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Delivering biodiversity and pollination services on farmland: a comparison of three wildlife-friendly farming schemes

Thesis submitted for the degree of Doctor of Philosophy

Centre for Agri-Environmental Research

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Declaration

I confirm that this is my own work and the use of all material from other sources has been properly and fully acknowledged.

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Abstract

Gains in food production through agricultural intensification have come at an environmental cost, including reductions in habitat diversity, species diversity and some ecosystem services. Wildlife-friendly farming schemes aim to mitigate the negative impacts of agricultural intensification. In this study, we compared the effectiveness of three schemes using four matched triplets of farms in southern England. The schemes were: i) a baseline of Entry Level Stewardship (ELS: a flexible widespread government scheme, ii) organic agriculture and iii) Conservation Grade (CG: a prescriptive, non-organic, biodiversity-focused scheme). We examined how effective the schemes were in supporting habitat diversity, species diversity, floral resources, pollinators and pollination services.

Farms in CG and organic schemes supported higher habitat diversity than farms only in ELS. Plant and butterfly species richness were significantly higher on organic farms and butterfly species richness was marginally higher on CG farms compared to farms in ELS. The species richness of plants, butterflies, solitary bees and birds in winter was significantly correlated with local habitat diversity.

Organic farms supported more evenly distributed floral resources and higher nectar densities compared to farms in CG or ELS. Compared to maximum estimates of pollen demand from six bee species, only organic farms supplied sufficient pollen in late summer. The density and species richness of pollinators did not vary between schemes. Both CG and organic farms supported more insect-flower visitation than ELS farms. Pollination services were higher on organic farms.

The results showed that prescriptive schemes (e.g. CG) and organic farming are important for supporting habitat diversity and that this is particularly beneficial for butterflies. Late summer emerged as a priority time of year to increase pollen supply on non-organic farms and management options to achieve this are discussed. The data can be used further to inform our understanding of how land management affects biodiversity, particularly pollinators.

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Data accessibility statement

Habitat diversity and species richness data used in Chapter 3 were deposited in the Dryad repository: http://dx.doi:10.5061/dryad.8n2c0 (Hardman et al. 2015) as part of the publication of the Journal of Applied Ecology article associated with this chapter.

Data used in Chapters 4 and 5 were deposited in the University of Reading Research Data Archive: http://dx.doi.org/10.17864/1947.69

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Chapter 1: Introduction

1.1 Global land use change

The area of land globally transformed or degraded by human activity is estimated to be between 39 and 50 % (Vitousek *et al.* 1997). Humans have modified land use through converting land to agricultural production, intensifying agricultural management, clearing forests and expanding urban areas (Foley *et al.* 2005). A quarter of net primary production is now used to meet human needs (Krausmann *et al.* 2013), yet food security is a major issue. Food supply is volatile due to climate change and global market fluctuations (Godfray & Garnett 2014) and the overall effect of climate change on global food production in the developing world is predicted to be negative (Parry *et al.* 2004). Demand for food is increasing due to growing populations, increases in per capita consumption and changing diets, whilst food waste causes inefficiencies (Foley *et al.* 2005). Therefore it is a global priority to find a sustainable balance between meeting the current food demand of the human population whilst minimising damage to other species and future generations.

1.2 Agricultural intensification

Agricultural expansion and intensification have major impacts for biodiversity and ecosystem services. Ecosystem services were summarised as "the benefits people obtain from ecosystems" in the Millennium Ecosystem Assessment (MEA 2005). This assessment recognised four main categories of ecosystem services: supporting services, which underpin all other services, such as photosynthesis and soil formation; provisioning services, such as water, timber and food; regulating services, such as pollination and climate regulation; and cultural services such as recreational opportunities and spiritual values. More recently, the cascade model has been used to describe how ecosystem processes (supporting services, such as vegetation cover), give rise to ecosystem functions (such as slow passage of water) and this provides an ecosystem service (such as flood protection, de Groot *et al.* 2010). When a good or service is used by humans, it gains a benefit, the economic value of which can be estimated. Using such methods, the impact of different agricultural practices on ecosystem services can be measured.

Agriculture is estimated to negatively affect 37 % of threatened species globally (8,482 species, IUCN 2015). One direct impact of agriculture on biodiversity and ecosystem services is through habitat loss and degradation when land is converted to agricultural use. This is particularly a problem in developing countries where between 1961 to 2000, the area of cropland increased by over 20% (Green *et al.* 2005). Overall, the rate of conversion of land for agriculture has slowed since the 1960s, with yield increases being achieved more through the intensification of production on existing agricultural land (Matson *et al.* 1997). Intensification has largely been achieved through the use of agrochemicals, machinery, irrigation, high-yielding livestock breeds and crop varieties. These methods come at an environmental cost, for example, pesticide use is one of several factors implicated in bee declines, with organophosphates and neonicotinoids thought to pose the largest threats to honeybees at a global scale (Goulson *et al.* 2015). Negative effects of neonicitinoid insecticides on bees (Goulson 2013, Rundlöf *et al.* 2015) and insectivorous birds (Hallmann *et al.* 2014) have been found. Synthetic nitrogen use has been associated with reduced plant diversity (Kleijn *et al.* 2009), eutrophication and human health risks (Matson *et al.* 1997). Agriculture contributes 10-12 % of total anthropogenic greenhouse gas emissions (Burney, Davis & Lobell 2010), leading to indirect effects on species through climate change. Intensive agriculture can exacerbate soil loss through erosion and exhaustion and it is estimated that soils are being lost at rates 10 – 40 times faster than it they are formed (Pimentel & Burgess 2013). Overall, intensive agriculture has had widespread impacts on biodiversity and ecosystem services, the understanding of which is an ongoing topic of research.

1.3 Biodiversity and agriculture

Making space for biodiversity amidst widespread environmentally damaging agricultural activities presents a huge challenge. The first major policy attempt to reconcile biodiversity and agriculture in Europe was the launch of the Agricultural Structures Regulation by the European Union in 1985, which resulted in the first agri-environment schemes (AES, Batáry *et al.* 2015). AES provide financial payments to farmers who agree to use less environmentally damaging farming methods. The payments are generally considered to be financial compensation for the estimated income foregone and the costs associated with environmental management. The negative relationship between yield and biodiversity has been a key argument for an alternative approach: land-sparing. This argument states that if low-intensity farming is used widely to enhance biodiversity within agricultural land (land-sharing), a large amount of land will be needed to feed the growing human population, so land conversion to agriculture will continue, resulting in further biodiversity loss. If however, yields are increased on existing agricultural land, it is argued that food targets will be met without converting more land to agriculture. This would leave intact wild habitats 'spared' for nature (Green *et al.* 2005).

