of value to bees as forage, nesting resources and navigational features, are also used by many other insect pollinator groups (Sotherton, 1984; Yeboah Gyan & Woodell, 1987a; 1987b; Holland *et al*., 2001; Defra, 2008a). The UK's Biodiversity Action Plan has identified 72 priority insect species that are associated with hedgerow flora (Wolton, 2009). ES Options that promote hedgerow maintenance, and limit cutting such that potential nesting sites are undisturbed, will also have comparatively high impact on the insect pollinator community.

Habitats good for certain hoverfly larvae, but of little or no use in terms of resource provision for other pollinators, include the wet and muddy margins of lakes, ponds, canals and slow-flowing rivers, shallow wet ditches, rotting tree stumps and dense woodland (Godfrey, 2003). Many hoverfly species live in forests, as these provide larval food sources (Rotheray 1993; Speight, 1996), but others colonise more open habitats such as field margins and fallow areas (Branquart & Hemptinne, 2000).

ES Options that potentially provide corridors or habitat islands (i.e. habitat connectivity) can offer benefits if these allow pollinators to travel short distances between nesting and feeding sites, and insect species to establish metapopulations that preserve viability. All insect pollinators are, to a greater or lesser extent, vulnerable to the effects of habitat fragmentation, and Lepidoptera in particular.

Apart from their obvious avoidance of pesticide usage, organic farms are particularly favourable for bumble bees, because they depend heavily on rotations involving legumes such as clover to maintain soil fertility (Defra, 2008a). Organic livestock farms may in the long term provide excellent habitat for bumble bees and other insect pollinators, as some of the best remaining habitats are unimproved grasslands grazed by cattle (Goulson, 2003a).

6.4 SUMMARY OF ES OPTIONS FOR POLLINATORS

Key options for providing nectar and pollen to a wide range of insect pollinators, including bees, flies and Lepidoptera, are:
Pollen and Nectar flower mixture (3)
Pollen and nectar seed mixtures in grassland areas (3)
Enhanced buffer strip on intensive grassland (3)
Floristically-enhance grass margins (3)
Species-rich meadows (3)
Orchards (2)

Additional (secondary) options providing some nectar and pollen to a range of insect pollinators:

Wild bird seed mixture (2)
Wild bird seed mixture in grassland areas (2)
Conservation headlands in cereal fields (2)
6 m uncropped cultivated margins on arable land (2)
Very low input grasslands (2)
Low input cereals (1)
Moorland (1)
Lowland heath (1)
Arable grassland (1)
Grassland – Hay making (1)

Options for providing breeding habitat, forage and habitat connectivity for a wide range of insect pollinators:

Hedgerow management (2)
Enhanced hedgerow management (3)
Hedge and ditch management combined (3)
Buffer strips on cultivated land and intensive grassland (1)
Field corner management (1)
Beetle banks (1)
Wild bird seed mixture (Will also provide seed for small mammals that provide bumblebee nest sites) (2)
Woodland edges (2)
Woodland (1)
Watercourses and erosion (buffer strips) (1)
Miscellaneous supplement small fields (1)

Options for providing breeding habitat, forage and habitat connectivity for a limited range of pollinators that have aquatic larval stages (e.g. Syrphidae):

Ditches (1)
Scrub (1)
Traditional water meadows(1)
Ponds (1)
Trees and Woodland (1)
Stone faced hedgebank management (1)
Buffer strips beside ponds and streams (1)
Reedbeds (1)
Fen (1)

Options that promote organic land use:

Basic payment for organic management.(2)

7 OPTION SCORING AND MAPPING OF ECOSYSTEM SERVICES

7.1 OPTION SCORING

ES options have been scored for each ecosystem service or group of ecosystem services scale from -1 to 3, as follows:

-1: negative impact

0: no significant effect

1: some benefit, but limited

2: significant benefit

3: substantial benefit

In most cases, quantitative evidence of the effects of ES options on ecosystem services or their agents (pollinators or pest predators, parasitoids etc.) is not available, so the scores are derived from expert opinion based on the literature reviews in previous chapters plus the personal experience of the authors. The scores apply to the ecosystem service concerned, or in the case of pollination and pest regulation, to its agents, rather than the direct benefit to agriculture, since this is very difficult or impossible to quantify on the basis of current knowledge. For example, we have good evidence that pollen and nectar mixtures attract large numbers of pollinators, and some limited evidence that they probably increase populations of some species, but we do not know the extent to which these effects will increase crop pollination or yields of most crops at the present time. However, we do know that absence or low numbers of pollinators is likely to affect crop yields, so a benefit can be inferred.

The scores are given in Appendix for the main types or groups of ecosystem services likely to benefit agricultural production.

7.2 MAPPING

Option scores (Appendix) were used to create maps at a 5 km^2 resolution showing the distribution of the major ecosystem services provided by Environmental Stewardship options that contribute to agriculture.

Ecosystem service scores for each holding were calculated according to Equation 1. Because units of measurement differ across options, funding associated with each option was used as the measure of quantity. For ELS, points were considered equivalent to pounds sterling; for HLS the payment rate per unit option was used.

A holding boundary dataset was created by merging field boundaries from the Defra CLAD database on the County/Parish/Holding (CPH) ID. This was intersected with a 5km grid covering England and the fraction of each holding in a 5km grid cell was calculated by dividing the intersected polygons by the size of the original holding polygon from the merged fields. These scores were then standardised by division by the mean score across all cells in England to allow comparison across the ecosystem services and mapped onto the 5km resolution grid.

$$ES_k = \sum_{j\ in\ k} F_{jk} \cdot \sum_{i\ in\ j} \frac{M_{ji} \cdot P_i \cdot S_i}{U_i} \qquad \text{Equation 1}$$

where:

ES_k = total ecosystem service for grid cell k
S_i = ecosystem service score for option i
U_i = unit of measure for option i
P_i = points (£) associated with option i
M_{ji} = measure of option i on holding j
F_{jk} = fraction of holding j in grid cell k

Maps are shown in Figure 7.1-Figure 7.4. These are accompanied by insets showing dominant agricultural land usage for comparison. The most recent year for which these were available was 2003, but major land use patterns are unlikely to have changed significantly since then.

Figure 7.1 Distribution of ecosystem services related to soil, nutrients and water arising from Environmental Stewardship, with inset showing agricultural land use