The extent to which a land-sparing or land-sharing approach is optimal varies with geographic context. Benefits of land-sparing have been found in the tropics (Phalan *et al.* 2011) and many species can only survive in intact tropical forests (Gibson *et al.* 2011). If effective mechanisms can link yield gains to habitat protection, the biodiversity benefit of land-sparing in the tropics could be great (Phalan, Green & Balmford 2014). However in Europe, land-sharing has a long history. Low-intensity farming has been carried out for thousands of years (Batáry *et al.* 2015) and many species of conservation concern are adapted to the habitats created by these activities, such as heathlands and calcareous grasslands (Tscharntke *et al.* 2005). The habitats that low-intensity agriculture creates also provide cultural services, such as health and leisure benefits along with the role of scenery as part of 'national identity' (Church *et al.* 2011). Recent research has found floristically diverse habitats that were part of AES had a particularly high aesthetic value (Junge *et al.* 2015). Land-sharing also softens the matrix between higher-quality habitat patches and this is likely to have benefits for species dispersal, particularly in light of climate change (Donald & Evans 2006). The extent to which species persist under varying agricultural intensity is a key factor in determining whether land-sparing or land-sharing is most appropriate.

Another consideration in the land-sharing vs. land-sparing debate is the functional role of biodiversity in agroecosystems. By enhancing ecosystem-service providers within agricultural production areas, yields could be intensified without using additional synthetic inputs (Bommarco, Kleijn & Potts 2013). This approach, termed 'ecological intensification', is an area of growing research, particularly in the fields of pollination, pest control and soil services. Given the rising prices of synthetic inputs and the damaging externalities associated with their use, this approach offers great potential for increasing yields and profitability whilst minimising environmental damage.

1.4 Pollinators and pollination services

For pollinators, a few common species have been found to provide the majority of pollination services (Kleijn *et al.* 2015), showing that pollination service arguments alone are not enough to ensure effective conservation of wider pollinator diversity. However the pollination service argument is likely to be a major reason behind the interest from the public, policy makers and growers towards pollinators. Globally, pollinators are important for 35% of food production (Klein *et al.* 2007) and the reproduction of 87.5% of flowering plant species (Ollerton, Winfree & Tarrant 2011). Pollinators also make substantial contributions towards the supply of micronutrients such as vitamin A and folate (Chaplin-Kramer *et al.* 2014). Valuation estimates on pollination services stand at 350 billion USD per year (Lautenbach *et al.* 2012) and health impact models have estimated that a 50% decline in pollination services would result in 700 000 more human deaths per year (Smith *et al.* 2015). The reliability of this estimate is limited by the quality of the global diet data used and the health impact is likely to be larger if data on subsistence agriculture and forest products are obtained.

The food security risk that a loss of pollination services presents has been highlighted by evidence of pollinator declines in Europe (Biesmeijer *et al.* 2006) and North America (Cameron *et al.* 2011). The European Red List shows that 9% of bee species are threatened with extinction, however 57% were data deficient (Nieto *et al.* 2014). Pollinators are threatened by the individual and combined effects of habitat loss, pesticide use, climate change, parasites and disease (Potts *et al.* 2010, Vanbergen *et al.* 2013, Goulson *et al.* 2015). Broad strategies to mitigate pollinator loss in agricultural areas include the protection and restoration of habitat, restrictions on the use of agro-chemicals and disease management (Vanbergen & the Insect Pollinators Initiative 2013). There is some evidence to show that declines in species richness have slowed more recently (Carvalheiro *et al.* 2013), however this may be because the most sensitive species have already been lost. In England, a National Pollinator Strategy was launched by the Government in 2014 (DEFRA 2014). This strategy includes “supporting pollinators on farmland” as a policy priority and “improving evidence on the status of pollinators and the service they provide” as a research priority. In designing new AES to support pollinators on farmland, policy-makers asked scientists how much flower-rich habitat is needed. A first estimate has been made (Dicks *et al.* 2015) and refinements of this estimate will be important in informing the new AES being developed in England.

1.5 European agri-environment schemes

European agri-environment schemes are funded through the Common Agricultural Policy (CAP), which is an EU policy that was first implemented in 1962 to support farm incomes in the European Community. In 1992, payments to farmers were partially decoupled from supporting agricultural production and EU member states were required to create agri-environment schemes (Hodge, Hauck & Bonn 2015). In 1999, a second pillar of the CAP was created to fund rural development and environmental objectives. Further decoupling occurred in 2005, where Pillar I payments were made via a single farm payment (subject to compliance with basic environmental rules) and Pillar II payments included those for agri-environment schemes (AES). AES account for the majority of conservation expenditure in Europe (Batáry *et al.* 2015). Initially, AES focused on protecting important landscapes and habitats, such as the UK Environmentally Sensitive Areas and Countryside Stewardship schemes which ran between 1987 and 2005 (Lobley & Potter 1998). Later, one major focus of AES in the UK was reversing declines in farmland birds. Specific options such as overwinter stubbles and skylark plots were found to benefit birds (Morris *et al.* 2004, Gillings *et al.* 2005) and these were incorporated into Environmental Stewardship (which was open for applications between 2005 and 2013). Currently, there is strong interest in developing AES which enhance a range of ecosystem services, which is likely to require landscape level collaboration (Prager, Reed & Scott 2012).

The effectiveness of AES has been questioned since many studies have shown limited effectiveness. Half of the schemes reviewed in 2003 had no positive effect on species richness or abundance (Kleijn & Sutherland 2003). However several of the schemes assessed did not have specific targets for biodiversity, such as Denmark and Greece, where the focus was on reducing nitrogen emissions and promoting organic farming. A more recent synthesis highlights an improved understanding of why effectiveness of AES is so variable (Batáry *et al.* 2015). The effectiveness of AES depends on the ecological contrast created (change in habitat conditions for a target group relative to a control, Scheper et al., 2013, Hammers et al., 2015) and the complexity of the surrounding landscape (Batáry *et al.* 2011). AES situated in landscapes of intermediate complexity (1-20% semi-natural habitat) have been found to be more effective than those in cleared (<1%) or complex (>20%). This was predicted by (Tscharntke *et al.* 2005) due to the simple landscapes offering an intermediate sized species pool to colonise the newly created habitats which the AES provides. In contrast, the species pool in the cleared landscapes is not large enough and the species pool in the complex landscapes is so large, the AES has a very small additional effect.