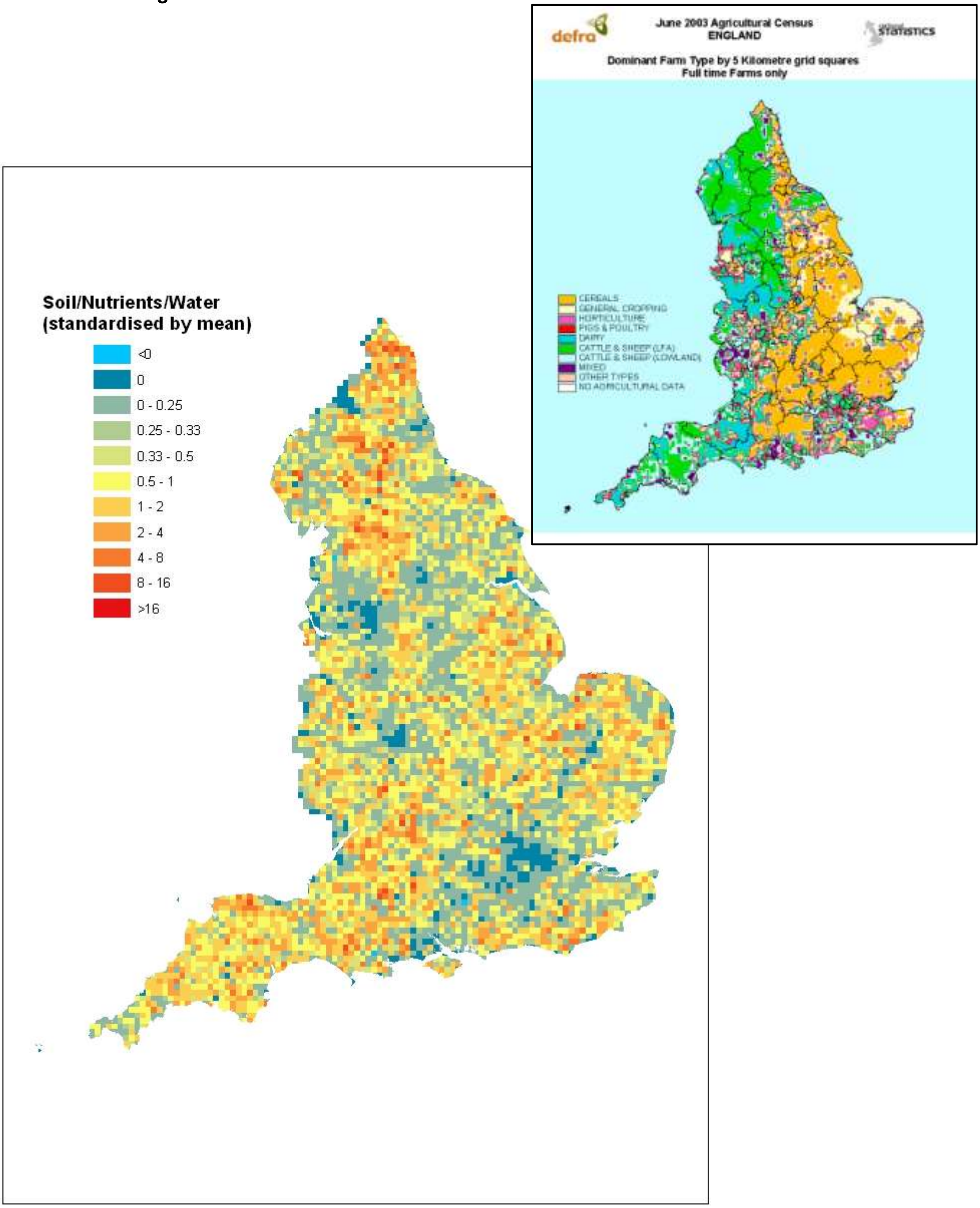


Figure 7.2 Distribution of ecosystem services related to genetic resources arising from Environmental Stewardship , with inset showing agricultural land use

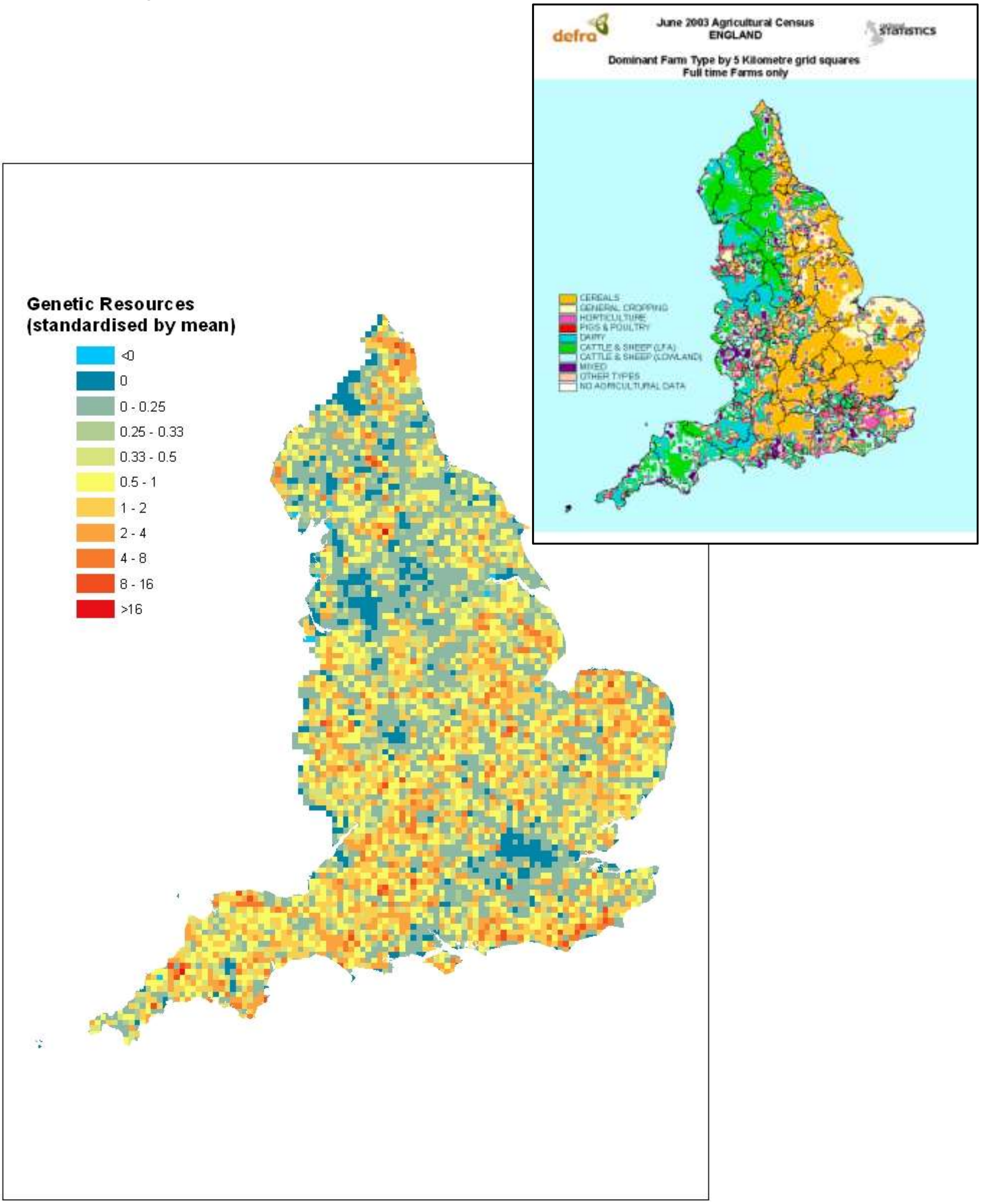


Figure 7.3 Distribution of pest regulation services arising from Environmental Stewardship, with inset showing agricultural land use