Some AES can be described as ‘horizontal’ or ‘broad and shallow’, meaning that they are relatively easy to implement, and suitable for national uptake. Alternatively schemes can be described as ‘zonal’ or ‘narrow and deep’, being targeted to certain priority landscapes, habitats or species requiring more specific management (Kleijn & Sutherland 2003). Many EU member states have both horizontal and zonal schemes. The English agri-environment programme that was active during this study was Environmental Stewardship. Although applications for this scheme have now closed, due to the long-term nature of the agreements (5-10 years), many farms are still in this scheme. Environmental Stewardship includes three whole-farm schemes: Entry Level Stewardship (ELS), Organic Entry Level Stewardship (OELS) and Uplands Entry Level Stewardship (UELS). It also includes a more targeted scheme: Higher Level Stewardship (HLS, Natural England 2015a), where farmers are not required to enter the whole farm into the scheme, but are paid for the amount of work carried out. The Entry Level schemes are horizontal (though the uplands scheme is only available in ‘Severely Disadvantaged Areas’ of mountain and hill farming). By contrast, the Higher Level scheme is zonal. It targets 110 geographic areas, which were considered to provide the greatest environmental outcomes. HLS also has ‘target themes’ outside of these areas, such as supporting UK Biodiversity Action Plan habitats and species, and reversing declines in farmland birds (Natural England 2015b).

1.6 Entry Level Stewardship

ELS is an English Government AES which includes wildlife conservation amongst its aims. ELS applications were accepted between 2005 and 2013. Farmers signed up for 5 year agreements, in which they agreed to deliver a combination of management options chosen from a menu of over 60 options. Options were available for arable land, grassland, boundary features, buffer strips, trees and woodland, historic and landscape features, crop diversity and soil and water protection. Each option earns the farmer a certain number of points per unit area or length, to reflect income foregone and management costs. Farmers need to meet a points target of 30 points per hectare in order to receive the flat rate payment of £30 per hectare. Farmers did not receive expert training or advice in how to carry out the management options, instead the requirements were detailed in a handbook (Natural England 2013a). Natural England aimed to maximise geographic coverage of ELS, and in 2013 the scheme covered 65% of England’s utilisable agricultural area (Natural England 2013b).

The effectiveness of ELS has been most widely studied for birds. Considerable regional variation in the effects of ELS on farmland bird population changes were found after three years (Davey *et al.* 2010). This could be attributed to regional variation in the landscape level uptake of particular options, regional variation in species habitat preferences, or regional variation in the ecological contrast compared to starting conditions. For example, the only region in which grass margins had a positive effect was in the East of England, where the landscape is highly arable, so the margins are likely to have added additional resources that were not present before. A later review at the national scale found positive effects for certain management options on population trends of farmland birds, specifically stubbles and wild bird crops, which provided winter food (Baker *et al.* 2012). Loss of food and nesting habitats in cropped areas are considered to be the key drivers of bird population decline (Butler, Vickery & Norris 2007). Despite the need for changes to in-field management, 34% of ELS options were for boundary management (Hodge & Reader 2010). Hedgerow management and low-input grassland management together accounted for half of all points awarded in ELS (Breeze *et al.* 2014). By giving farmers so much flexibility over option choice, the ELS scheme has paid farmers for continuing the management that was in place before scheme entry in many cases. Half of farmers with hedgerow management options did not need to change management to meet ELS requirements, and four out of five with low-input grassland options did not need to change management (Boatman *et al.* 2007). Although the national effectiveness of ELS on other taxonomic groups has not been studied, an analysis of option choice for pollinators suggests that gains could have been greater if the most beneficial options had been taken up more widely (Breeze *et al.* 2014) and this is likely to be also true for other taxonomic groups.

1.7 Organic agriculture

Organic agriculture is an internationally recognised ecological farming standard. In Europe, the standard for organic production was defined in a regulation in 2007 (European Union 2007). This document states that organic agriculture aims to achieve 'the best environmental practices' and 'a high level of biodiversity' through 'the appropriate design and management of biological processes based on ecological systems using natural resources which are internal to the system'. Mineral nitrogen fertilisers should not be used; instead there is a focus on tillage and cultivation that increases soil organic matter and the use of crop rotations and manures to recycle nutrients. Rather than using synthetic pesticides, organic farming encourages the protection of natural enemies of pests. Organic farming also aims to achieve high animal welfare and contribute to rural development. Across the EU-27 in 2011, organic agriculture covered 5.4% of utilised agricultural area (European Union 2013). The country with the highest proportion of organically farmed land was Austria (19%), whilst the UK falls slightly below the overall average at 4%. Between 2002 and 2011 the area of organically farmed land across the EU-27 increased by on average 6% per year.

Organic agriculture is widely supported throughout EU member states (Batáry *et al.* 2015). In England, grants supporting organic conversion are available, and farmers in organic ELS in England receive double the standard payment per hectare per year of conventional ELS (Natural England 2015a). Benefits of organic farming for biodiversity have been shown in meta-analyses (Bengtsson, Ahnström & Weibull 2005, Tuck *et al.* 2014) and a review (Hole *et al.* 2005). Benefits of organic farming for reducing negative environmental impacts include enhancing soil organic matter and preventing nutrient loss per unit field area (Tuomisto *et al.* 2012). However since the land area use efficiency is lower, these benefits were not seen when calculated per unit product. The most reliable estimate of the global average yield cost of organic farming is around 20% (Ponisio *et al.* 2015). This meta-analysis is superior to previous attempts because it accounted for the sampling variance within studies and the nesting of data. An interesting finding of this study was that organic-conventional yield gaps can be reduced to 8-9% through the use of multi-cropping and diverse crop rotations.