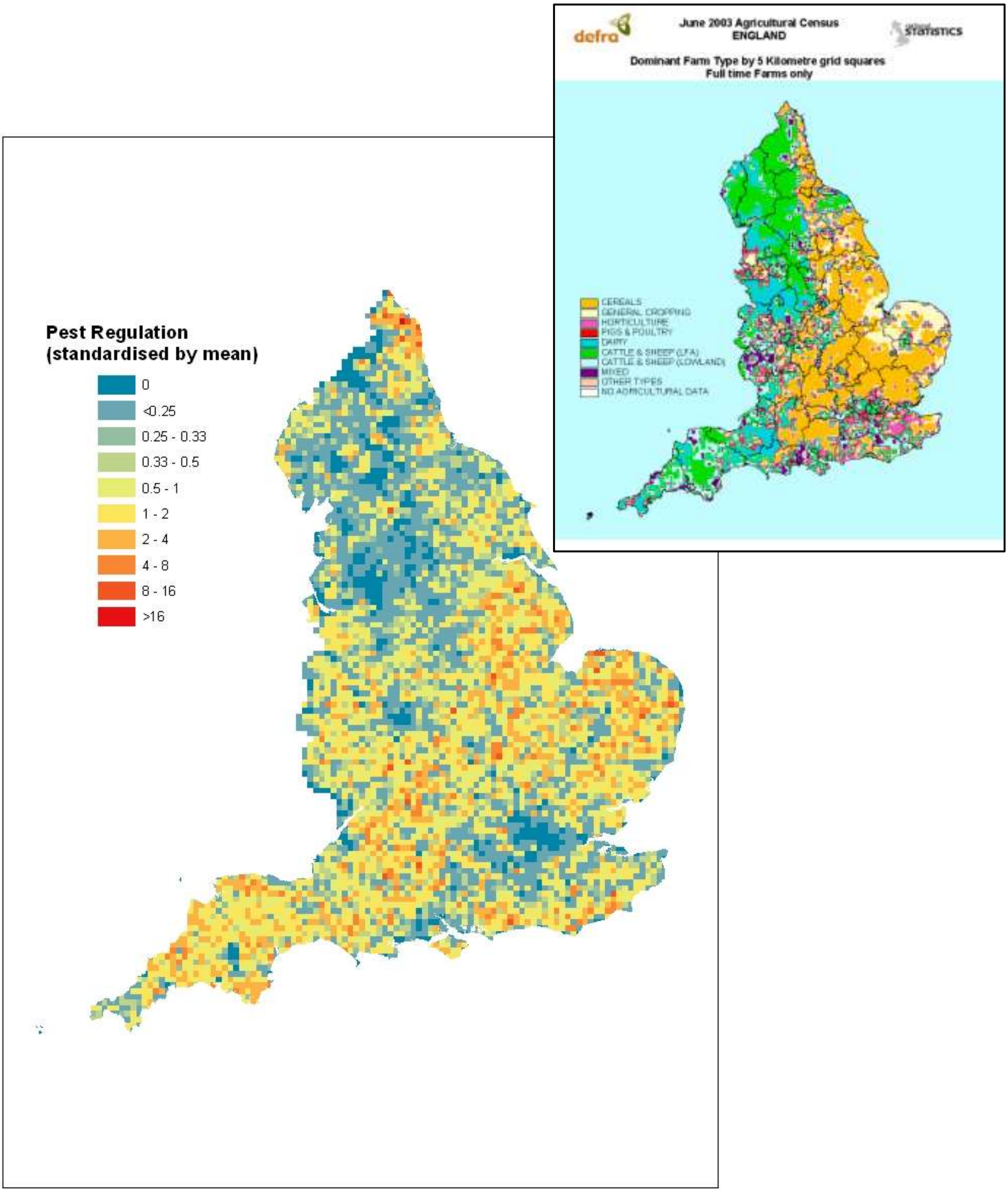
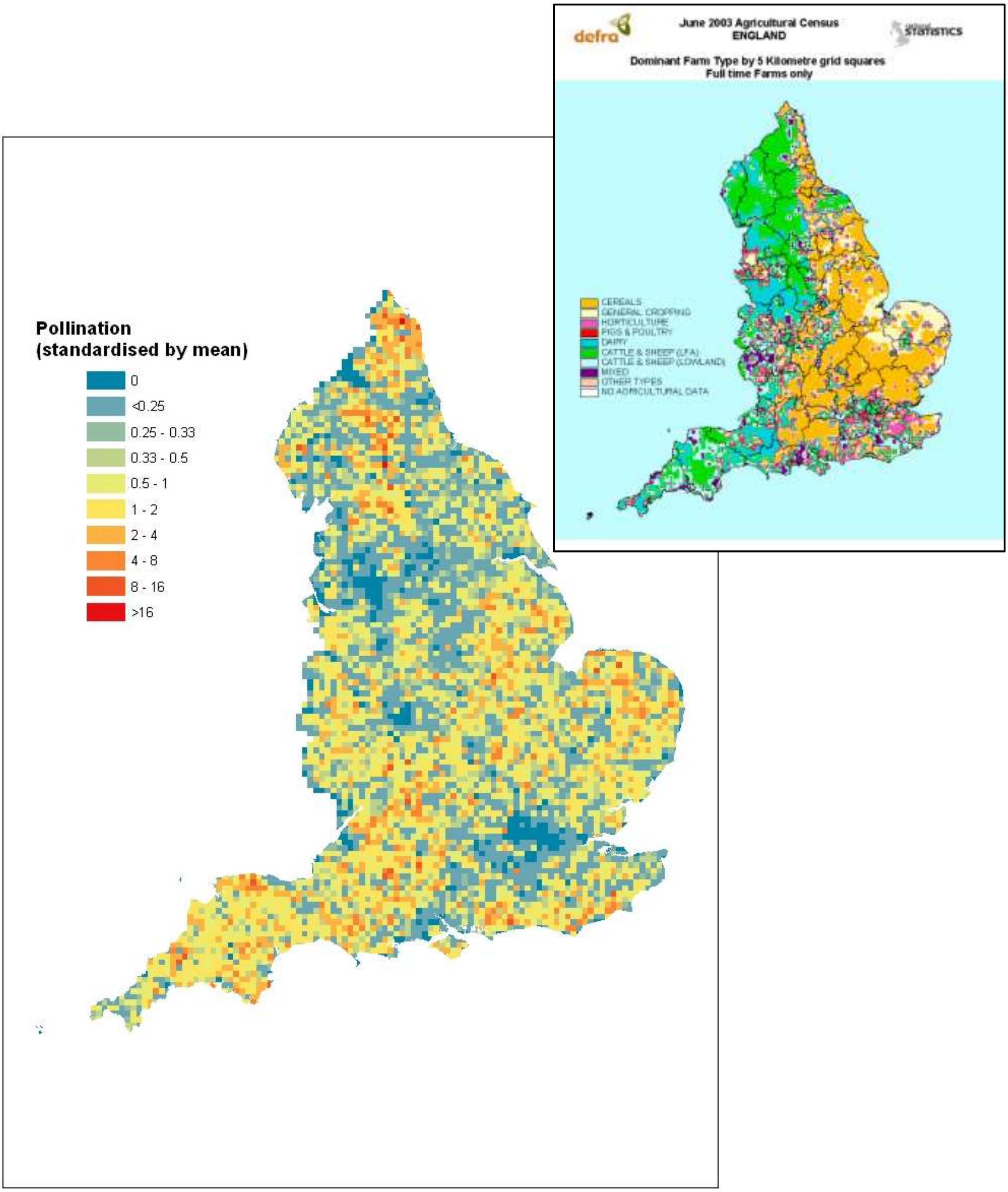


Figure 7.4 Distribution of pollination services arising from Environmental Stewardship, with inset showing agricultural land use



7.3 DISCUSSION

7.3.1 Distribution of key options for ecosystem services

For ecosystem services related to soil, water and nutrient cycling, there appears to be an association between levels of ecosystem services, arable and grazing livestock (including dairy). This reflects the types of options that contribute to provision of the services concerned. Areas of general high delivery are East Anglia, the East Midlands and Lincolnshire, the South West, and the northern uplands. Option groups associated with arable that have high scores related to soil erosion and the reduction of diffuse water pollution include ditch management, archaeology under cultivated soils, buffer strips, field corners, extended stubbles, and most of all, winter cover crops (which can also help to reduce nitrate leaching) and arable reversion to grassland. Options for management of maize to reduce erosion are also important, though as most maize is grown for livestock feed they are more important on livestock or mixed farms.

The most effective option groups connected to grassland with high scores include the prevention of erosion or runoff from intensively managed grassland and seasonal livestock removal from intensively managed grassland or grassland next to watercourses, and fencing watercourses, Others include ditch management, management of maize to reduce erosion, options for the creation of grassland, bracken control and the nil fertiliser supplement.