The overall average increase in species richness associated with organic farming over literature published in the last 30 years was estimated to be 30% (Tuck *et al.* 2014). However the effectiveness of organic agriculture for supporting biodiversity varies between taxa and farming systems. Species richness of plants is affected more positively by organic farming than other taxonomic groups (Bengtsson, Ahnström & Weibull 2005, Tuck *et al.* 2014). When separated by functional group, producers and pollinators showed the most positive responses (Tuck *et al.* 2014). Positive effects of organic farming on birds have been found in several studies (see Bengtsson, Ahnström & Weibull 2005 and Hole *et al.* 2005), but responses were variable. Since organic farming emphasises soil health, we would expect to find positive effects of organic farming on soil biodiversity. In a 21-year comparison of organic and conventional systems in Switzerland, a higher biomass and abundance of earthworms was found in organic systems (Mäder *et al.* 2002). However the effectiveness of organic farming for supporting biodiversity is moderated by landscape context. It was only in homogenous landscapes that organic farming was found to benefit butterfly species richness (Rundlöf & Smith 2006) and bird species richness (Smith *et al.* 2010)**.** Tuck et al. (2014) found that organic farming had a more positive effect on species richness in landscapes dominated by arable land. However, positive effects of organic farming have also been found in grass-dominated systems (Power & Stout 2011).

1.8 Higher Level Stewardship

Although Higher Level Stewardship (HLS) was not studied specifically here, three-quarters of the CG and organic farms were also in HLS and so it is described here. As the upper tier of Environmental Stewardship, HLS is regionally targeted and competitive. It focuses on the conservation of particular species and habitats. Farmers sign up to 10 year agreements and are paid for the work carried out. Management options include those for priority bird species (e.g. breeding waders), those for creation, restoration and maintenance of priority habitats (e.g. heathland), as well as more complex versions of some of the ELS options, such as floristically enhanced field margins. HLS covered 13% of England's utilisable agricultural land area in 2013 (Natural England 2013b). Farms in HLS were found to enhance breeding densities of priority farmland bird species (Bright *et al.* 2015). In addition, HLS farms implementing pollinator-friendly options, such as floristically enhanced margins, were found to support greater nest densities of two bumblebee species than farms in ELS without pollinator-friendly options (Wood *et al.* 2015).

1.9 Countryside Stewardship

England has a new AES, Countryside Stewardship (Natural England 2015c), for which applications opened in July 2015. This scheme includes a mid-tier and a higher-tier, both of which are competitive. The mid-tier is open to all farmers, and applications will be scored according to how far they meet regional targets. The higher-tier will be similar to the Higher Level Stewardship scheme within Environmental Stewardship and will target "the most environmentally significant sites which need complex management" (Natural England 2015d). Higher tier applications are favoured when they meet regional priorities for habitat creation, restoration and/or maintenance. Examples of priority habitats include woodland, fen and heathland. Both tiers of Countryside Stewardship favour applicants who agree to deliver management options from a "Wild Pollinator and Farm Wildlife Package". The favoured prescriptions are supported by scientific evidence, such as skylark plots for breeding skylarks (Morris *et al.* 2004), nectar flower mix for foraging bumblebees (Carvell *et al.* 2007), along with stubbles (Baker *et al.* 2012), wild bird seed mix (Henderson, Vickery & Carter 2004) and ryegrass left to go to seed (Buckingham *et al.* 2011) for foraging winter birds.

1.10 Conservation Grade

In addition to Government schemes, farmers can also enter ecological certification schemes, such as the Conservation Grade (CG) scheme (www.conservationgrade.org). CG is a market-funded 'Fair to Nature' farming protocol that is designed to "deliver the highest levels of on-farm wildlife and biodiversity through habitat creation and management" (Conservation Grade Producers Ltd 2015). CG farmers are required to follow the CG farming protocol and in return they receive a premium crop price via their contracts with CG Licensees (companies who source CG produce and use the CG "Fair to Nature" logo on their products). The protocol requires farmers to manage 10% of the farm as wildlife habitat, which must comprise of:

i. Pollen and nectar rich habitat: 4% (including a minimum of 1.5% grass and wildflower mixture and the remainder grass and legume mixture)
ii. Wild bird food crops: 2%
iii. Tussock and fine grass mixtures: 2% (or 1.5% if ACNR used)
iv. Annually cultivated natural regeneration (ACNR): 0.5%
v. Other habitats: 2% (this includes woodland, hedgerows, water courses and ponds)

The pollen and nectar rich habitat can include existing naturally occurring floristically rich habitat such as meadows. Wild bird crops must include at least three sown species, such as: spring wheat, kale and quinoa. The CG protocol recommends specific seed mixes to be sown for components i-iii (above). The protocol is designed so that the habitats created can also be entered into ELS and HLS. CG farmers must also undertake hedgerow management, which involves cutting some hedgerows every two years and some every three years. The protocol advises farmers to protect watercourses and waterside habitats and provide nesting and roosting sites such as bird and bat boxes. Supplementary feeding of birds in winter is encouraged. Farmers are invited to attend biannual training events on CG farms to update their knowledge on management techniques. In England the scheme involves around 80 farmers and approximately 32,375 ha of land (roughly 0.4% of England's utilisable agricultural area).

There is evidence that the sown options recommended by CG are beneficial for supporting certain taxonomic groups: pollen and nectar mix for bumblebees (Carvell *et al.* 2007), winter bird crops for birds (Henderson, Vickery & Carter 2004) and tussocky grass mix for predatory arthropods (Collins *et* *al.* 2003). The field margin options included in the CG protocol were found to often contain more than double the number of invertebrates found in crop edges (Meek *et al.* 2002). However these results are from four field margins established as part of a carefully controlled scientific trial, on only two farms. What is lacking is an assessment of the effectiveness of CG habitats created by a range of farmers as part of their normal management. Apart from our study, we are only aware of four other studies to examine the effectiveness of management by CG farmers for particular taxonomic groups. These studies were carried out in collaboration with this study, using a subset of the same sites. A study of butterflies in 2012 found no significant differences in abundance or diversity between CG, organic and ELS schemes (Edhouse 2012), but was hampered by a particularly wet summer. A study of birds in winter, found that the density of granivorous passerines was higher on CG farms than organic farms (Harrison 2013). Another study found that hoverfly functional diversity was slightly higher and less variable between farms in the CG scheme compared to organic farms (Cullum 2014). A study of bats found a higher level of activity on organic farms than on CG or ELS farms (Pantling 2014).

1.11 Spatial and temporal scales

When designing scientific studies and implementing agri-environmental policy it is important to consider the spatial and temporal scale most appropriate for the target taxonomic group or ecosystem service. Different taxonomic groups use the landscape at different spatial scales. For bees, foraging range varies with body size (Greenleaf *et al.* 2013). UK bumblebee species typically have foraging ranges of between 450 and 800 m (Knight *et al.* 2005, Carvell *et al.* 2012) although can travel as far as 9.8 km when travelling back to their nest after experimental displacement (Goulson & Stout 2001). In contrast, for solitary bees, it appears that the presence of nesting and foraging habitats within a radius of a few hundred metres is optimal for several species (Gathmann & Tscharntke 2002, Zurbuchen *et al.* 2010). Bees can use floral resources from a range of different habitat types, but they need to be provided within an appropriate radius of the nest, since they are central place foragers. Solitary bees were found to be more sensitive to changes in local landscape composition (up to 750 m radius) than bumblebees (Steffan-Dewenter *et al.* 2002). Despite a developing knowledge of the spatial scales at which species use the landscape, through technological advancements such as harmonic radar (Osborne *et al.* 1999), geolocators (Vickery *et al.* 2014) and molecular analysis (Carvell *et al.* 2012), many studies are still conducted at sub-optimal spatial scales, because the optimal study scale is often not known or not practically feasible (Jackson & Fahrig 2015).

AES are usually implemented at the farm scale, for ease of administration. However, landscape scale conservation is extremely important because some species use habitats at scales larger than individual farms. Resources such as forage and nesting sites need to be spaced out around the landscape in order to benefit a sufficient proportion of the population. Recent estimates for winter bird food crops suggest that separating patches by 1km would allow all individuals in local chaffinch and yellowhammer populations to have sufficient access to food (Siriwardena 2010). The distribution of habitat patches and the connectivity between them is also of particular importance when we consider climate-induced range changes, such as those recently observed for bumblebees (Kerr *et al.* 2015). The need for landscape scale conservation was recognised by the Lawton review of England's wildlife sites which found them to be too small and too isolated (Lawton *et al.* 2010). In response a Nature Improvement Area (NIA) programme was launched, which aimed to 'create joined up and resilient ecological networks' (Natural England 2014) through expansion and creation of wildlife sites and corridors together with more sensitive management of agricultural land. Evidence for the effectiveness of the NIA programme is so far lacking. However, evidence that landscape level AES management is beneficial comes from a study in the English uplands, where field-level abundances of birds of conservation concern were enhanced by landscape-level AES uptake (Dallimer *et al.* 2010).

Temporal scale is also an important factor to consider when implementing and monitoring an AES. Bird populations have been found to take several years to respond to changes in management intensity (Chamberlain *et al.* 2000) whereas plant and butterfly species richness have been found to respond very rapidly to organic conversion (Jonason *et al.* 2011). The effects of farming on biodiversity through temporal changes in land management are understudied. A recent study showed that crop rotations which included a year of grass ley supported a higher species richness of solitary bees compared to fields that were only sown with cereals in the last five years (Le Féon *et al.* 2013). There is a need for more long-term studies to understand the role of crop diversity over time as well as the long-term effect of AES. Spatial and temporal variation in foraging resources for birds (in terms of seeds and insects) and pollinators (in terms of pollen and nectar) is also an important area for further research.

1.12 Research aim and objectives

In this study, we examine three schemes currently in place in England which present a framework with which to compare contrasting approaches to AES design. The comparison offers an insight into the effectiveness of a 'broad and shallow' national Government scheme (ELS), compared to a market-funded scheme with a formulaic prescription for wildlife habitat provision (Conservation Grade or CG). It also offers a comparison between farms that are organic (integrating biodiversity and food production) and farms that are non-organic and prescriptive (usually separating wildlife habitat and food production habitats, ELS and CG). The CG and ELS schemes do not explicitly include the support of ecosystem services within their protocols, whereas organic farming includes reference to management of "ecological systems" (European Union 2007).

This thesis aims to evaluate the effectiveness of three contrasting wildlife-friendly farming schemes currently in place in England, in terms of supporting biodiversity and an associated ecosystem service (pollination). Specifically it answers the following research questions:

1. How effective are the three wildlife-friendly farming schemes in supporting a diversity of habitats and species?
2. How did the schemes compare in their spatial provision of floral resources, pollinators and pollination services?
3. How did the seasonal supply of floral resources and the density of bee-flower visitation vary between schemes?

One of the main mechanisms by which agricultural intensification is thought to have caused biodiversity declines is by reducing habitat diversity. However the spatial scale at which habitat diversity influences species diversity in agroecosystems is unknown. We also do not know what the most effective design of wildlife-friendly farming scheme for supporting habitat diversity in intensive farmland is. Chapter 2 quantifies the habitat diversity associated with each of the three schemes, using cropping plans and AES maps for local scales and land use maps for landscape scales. For a range of taxonomic groups, it investigates the extent to which species richness is positively correlated with habitat diversity. It compares farms in the three schemes on species richness of plants, butterflies, solitary bees, bumblebees and birds. It also estimates how far variation in habitat diversity explains variation in species richness between schemes.

A major difference between the schemes is that organic farmers are required to change crop field management, whereas ELS and CG farmers are not. What is unknown is how this difference in management affects the spatial distribution of floral resources, pollinators and pollination services. In Chapter 3, I create maps of flower density for each farm. I examine differences in floral resources, pollinators and pollination services between crop and non-crop habitats in the three schemes.

Supporting pollinators throughout their life cycles requires seasonal continuity of floral resources. Estimates of pollen demand and how much flower-rich habitat is needed to supply this demand have recently been made (Dicks *et al.* 2015). However estimates of floral resource supply at farm scales have not been attempted. In Chapter 4, I estimate floral resource supply on farms, during four seasonal sampling rounds. I convert field data on open flower density to pollen and nectar density using a recently collected dataset on the pollen and nectar contents of wildflowers. I compare estimates of pollen supply with estimates of pollen demand to find out at what time of year floral resources may be lacking. I compare the schemes in terms of how well they supply floral resources and support bee-flower visitation.

Finally in Chapter 5, I synthesise the main findings and interpret them in light of the wider literature. I consider the implications of the findings for management and policy, critically evaluate the methods used for data collection and make suggestions further research.