Two of the types of ecosystems services studied in detail, pest regulation and pollination, are of particular relevance to arable cropping, so an association between their delivery and areas dominated by arable or mixed agriculture may be considered a desirable outcome. For pest regulation, there is clearly an association with arable and mixed farming areas, but delivery also appears to be high in the south-west peninsula. Key options / option groups include hedgerow management, stone-faced hedgebanks, earth banks, buffer strips, uncropped cultivated margins, seed mixtures for birds and insects, undersown spring cereals, extended overwintered stubble, beetle banks, and options associated with low input grassland and species-rich grassland. Many of these options are applicable to both arable and livestock farms, and this is reflected in the high levels of delivery in the south west, where mixed farming and small fields with hedges and banks are an integral part of the landscape in many areas. Options creating habitat and resources for pest natural enemies are less common in the northern uplands.

The map for pollination services is very similar to that for pest regulation. This is not surprising, as many of the high impact options are similar between the two groups. For pollination however, there is slightly more emphasis on species-rich grassland and less on buffer strips (unless floristically enhanced), reflecting the importance of floral resources. Traditional orchards are also important for pollinators.

The main difference between the maps for pest regulation and pollination is the higher level of pollination delivery in the northern Pennines. This probably results from the presence of options for management of species-rich grassland and moorland.

Pollination is particularly important for many fruit crops, which are insect pollinated and often flower early in the year when numbers of pollinators are not high. However, the map indicates that pollination services in areas where horticulture and orchards are important do not have high delivery of pollination services through Environmental Stewardship.

Low values in areas where horticulture is predominant reflect low uptake of ELS among horticultural holdings. The probability of horticultural holdings entering ELS was significantly lower than for arable and grazing livestock holdings (Table 7.1), though differences were much smaller for OELS and HLS (Boatman *et al.,* 2007).

Table 7.1 Fitted probabilities (%) (from logistic regressions) of holdings entering ELS and OELS by farm type*

Factor	ELS	OELS
Farm type		
Cereals	20.1[g]	0.41[b]
General cropping	18.6[f]	0.60[b,c]
Horticulture	5.6[a]	0.64[b,c]
Specialist pigs	5.7[a]	0.01[a]
Specialist poultry	4.4[a]	0.33[a,b]
Dairy	16.5[e]	0.89[c]
LFA Grazing livestock	9.3[b]	0.19[a]
Lowland Grazing livestock	10.7[c]	0.61[b,c]
Mixed	14.1[d]	0.72[c]
Other types	4.6[a]	0.14[a]

* Superscript letters indicate statistically significant differences at the 5% level. Probabilities followed by the same letter are not significantly different. Reproduced from Boatman *et al*., 2007.

It is difficult to generalise about genetic resources because relatives of crop plants can occur in a wide range of habitats. Options related to traditional orchards, species-risk grasslands and saltmarshes are particularly highlighted, but a range of other options can contribute where wild relatives are present. For animals, the rare breeds supplement is the key option. The map indicates a broad distribution of relevant options, with no strong patterns emerging other than a general southerly bias.

8 GENERAL DISCUSSION AND CONCLUSIONS

This report has identified the potential contributions of a number of Environmental Stewardship options to the provision or enhancement of ecosystem services of benefit, or potential benefit, to agricultural production. It is clear that Environmental Stewardship has much to offer in this regard, though there is scope for improvement through greater geographical targeting of options. However, the direct provision of ecosystem services *per se* is not generally a specific objective of ES options; thus most of the benefits for ecosystem services identified in this report arise as by-products, rather than as direct objectives, of the options concerned.

A few options have been designed to promote agents of ecosystem services. Nectar mixtures are designed to benefit bumble bees, which are important pollinators, but the rationale behind their development was probably driven by conservation concerns as a result of the large declines observed in many bumble bee species, rather than to promote pollination. Beetle banks were developed to promote pest regulation by polyphagous ground predators, but comparable measures to enhance impacts of other predatory or parasitic taxa have not been developed. Both pollination and pest regulation services are provided by suites of taxa, and for best results the whole range need to be fully functional. Pest predators attack the pests in different ways, at different stages in their life cycles and at different times. The net effect is the result of the combined impact of all taxa combined. If conditions in any one year are unfavourable for certain taxa, others may be able to substitute and thus prevent pests reaching yield-damaging thresholds. Many pollinators are adapted to particular types of floral structure, and hence a range of different types of pollinator are required to service the full range of UK crops and wild flora (including crop wild relatives).

One option that is particularly relevant to both pollination and pest regulation is floristically enhanced field margins. This provides pollen and nectar for pollinators throughout the year and, being perennial, is long-lasting, in contrast to nectar mixtures that often need to be replaced after a few years. In addition to several species of hoverflies, important pollinators as adults, have larvae that are voracious predators of aphids. In addition, adult parasitoid wasps, also effective aphid control agents, require floral resources as adults. However, this option is only available under HLS. In view of the multiple benefits arising, its inclusion in ELS would be advantageous to promote these services on a larger scale. Development of seed mixtures designed specifically to benefit key species of pollinators, predators and parasitoids could help to maximise impact. Some progress in this regard was made in the Defra LINK-funded 3D farming project, but the results have not yet been implemented in the guidelines for ES options. A similar project is currently under way to develop seed mixtures to promote beneficial arthropods in horticultural crops[8]. There is scope for further work to design options that benefit suites of species and hence the associated services within ES.

The area where most progress has been made is the protection of soil and nutrient cycling, through measures to reduce soil loss by erosion and run-off. These also help to maintain a clean water supply through reduced diffuse pollution. There are several

[8] http://www.ecostac.co.uk/

options available to tackle these issues at different stages, and 'bundles' have been developed and are promoted through advice available to agreement holders[9]

Options that benefit soil and water are likely to achieve maximum impact when implemented together with measures to limit soil erosion and diffuse water pollution in the crop production area as a whole. Research shows variable results from management such as buffer strips because of issues of case-specificity. Location of options is critical and the availability of advice on option choice and location, as in the Catchment Sensitive Farming Initiative, can increase dividends substantially (Ramwell & Boatman, 2010).

8.1 DETRIMENTAL IMPACTS

A few options have been given negative scores with respect to certain services. These are mostly options that relate to specific types of habitat or feature, and are likely to cover limited areas. Where associated with the target feature, the benefits are in general likely to outweigh negative impacts and it will continue to be appropriate to use them in the appropriate circumstances. For example, removal of scrub on archaeological sites could have some detrimental impacts on soil but this option is only likely to be applied on very small areas such as barrows, and the benefits for archaeology would outweigh the negative impacts. The potential for negative impacts should however be taken into account when deciding whether, for example, to advise take-up of the options concerned. The increasing availability of advice and support to aid option selection, now including the entry-level schemes, will aid effective targeting of options. In some cases, the potential for negative impacts is highlighted in the scheme handbooks. For example, the ELS handbook states that option EF13 (uncropped, cultivated areas for ground-nesting birds on arable land) *"must not be located on parcels at risk of soil erosion or run-off (as identified on your FER)..."* In general, provided options are appropriately located, the overall balance of impacts is likely to be positive.

8.2 OPTION BUNDLES

In addition to targeting of specific options, consideration could be given to promoting option 'bundles' to enhance delivery of particular ecosystem services where they are of particular importance. This type of approach has already been adopted with respect to options linked to specific objectives of Environmental Stewardship, such as farmland birds, other taxa of particular interest, and reduction of diffuse water pollution. Maps of priority areas have also been produced by Natural England to guide the targeting of these option bundles to appropriate areas[10]. These priority themes include 'butterflies, bees and vulnerable grassland' and 'farming for cleaner water and healthier soil', which are closely linked to ecosystem services included in this report.

The Natural England advisory leaflet 'Farming for Farm Wildlife' lists ELS/OELS options that could be appropriately combined to provide floral resources and nesting habitat for pollinators. Buffer strips could also provide nesting habitat and if wild flowers are included in the seed mixture, floral resources as well. A bundle of options should include undisturbed ground for nesting cover, in hedge bases, ditch banks, buffer strips and/or beetle banks, a source of early pollen and nectar, such as hedges with early flowering shrubs and trees or traditionally managed orchards, and habitats

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[9] http://www.naturalengland.org.uk/ourwork/farming/funding/es/agents/elsoptions/waterandsoil.aspx

[10] http://www.naturalengland.org.uk/ourwork/farming/funding/es/agents/elsoptions/default.aspx

that provide floral resources throughout the rest of the season, such as nectar mixtures, florally enhanced margins, and species-rich meadows.

There may also be scope for developing an option bundle to enhance pest regulation through natural agents (predators, parasitoids etc.). As this service is of particular benefit to crop production rather than the wider environmental objectives of the scheme, it may be more appropriate to promote it to farmers, agents and advisers for uptake on farms where this type of approach is relevant, rather than targeting on a geographical basis as for the other bundles described above.

Evidence suggests that biocontrol is most effective where many different guilds of natural enemies operate in concert. This is because they tend to operate at different times and through different mechanisms, hence maintaining a diversity of natural enemies will result in sustained pressure on pest species, with the greatest chance of suppressing their populations below threshold levels at which damage becomes economically significant. Therefore, the greatest impacts on pests are likely to arise from implementing a combination of measures to encourage the full range of predators and parasitoids. The provision of floral resources for the pollen and nectar feeding adults of hoverflies and parasitoids combined with overwintering habitat for polyphagous predators such as ground and rove beetles and spiders, throughout the landscape where susceptible crops are grown, is likely to produce the greatest dividends. Options providing overwintering cover at field edges include management of hedges, banks and buffer strips, while beetle banks provide overwintering habitat within fields, helping to facilitate re-distribution into the crop in large fields. Options that can provide floral resources on arable land include floristically enhanced margins, uncropped cultivated margins and conservation headlands, and seed mixtures for birds and insects (provided these include nectar-producing flowering plants). An option bundle for pest regulation could therefore include hedgerow or ditch management, buffer strips, beetle banks and one or more of the options providing floral resources. Such a bundle implemented across the farm could maintain populations of natural enemies at good levels, with the prospect of keeping pest levels below damaging thresholds in most years. Wild relatives of crop plants vary greatly in their habitat requirements and are often very local in their distribution, so any targeting of options to benefit them would be most appropriately done on a case-by-case basis. Conservation of genetic diversity among livestock is not necessarily linked to geographical areas, and is more likely to be linked to the type of farm and the interests and motivations of the farmer concerned. The geographical targeting approach is probably not therefore generally appropriate for genetic conservation. An exception might be the conservation of traditional varieties of long-lived crops such as tree fruit, where areas with traditionally managed orchards could be targeted.

8.3 AREAS WHERE FURTHER WORK IS REQUIRED

There is a wealth of research data showing the value of certain habitats for natural enemies of pest species, but there are very few studies that have addressed the effects on the pest itself or on crop productivity directly. This is a key research gap at the present time.

Likewise much work has been carried out to develop prescriptions for habitats that provide floral resources for pollinators, especially bumble bees. However, most of these studies only monitor numbers within the habitats provided and more evidence is needed of effects on populations at the landscape scale. In addition, the importance of providing breeding habitats in addition to floral resources has not been sufficiently studied.

Conservation of genetic resources is only a secondary objective of HLS, and the only options directly linked to this objective are those for traditional orchards and for grazing of rare breeds of livestock. The provision of habitats for wild relatives of crop plants is the area that has received least attention. Whilst a number of options have been identified that can potentially benefit these species, the evidence for the actual level of benefits is sparse and hence has been inferred to a large extent. The variety of species and habitat requirements involved implies a substantial research requirement, so it is suggested that effort should be targeted at least initially at species and habitats that are rare and/or declining. Some crop wild relatives are BAP priority species and in these cases supporting appropriate elements of the Species Action Plans could be the way forward. Development of options to conserve other wild relatives of crops would be beneficial where these are rare or in decline.

In many cases ES options involve taking land out of production, resulting in a loss of output, and this needs to be balanced against the benefits arising. Very few such cost/benefit calculations have been carried out. For some benefits, such as increased soil organic matter in areas taken out of arable cultivation, realisation of the benefit for agriculture would be dependent on the area being returned to cultivation. Such potential benefits cannot be discounted, but have been highlighted to distinguish them from those that accrue directly.

Although potential impacts can be readily identified, when it comes to quantitative estimation of impacts, the evidence base is patchy and often poor. The systems involved are often complex and involve multiple interactions which are difficult to investigate experimentally. For example, both pollination and pest regulation services are provided by a large range of invertebrate taxa, which have widely varying habitat and resource requirements, so that the net result of any one intervention is often difficult to quantify. Even where benefits of habitat provision through ES options or similar management for particular taxa are clear, the impacts on crop production are generally difficult to ascertain with any degree of accuracy because of interactions with other taxa and environmental factors including weather, soil type, landscape matrix etc.

There is a pressing need for further work to investigate the provision of ecosystem services by ES options, and the impact on agricultural production. Such work needs to consider intervention and impacts at a landscape as well as field and farm scale, and how the resulting benefits can be optimised with minimal impact on the farming system. Large-scale, multi-disciplinary approaches to research are therefore most likely to provide useful outcomes. These should build on existing work and target knowledge gaps to provide a more comprehensive understanding of what can be achieved.

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Appendix 1 Groupings of Environmental Stewardship options for analysis of ecosystem services (Modified from LUC, 2009, Appendix 2)

Options introduced in 2009 and 2010 are in italics. Options no longer available are listed at the end of the table.

Option groups	Environmental Stewardship option code							
	ELS	OELS	UELS	ELS in HLS	HLS maintain	HLS restore	HLS create	HLS suppl.
Hedgerows								
Hedgerow management (on both sides of hedge)	EB1	OB1						
Hedgerow management (on one side of hedge)	EB2	OB2						
Enhanced hedgerow management	EB3	OB3						
Hedgerows of very high environmental value (both sides)					HB11			
Hedgerows of very high environmental value (one side)					HB12			
Hedgerow restoration			UB14					
Stone-faced hedgebanks								
Stone-faced hedgebank management on both sides	EB4	OB4	UB4					
Stone-faced hedgebank management on one side	EB5	OB5	UB5					
Stone-faced hedgebank restoration			*UB15*					
Ditches								
Ditch management	EB6	OB6						
Half ditch management	EB7	OB7						
Ditches of very high environmental value					HB14			
Hedges and ditches combined								
Combined hedge and ditch management (incorp. EB1 or EB2)	EB8	OB8						
Combined hedge and ditch management (incorporating EB2)	EB9	OB9						
Combined hedge and ditch management (incorporating EB3)	EB10	OB10						
Stone walls								
Stone wall protection and maintenance	EB11	OB11	UB11					
Stone wall restoration			UB17					
Earth banks								
Earth bank management on both sides	*EB12*	*OB12*	*UB12*					
Earth bank management on one side	*E B13*	*EB12*	*UB13*					
Earth bank restoration			*UB16*					