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Chapter 2: Study design and overview of methods

This chapter incorporates material included as supplementary information when Chapters 3-5 were written as research articles for publication.

2.1 Study farms

To compare the three wildlife-friendly farming schemes: ELS, CG and organic, we aimed to find matched triplets of farms that were as similar as possible in all other respects. Starting from the list of the 80 CG farms in the UK, we selected CG farms that had similar farms in ELS and organic ELS schemes nearby. These farm triplets were matched as far as possible based on National Character Area ("defined by a unique combination of landscape, biodiversity, geodiversity, history, and cultural and economic activity" Natural England 2011a), soil type (NSRI 2011), crops grown and livestock reared, the presence of an HLS scheme and farm size (Table 2.1). Four suitable matched triplets were found (termed regions), which were named based on the National Character Area that they were most closely affiliated with (CN = Chilterns North, CS = Chilterns South, HD = Hampshire Downs, LW = Low Weald), shown in Figure 2.1. All farms had been in the focal schemes (ELS, CG or organic conversion) for at least 5 years before the surveys started in 2012, with the exception of one ELS farm, which started in 2010 (Table 2.1, further details of dates of entry into other schemes in Appendix 1).

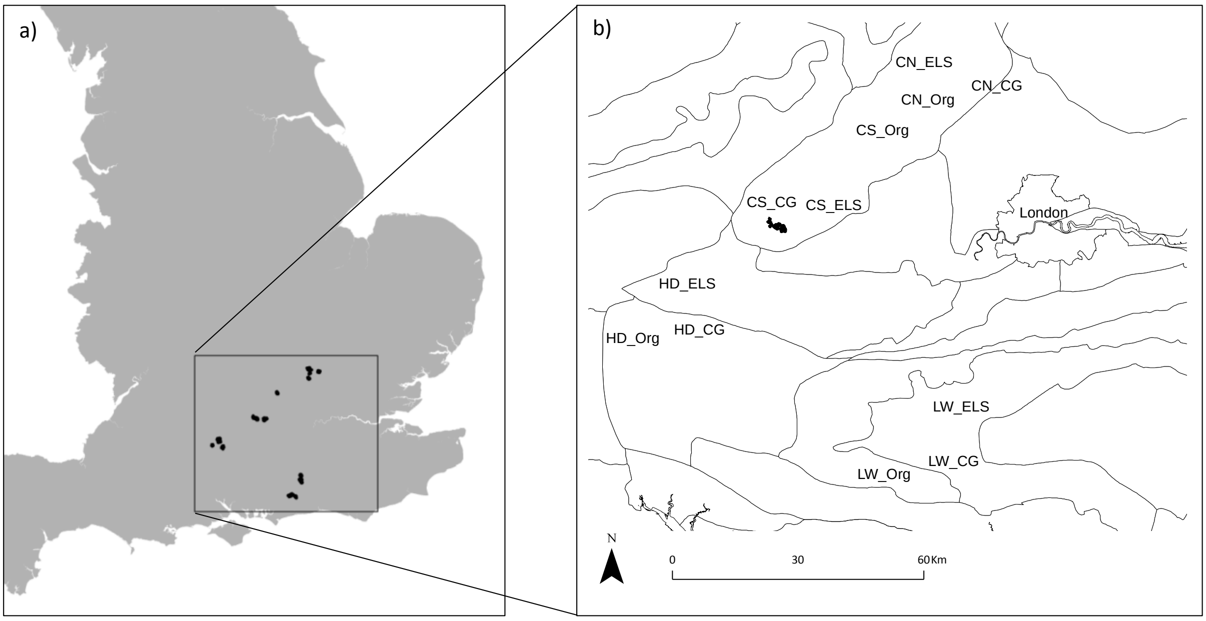

Figure 2.1: Map of the twelve study farms, in four matched triplets, showing a) locations within England, and b) locations with respect to National Character Areas boundaries of England (Natural England 2011a). Farms are labelled by their region (CN = Chilterns North, CS = Chilterns South, HD = Hampshire Downs, LW = Low Weald) and wildlife-friendly farming scheme type (CG = Conservation Grade, ELS = Entry Level Stewardship, Org = organic)

Table 2.1: Characteristics of the twelve study farms, NCA = National Character Area, HLS = Higher Level Stewardship, Starting year = year farm entered focal scheme.

Farm code	NCA	Soil type	Crops	Livestock	HLS (Y/N)	Farm size (ha)	Starting year
LW_ELS	Low Weald	Slowly permeable seasonally wet slightly acid but base-rich loamy and clayey soils	Wheat, barley, oats	Beef cattle, sheep	N	183.8	2007
LW_Org	Wealden Greensand	Slightly acid loamy and clayey soils with impeded drainage. Freely draining slightly acid loamy soils.	Barley-pea mix, turnips, lucerne, clover	Dairy cows	Y	344.5	1999
LW_CG	Low Weald	Slowly permeable seasonally wet slightly acid but base-rich loamy and clayey soils. Freely draining slightly acid loamy soils.	Wheat, OSR, oats, maize	Beef cattle, sheep	Y	344.7	2006
CS_ELS	Chilterns	Slightly acid loamy and clayey soils with impeded drainage. Freely draining slightly acid loamy soils.	Wheat, OSR, barley, maize, poppies	Beef cattle	N	295.4	2010
CS_Org	Chilterns	Slightly acid loamy and clayey soils with impeded drainage.	Wheat (ancient varieties)	Beef cattle, pigs	Y	144.5	1997
CS_CG	Chilterns	Slightly acid loamy and clayey soils with impeded drainage.	Wheat, OSR, barley, oats, linseed	Beef cattle	N	356.5	2004
CN_ELS	Chilterns	Slightly acid loamy and clayey soils with impeded drainage.	Wheat, oats, barley, OSR	Beef cattle, horses	N	475.7	2007
CN_Org	Chilterns	Slightly acid loamy and clayey soils with impeded drainage.	Wheat, oats, field beans, rye, spelt, clover	Beef cattle, horses	Y (Entered in 2013)	111.7	1998
CN_CG	Chilterns	Slightly acid loamy and clayey soils with impeded drainage. Freely draining lime-rich loamy soils.	Wheat, oats, barley, peas, field beans	Beef cattle, horses, sheep	Y	182.7	2006
HD_ELS	Hampshire Downs/Thames Basin Heaths	Shallow lime-rich soils over chalk or limestone. Slowly permeable seasonally wet slightly acid but base-rich loamy and clayey soils.	Wheat, barley, mustard, OSR	Sheep	N	672.1	2007
HD_Org	Hampshire Downs	Shallow lime-rich soils over chalk or limestone	Wheat, barley, oats, spelt, einkorn, clover	Sheep, cows, turkeys	Y	118.8	1999
HD_CG	Hampshire Downs	Shallow lime-rich soils over chalk or limestone. Freely draining slightly acid loamy soils	Wheat, barley, oats, OSR	Sheep	Y	266.8	2006