Option groups	Environmental Stewardship option code							
	ELS	OELS	UELS	ELS in HLS	HLS maintain	HLS restore	HLS create	HLS suppl.
In-field trees								
Protection of in-field trees on arable/rotational land	EC1	OC1		HC1				
Protection of in-field trees on grassland	EC2	OC2		HC2				
Ancient trees in arable fields					HC5			
Ancient trees in intensively-managed grass fields					HC6			
Hedgerow trees								
Establishment of hedgerow trees by tagging	*EC23*	*OC23*						
Hedgerow tree buffer strips on cultivated/rotational land	*EC24*	*OC24*		*HC24*				
Hedgerow tree buffer strips on grassland	*EC25*	*OC25*		*HC25*				
Woodland fences								
Maintenance of woodland fences	EC3	OC3						
Sheep fencing around small woodlands			*UC5*					
Woodland livestock exclusion			*UC22*					
Woodland edges								
Management of woodland edges	EC4	OC4		HC4				
Wood pasture and parkland								
Wood pasture and parkland					HC12	HC13	HC14	
Woodland								
Woodland					HC7	HC8	HC9-10	
Scrub								
Successional areas and scrub					HC15	HC16	HC17	
Orchards								
High value traditional orchards					HC18	HC20	HC21	
Traditional orchards in production					HC19			
Archaeology under grassland & moorland								
Take archaeological features currently on cultivated land out of cultivation	ED2	OD2		HD2				
Archaeological features on grassland	ED5	OD5		HD5				
Management of scrub on archaeological sites	ED4	OD4		HD4				
Arable reversion by natural regeneration							HD7	
Maintaining visibility of archaeological features on moorland			*UC22*					

Option groups	Environmental Stewardship option code							
	ELS	OELS	UELS	ELS in HLS	HLS maintain	HLS restore	HLS create	HLS suppl.
Archaeology under cultivated soils								
Reduce cultivation depth on land where there are archaeological features	ED3	OD3		HD3				
Crop establishment by direct drilling (non-rotational)							HD6	
Archaeology and high water levels								
High water levels to protect archaeology					HD8			
Designed water bodies								
Designed/engineered water bodies					HD9			
Traditional water meadows								
Traditional water meadows					HD10	HD11		
Farm buildings								
Maintenance of weatherproof traditional farm buildings	ED1	OD1	UD12	HD1				
Buffer strips								
2 m buffer strips on cultivated/rotational land	EE1	OE1		HE1				
4 m buffer strips on cultivated/rotational land	EE2	OE2		HE2				
6 m buffer strips on cultivated/rotational land	EE3	OE3		HE3				
2 m buffer strips on intensive/organic grassland	EE4	OE4		HE4				
4 m buffer strips on intensive/organic grassland	EE5	OE5		HE5				
6 m buffer strips on intensive/organic grassland	EE6	OE6		HE6				
Enhanced buffer strips								
Enhanced buffer strips on intensive grassland					HE11			
Floristically enhanced grass margin							HE10	
Buffer strips beside ponds and streams								
Buffering in-field ponds in improved/oganic grassland	EE7	OE7		HE7				
Buffering in-field ponds in arable/rotational land	EE8	OE8		HE8				
6m buffer strips on cultivated/rotational land next to a watercourse	*EE9*	*OE9*						
6m buffer strips on intensive/organic grassland next to a watercourse	*EE10*	*OE10*						

Option groups	Environmental Stewardship option code							
	ELS	OELS	UELS	ELS in HLS	HLS maintain	HLS restore	HLS create	HLS suppl.
Uncropped cultivated margins/plots for arable flora								
6m uncropped, cultivated margins on arable land	EF11	OF11		HF11				
Cultivated fallow plots or margins for arable flora (rotational or non-rotational)[11]					HF20			
Conservation headlands								
Conservation headlands in cereal fields	EF9			HF9				
Conservation headlands in cereal fields with no fertilisers or manure	EF10			HF10				
Unharvested, fertiliser-free conservation headlands (rotational)					HF14			
Field corners								
Field corner management in arable fields	EF1	OF1		HF1				
Take field corners out of management in grass fields	EK/EL1	OK/OL1		HK/HL1				
Seed mixtures sown for birds or insects								
Wild bird seed mixture	EF2	OF2		HF2				
Pollen and nectar flower mixture	EF4	OF4		HF4				
Enhanced wild bird seed mix plots (rotational or non-rotational)							HF12	
Fallow plots for ground nesting birds								
Skylark plots	EF8	OF8		HF8				
Uncropped cultivated areas for ground-nesting birds on arable land[12]	EF13	OF13		HF13				
Low input cereals								
Reduced herbicide cereal crops followed by overwintered stubble[13]	EF15			HF15				
Low input spring cereal to retain or re-create an arable mosaic					HG7			
Undersown spring cereals								
Under sown spring cereals	EG1	OG1		HG1				

[11] Classified by LUC with fallow plots for ground-nesting birds
[12] Replaces HF13
[13] Replaces HF15

Option groups	Environmental Stewardship option code							
	ELS	OELS	UELS	ELS in HLS	HLS maintain	HLS restore	HLS create	HLS suppl.
Over-wintered stubbles								
Over-wintered stubbles	EF6	OF6		HF6				
Extended overwintered stubble	EF22							
Whole crop silage and overwintered stubbles								
Cereals for whole crop silage followed by over-wintered stubbles	EG4	OG4		HG4				
Fodder crops and over-wintered stubbles								
Brassica fodder crops followed by overwintered stubbles	EG5	OG5			HG5			
Fodder crop management to retain or recreate an arable mosaic					HG6			
Maize crops and resource protection								
Management of maize crops to reduce soil erosion	EJ2	OJ2		HJ2				
Enhanced management of maize crops to reduce soil erosion and run-off	EJ10			HJ10				
Arable to grassland								
Arable reversion to unfertilised grassland to prevent erosion or run-off					HJ3			
Arable reversion to grassland with low fert. input to prevent erosion or run-off					HJ4			
Infield grass areas to prevent erosion or runoff[14]	EJ5			HJ5				
Intensively managed grassland and soils								
Preventing erosion or run-off from intensively managed improved grassland					HJ6			
Seasonal livestock removal on grassland with no input restriction					HJ7			
Watercourses and erosion								
12m buffer strips for watercourses on cultivated/rotational land	EJ9	OJ9		HJ9				
Maintenance of watercourse fencing	EJ11	OJ11		HJ11				
Post and wire fencing along water courses			UJ3					
Winter livestock removal next to streams, rivers & lakes			UJ12					

[14] Replaces HJ5

Option groups	Environmental Stewardship option code							
	ELS	OELS	UELS	ELS in HLS	HLS maintain	HLS restore	HLS create	HLS suppl.
Winter cover crops								
Winter cover crops	*EJ13*	*OJ13*		*HJ13*				
Beetle banks								
Beetle banks	EF7	OF7		HF7				
Low input grassland								
Permanent grassland with low inputs (lowlands and LFA)	EK/EL2	OK/OL2		HK/HL2				
Permanent grassland with very low inputs (lowlands and LFA)	EK/EL3	OK/OL3		HK/HL3				
Species rich grassland								
Species-rich, semi-natural grassland					HK6	HK7	HK8	
Grassland for target features					HK15	HK16	HK17	
Rush pastures								
Management of rush pastures (lowlands and LFA)	EK/EL4	OK/OL4		HK/HL4				
Wet grassland								
Wet grassland for breeding waders					HK9	HK11	HK13	
Wet grassland for wintering waders and wildfowl					HK10	HK12	HK14	
Mixed stocking								
Mixed stocking	EK5	OK5		HK5				
Rare breeds (supplement)								
Native breeds at risk grazing supplement								HR2
Upland meadows								
Haymaking			*UL20*					
No cutting strip within meadows			*UL21*					
Upland grassland & moorland								
Enclosed rough grazing in the LFA	EL5	OL5		HL5				
Management of upland grassland for birds			*UL23*					
Rough grazing for birds					HL7	HL8		
Management of enclosed rough grazing for birds			*UL22*					
Cattle grazing on upland grassland and moorland			*UL18*					
Moorland and rough grazing in the LFA	EL6			HL6				
Moorland					HL9	HL10	HL11	
No supplementary feeding on moorland			*UL17*					

Option groups	Environmental Stewardship option code							
	ELS	OELS	UELS	ELS in HLS	HLS maintain	HLS restore	HLS create	HLS suppl.
Shepherding (supplement) Shepherding								HL16
Lowland heathland Lowland heathland					HO1	HO2-3	HO4-5	
Coastal saltmarsh Coastal saltmarsh					HP5	HP6	HP7-9	
Sand dunes Sand dunes					HP1	HP2	HP3-4	
Ponds Ponds of high wildlife value < 100 sq m Ponds of high wildlife value > 100 sq m					HQ1 HQ2			
Reedbeds Reedbeds					HQ3	HQ4	HQ5	
Fen Fen					HQ6	HQ7	HQ8	
Lowland raised bog Lowland raised bog					HQ9	HQ10		
Open access Linear and open access base payment Permissive open access					HN1 HN2			
Linear access Permissive footpath access Permissive bridleway / cycle path access Access for people with reduced mobility					HN3 HN4 HN5		HN6 HN7	
Educational access Educational access – payment per visit Educational access – base payment					HN9 HN8			
Basic payment for organic management Basic payment for organic management		OU1						

Option groups	Environmental Stewardship option code							
	ELS	OELS	UELS	ELS in HLS	HLS maintain	HLS restore	HLS create	HLS suppl.
Upland management requirements								
Moorland commons and shared grazing requirements			*UX1*					
Upland grassland and arable requirements			*UX2*					
Moorland requirements			*UX3*					
Miscellaneous supplements								
Control of invasive plant species								HR4
Small fields								HR6
Difficult sites								HR7
Group applications								HR8
Trees and woodland								
Woodland livestock exclusion								*HC11*
Grassland								
Hay-making								HK18
Bracken control								HR5
Raised water levels								HK19
Inundation grassland								HQ13
Cattle grazing								HR1
Moor and heath								
Seasonal livestock exclusion								HL15
Moorland re-wetting supplement								HL13
Management of heather, gorse and grass by burning, cutting or swiping								HL12
The coast								
Extensive grazing on saltmarsh								HP10
Saltmarsh livestock exclusion								HP11
Wetland								
Wetland cutting								HQ11
Wetland grazing								HQ12
Soils								
Nil fertiliser								HJ8

Options involving set-aside land are no longer available and have been removed (EF3/HF3; EF5/HF5; HF16, 17, 18, 19). Other options no longer available include: EG3/OG3 (Pollen and nectar seed mixtures in grassland areas); EJ/OJ/HJ1 (Management of high erosion risk cultivated land). The following HLS options have been replaced by ELS/OELS options: HF13 (Fallow plots for ground-nesting birds (rotational or non-rotational), replaced by EF13 (Uncropped cultivated areas for ground-nesting birds on arable land); HF15 (Reduced herbicide, cereal crop management preceding over-wintered stubble and a spring crop), replaced by EF15 (Reduced herbicide cereal crops followed by overwintered stubble); EG2/OG2 (Wild bird seed mixture in grassland areas); HJ5 (Infield grass areas to prevent erosion or runoff), replaced by EJ5. The following ELS/OELS options have been replaced by HLS options: EG/OG5 (Brassica fodder crops followed by overwintered stubbles) replaced by HG5.

Appendix 2 Scores for ES option groups indicating benefits for ecosystem services or their agents

Option groups	Soil, Nutrients, water	Genetic resources	Pest regulation	Pollination
Hedgerows				
Hedgerow management (on both sides of hedge)	1[1]	1	3	2
Hedgerow management (on one side of hedge)	1[1]	1	3	2
Enhanced hedgerow management	1[1]	1	3	3
Hedgerows of very high environmental value (both sides)	1[1]	1	3	3
Hedgerows of very high environmental value (one side)	1[1]	1	3	3
Hedgerow restoration	1[1]	0	3	0
Stone-faced hedgebanks				
Stone-faced hedgebank management on both sides	1[1]	0	2	1
Stone-faced hedgebank management on one side	1[1]	0	2	1
Stone-faced hedgebank restoration	1[1]	0	2	1
Ditches				
Ditch management	2	0	1	1
Half ditch management	2	0	1	1
Ditches of very high environmental value	2	0	1	1
Hedges and ditches combined				
Combined hedge and ditch management (incorp. EB1 or EB2)	2	1	3	2
Combined hedge and ditch management (incorporating EB2)	2	1	3	2
Combined hedge and ditch management (incorporating EB3)	2	1	3	3
Stone walls				
Stone wall protection and maintenance	1	0	0	0
Stone wall restoration	1	0	0	0
Earth banks				
Earth bank management on both sides	1	0	2	1
Earth bank management on one side	1	0	2	1
Earth bank restoration	1	0	2	1
In-field trees				
Protection of in-field trees on arable/rotational land	1	0	1	0
Protection of in-field trees on grassland	0	0	1	0
Ancient trees in arable fields	1	0	1	0
Ancient trees in intensively-managed grass fields	0	0	1	0

Option groups	Soil, Nutrients, water	Genetic resources	Pest regulation	Pollination
Hedgerow trees				
Establishment of hedgerow trees by tagging	0	1	1	0
Hedgerow tree buffer strips on cultivated/rotational land	2	1	1	1
Hedgerow tree buffer strips on grassland	0	1	1	1
Woodland fences				
Maintenance of woodland fences	0	0	0	0
Sheep fencing around small woodlands	0	0	0	0
Woodland livestock exclusion	0	0	0	0
Woodland edges				
Management of woodland edges	1	0	1	1
Wood pasture and parkland				
Wood pasture and parkland	1	0	1	0
Woodland				
Woodland	1	1	1	1
Scrub				
Successional areas and scrub	1	1	1	1
Orchards				
High value traditional orchards	3	3	1	3
Traditional orchards in production	3	3	1	3
Archaeology under grassland & moorland				
Take archaeological features currently on cultivated land out of cultivation	2	0	1	0
Archaeological features on grassland	0	0	1	0
Management of scrub on archaeological sites	-1	0	1	0
Arable reversion by natural regeneration	2	0	1	1
Maintaining visibility of archaeological features on moorland	0	0	1	0
Archaeology under cultivated soils				
Reduce cultivation depth on land where there are archaeological features	3	0	1	0
Crop establishment by direct drilling (non-rotational)	3	0	1	0
Archaeology and high water levels				
High water levels to protect archaeology	1	0	0	0
Designed water bodies				
Designed/engineered water bodies	0	0	0	0

Option groups	Soil, Nutrients, water	Genetic resources	Pest regulation	Pollination
Traditional water meadows				
Traditional water meadows	1	1	0	1
Farm buildings				
Maintenance of weatherproof traditional farm buildings	0	0	0	0
Buffer strips				
2 m buffer strips on cultivated/rotational land	2	1*	1	1
4 m buffer strips on cultivated/rotational land	2	1*	2	1
6 m buffer strips on cultivated/rotational land	2	1*	2	1
2 m buffer strips on intensive/organic grassland	0	1*	1	1
4 m buffer strips on intensive/organic grassland	0	1*	1	1
6 m buffer strips on intensive/organic grassland	0	1*	1	1
Enhanced buffer strips				
Enhanced buffer strips on intensive grassland	0	1*	1	3
Floristically enhanced grass margin	2	1*	3	3
Buffer strips beside ponds and streams				
Buffering in-field ponds in improved/oganic grassland	0	1*	1	1
Buffering in-field ponds in arable/rotational land	2	1*	1	1
6m buffer strips on cultivated/rotational land next to a watercourse	2	1*	1	1
6m buffer strips on intensive/organic grassland next to a watercourse	0	1*	1	1
Uncropped cultivated margins/plots for arable flora				
6m uncropped, cultivated margins on arable land	0	1	2	2
Cultivated fallow plots or margins for arable flora (rotational or non-rotational)	0	1	2	2
Conservation headlands				
Conservation headlands in cereal fields	0	1	1	2
Conservation headlands in cereal fields with no fertilisers or manure	0	1	1	2
Unharvested, fertiliser-free conservation headlands (rotational)	1	1	1	2
Field corners				
Field corner management in arable fields	2	1*	1	1
Take field corners out of management in grass fields	0	1*	1	1