2.2 Habitat mapping on farm

This study examines farm-level schemes which affect both crop and non-crop habitats. In order to represent the entire habitat composition of each farm, a proportional stratified random sampling strategy was designed. Firstly, habitat maps were created of each farm using Arc GIS v.10 (ESRI 2014), with a minimum mappable unit of 0.01 ha. Maps were based on farm maps and cropping plans from farmers (including woodland, tree planting areas and game cover crops), along with Environmental Stewardship maps from Natural England (2015). Habitat categories are listed in Appendix 2. Habitat maps on farms were ground-truthed using a handheld GPS-enabled PC with Arc Pad software (accuracy ± 4m), to check the dimensions and locations of habitats at the start of each survey season. Hedgerows and tree lines on farms were mapped using Google maps aerial images (Google 2013) and area was calculated by multiplying the length by a mean width of 1.93 m (data from 14 hedges in Berkshire and Oxfordshire, Garratt, M.P. pers. comm.).

2.3 Proportional stratified sampling design

The area of each habitat on each farm was calculated in Arc GIS (e.g. Figure 2.2). Then a weighting system was used to give areas of land in Environmental Stewardship (ES) options a greater representation in the proportional stratified sample. If allocated solely by area, small areas of high value for biodiversity may have been missed. The habitats not in ES were given a weighting of 1, whereas the ES habitats were weighted using the following equation: Number of ES points / (85 x 0.9). This equation was used because the lowest number of points that any one ES option earned was 85. Therefore the lowest scoring ES option had a weighting of 1.05 and the weighting for other options increased proportionally up to the highest scoring option which earned 485 points and received a weighting of 6.34. The proportion that each habitat's weighted area made of the summed weighted habitat areas for each farm was used to assign the number of sampling points or length of transect to be sampled in each habitat (an example is shown in Figure 2.2 and full details of the number of sampling points per habitat per farm per year, plus a worked example of stratified sampling design, are given in Appendices 3 and 4).

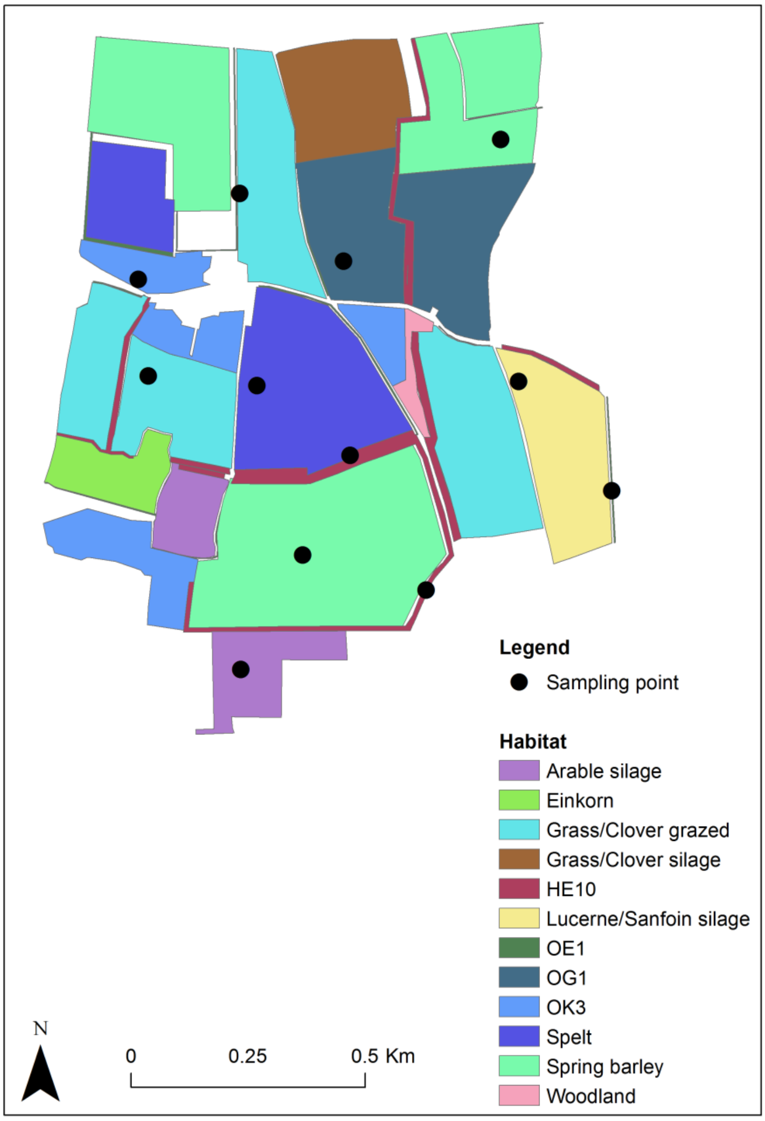

Figure 2.2: Example of twelve sampling points allocated to different habitats on one organic farm in 2013, with habitats coloured according to their Environmental Stewardship codes, crop type or other habitat type (for Environmental Stewardship option codes see Natural England 2015).

2.4 Farm habitat composition

We classified the habitat composition of each farm by grouping the habitat types into broader habitat categories: AES grass, AES margin, improved grass, mass-flowering entomophilous crop, non-mass flowering entomophilous crop, other and hedgerow (Table 2.2). Other was a category for habitats that were not production areas, nor part of an AES. There were no significant differences in habitat composition between scheme types (Table 2.3).