Option groups	Soil, Nutrients, water	Genetic resources	Pest regulation	Pollination
Seed mixtures sown for birds or insects				
Wild bird seed mixture	1	1**	2	2
Pollen and nectar flower mixture	2	-1	2	3
Enhanced wild bird seed mix plots (rotational or non-rotational)	1	1**	2	3
Fallow plots for ground nesting birds				
Skylark plots	0	0	0	0
Uncropped cultivated areas for ground-nesting birds on arable land	-1	0	1	0
Low input cereals				
Reduced herbicide cereal crops followed by overwintered stubble	1	1	1	1
Low input spring cereal to retain or re-create an arable mosaic	1	1	1	1
Undersown spring cereals				
Under sown spring cereals	1	0	2	0
Over-wintered stubbles				
Over-wintered stubbles	1	0	0	0
Extended overwintered stubble	2	0	2	1
Whole crop silage and overwintered stubbles				
Cereals for whole crop silage followed by over-wintered stubbles	1	0	1	0
Fodder crops and over-wintered stubbles				
Brassica fodder crops followed by overwintered stubbles	-1	0	0	0
Fodder crop management to retain or recreate an arable mosaic	-1	0	0	0
Maize crops and resource protection				
Management of maize crops to reduce soil erosion	2	0	0	0
Enhanced management of maize crops to reduce soil erosion and run-off	2		0	0
Arable to grassland				
Arable reversion to unfertilised grassland to prevent erosion or run-off[2]	3	0	1	1
Arable reversion to grassland with low fert. input to prevent erosion or run-off[2]	3	0	1	1
Infield grass areas to prevent erosion or runoff[2]	3	0	1	0
Intensively managed grassland and soils				
Preventing erosion or run-off from intensively managed improved grassland	3	0	1	0
Seasonal livestock removal on grassland with no input restriction	2	1	1	0

Option groups	Soil, Nutrients, water	Genetic resources	Pest regulation	Pollination
Watercourses and erosion				
12m buffer strips for watercourses on cultivated/rotational land	3	1	1	1
Maintenance of watercourse fencing	1	0	1	0
Post and wire fencing along water courses	2	0	1	0
Winter livestock removal next to streams, rivers & lakes	3	0	0	0
Winter cover crops				
Winter cover crops	3	0	1	0
Beetle banks				
Beetle banks	1	0	2	1
Low input grassland				
Permanent grassland with low inputs (lowlands and LFA)	0	1	2	1
Permanent grassland with very low inputs (lowlands and LFA)	0	1	2	2
Species rich grassland				
Species-rich, semi-natural grassland (maintenance, restoration, creation)[3]	0-2	2	2	3
Grassland for target features (maintenance, restoration, creation)[3]	0-2	2	1	2
Rush pastures				
Management of rush pastures (lowlands and LFA)	1	0	0	0
Wet grassland				
Wet grassland for breeding waders (maintenance, restoration, creation)[3]	0-2	0	0	0
Wet grassland for wintering waders and wildfowl (maintenance, restoration, creation)[3]	0-2	0	0	0
Mixed stocking				
Mixed stocking	0		0	0
Rare breeds (supplement)				
Native breeds at risk grazing supplement	0	3	0	0
Upland meadows				
Haymaking	0	2	2	1
No cutting strip within meadows	0	2	2	1

Option groups	Soil, Nutrients, water	Genetic resources	Pest regulation	Pollination
Upland grassland & Moorland				
Enclosed rough grazing in the LFA	0	0	0	0
Management of upland grassland for birds[4]	0	0	0	0
Rough grazing for birds	1	0	0	0
Management of enclosed rough grazing for birds	0	0	0	0
Cattle grazing on upland grassland and moorland	0	0	0	0
Moorland and rough grazing in the LFA	0	0	0	1
Moorland [4]	1	0	0	1
No supplementary feeding on moorland	1	0	0	1
Shepherding (supplement)				
Shepherding	2	0	0	0
Lowland heathland				
Lowland heathland	-1	1	0	1
Coastal saltmarsh				
Coastal saltmarsh	1	3	0	0
Sand dunes				
Sand dunes	1	0	0	0
Ponds				
Ponds of high wildlife value < 100 sq m	0	0	0	1
Ponds of high wildlife value > 100 sq m	0	0	0	1
Reedbeds				
Reedbeds (maintenance, restoration, creation)[3]	0-2	0	0	1
Fen				
Fen (maintenance, restoration, creation)[3]	0-2	0	0	1
Lowland raised bog				
Lowland raised bog (maintenance, restoration)[5]	0-1	0	0	0
Open access				
Linear and open access base payment	0	0	0	0
Permissive open access	0	0	0	0

Option groups	Soil, Nutrients, water	Genetic resources	Pest regulation	Pollination
Linear access				
Permissive footpath access[6]	0	0	0	0
Permissive bridleway / cycle path access[6]	0	0	0	0
Access for people with reduced mobility	0	0	0	0
Educational access				
Educational access – payment per visit	0	0	0	0
Educational access – base payment	0	0	0	0
Basic payment for organic management				
Basic payment for organic management	2	1	1	2
Upland management requirements				
Moorland commons and shared grazing requirements	1	0	0	0
Upland grassland and arable requirements	1	0	0	0
Moorland requirements	1	0	0	0
Miscellaneous supplements				
Control of invasive plant species	0	0	0	-1
Small fields	0	0	0	1
Difficult sites	-1	0	0	0
Group applications	1	0	0	0
Trees and woodland				
Woodland livestock exclusion	1	0	0	0
Grassland				
Hay-making	0	2	2	1
Bracken control	2	0	0	0
Raised water levels	1	0	0	0
Inundation grassland	1	0	0	0
Cattle grazing	0	0	0	0
Moor and heath				
Seasonal livestock exclusion	0	0	0	0
Moorland re-wetting supplement	1	0	0	0
Management of heather, gorse and grass by burning, cutting or swiping	-1	0	0	0

Option groups	Soil, Nutrients, water	Genetic resources	Pest regulation	Pollination
The coast				
Extensive grazing on saltmarsh	0	-1	0	0
Saltmarsh livestock exclusion	0	2	0	0
Wetland				
Wetland cutting	0	0	0	0
Wetland grazing	0	0	0	0
Soils				
Nil fertiliser	2	0	0	0

[1] Although the benefits of hedgerows and stone-faced hedgebanks are equivalent to a score of 2, the options onlyu involve management of existing features, and are therefore scored as 1.
[2] These options are given high scores because they are targeted at areas at risk of erosion.
[3] Where options for creation, restoration and maintenance exist, creation options get the higher score and maintenance and restoration options get the lower score.
[4] Score reflects inclusion of grip-blocking in the prescription.
[5] 0 for maintenance, 1 for restoration.
[6] scores assume siting appropriate to prevent channelling and runoff (if this is not the case, score = -1).
* Buffer strips, field corners etc. may protect adjacent habitats containing crop wild relatives. However, if these and other habitats are sown with species that occur in adjacent habitats, but using seed of non-local provenance, they could be detrimental to genetic conservation.
** wild bird seed mixtures may allow ruderal crop wild relatives to grow and reproduce within the sown crop, however if varieties of crops related to wild relatives are grown there could be a detrimental impact on the gene pool of the wild relatives through introgression.