Table 2.2: Definitions of habitat categories

Habitat category	Definition
AES grass	Grassland in Environmental Stewardship, includes low-input grassland, species-rich grassland, heathland restoration.
AES margin	Land at the edge of arable fields in Environmental Stewardship, includes field margins, grass buffer strips, flower plantings, wild bird crops, uncultivated arable blocks.
Improved grass	Grassland not in Environmental Stewardship, including grass ley and permanent pasture.
Mass-flowering entomophilous crops	Crops which provide potential floral resources for pollinators: clover, sainfoin, lucerne, field bean, field pea, oilseed rape, poppy, linseed and kale.
Non-mass flowering entomophilous crops	Crops which do not provide potential floral resources for pollinators: cereals and turnips.
Other	Woodland, tree planting areas, game cover crops and fallow.
Hedgerow	Lines of shrubs and trees bordering the field edge.

The proportional area of fixed semi-natural habitat was calculated for each farm. We defined fixed semi-natural habitat as habitat that was present before the scheme, was relatively unchanged by the scheme and was not likely to be turned to production land in future. We wanted to check whether farms in the additional schemes (CG and organic) had larger areas of fixed semi-natural habitat. The fixed semi-natural habitat types in this study were species-rich grassland (HK15, HK6, HK7, HK8), chalk down (EK3, HK3), wet grassland (HK10), fen and marsh (EK3), heathland (HO1, HO2), woodland (including HC7) and scrub. The proportional area of fixed semi-natural habitat and the density of hedgerows per farm did not vary between scheme types (Table 2.3).

Table 2.3: Habitat composition by year for farms in the three schemes (mean ± SE of the proportional area (%), over four farms per scheme type), with Friedman Chi[2] testing for differences between schemes

Year / Habitat category	Scheme type: ELS	CG	Org	Friedman Chi^2 (2 df)	P value
2012					
AES grass	5.8 ± 3	15.2 ± 5.7	17.1 ± 6.7	0.13	0.94
AES margin	4 ± 1.3	9.4 ± 3.1	2 ± 1.2	3.5	0.17
Imp grass	20.4 ± 10	9.5 ± 4.4	22.4 ± 7.8	2	0.37
MFC	12.3 ± 7.3	22.5 ± 5.9	18.7 ± 7.3	1.5	0.47
Other	10.9 ± 6	9.5 ± 3.2	8.6 ± 4.8	1.7	0.42
Non-MFC	46.6 ± 10.7	33.9 ± 7.1	31.2 ± 12	2	0.37
2013					
AES grass	6 ± 3.1	14.5 ± 5.2	20 ± 6.1	2.8	0.25
AES margin	3.7 ± 1	7.6 ± 2.2	2 ± 1.3	3.5	0.17
Imp grass	20.5 ± 10.2	8.7 ± 3.8	25.9 ± 9.8	1.5	0.47
MFC	10.4 ± 6	7.2 ± 4.5	13.2 ± 4.5	0.6	0.75
Other	11.1 ± 6.2	10.2 ± 3.2	8.8 ± 4.9	0.5	0.78
Non-MFC	48.4 ± 13.9	51.8 ± 5	30 ± 16.6	2	0.37
2014					
AES grass	5.5 ± 2.9	13.8 ± 5	22.1 ± 3.9	5.7	0.06
AES margin	4.6 ± 2.2	8 ± 2.1	2.2 ± 1.3	3.5	0.17
Imp grass	22 ± 12.2	9.6 ± 4.7	21.8 ± 12.2	3.5	0.17
MFC	8.9 ± 8.9	6.9 ± 4.1	21.7 ± 8.5	0.9	0.63
Other	8.3 ± 3.8	12.3 ± 3.9	8.6 ± 4.8	1.7	0.42
Fixed semi-natural	10.3 +- 5.2	14.0 +- 7.0	13.4 +- 6.7	0.5	0.78
Hedgerow density	40.5 ± 7.3	63.1 ± 8.1	72.5 ± 10.9	3.5	0.17

2.5 Farm intensity

To check whether farms in different schemes varied in farm intensity, data on several intensity parameters were collected through farmer interviews (Table 2.4). Farmers were asked to provide data for the years 2011 – 2013, but the data farmers had available did not always cover all years. Differences between scheme types were tested using i) GLMMs with nested random effects for farm nested in region, for parameters data was available over several years or crop types, with scheme type differences tested using a likelihood ratio test (LRT), ii) Friedman Chi^2 for parameters where only one year of data was available and three scheme types were tested (n=12), iii) Welch's two-sample t-test for parameters where only one year of data was available and two scheme types were tested (n=8).

The mean number of crops per year did not differ significantly between scheme types (Years: 2012-2014, GLMM, LRT, Chi^2= 1.42, df=2, n=36, p=0.491). The number of insecticide products used did not vary between CG and ELS farms (Year: 2012, t=0.392, df=5.48, n=8, p=0.710). The amount of synthetic nitrogen applied (kg/ha) did not differ significantly between CG and ELS farms (Years 2012 and 2013, GLMM, LRT, Chi^2 =0.079, df=1, n=30, p=0.779). The most frequently grown crop across all farms was wheat, so yield comparisons were only tested for wheat. Spring wheat was grown by some organic farms only. Overall, wheat yields differed significantly between schemes (Years: 2009-2013, GLMM, LRT, Chi^2= 13.70, df=2, n=52, p=0.001). Post-hoc tests revealed that wheat yields were significantly lower on organic farms compared to CG (p=0.001) or ELS (p=0.005). Stocking density did not differ significantly between scheme types (Year: 2013, Friedman Chi^2 = 2, df = 2, n=12, p-value = 0.3679). Mean field size was significantly smaller on organic farms (Year: 2013, GLMM, LRT,

Chi^2=5.43, df=2, n=327, n=12, p=0.066, post-hoc test: Org<ELS, p=0.021). Farm size did not differ significantly between scheme types (Year: 2013, Friedman Chi^2= 3.5, df = 2, n=12, p-value = 0.1738, Table 2.1).

Table 2.4: Farm intensity parameters collected through farmer interviews

Farm	Mean no. of crops per year (±SE)	No. of insecticide products in 2012	Mean nitrogen fertiliser (N kg/ha) (±SE)	Mean wheat yield (t/ha) (±SE)	Stocking density in 2013 (LU/ha)	Mean field size (ha) (±SE)
LW_ELS	2.67±0.33	6	149.91±12.7	6.85±0.23	0.33	4.48±0.46
CS_ELS	3.33±0.33	6	197.75±34.7	6.81±0.23	1.3	12.53±1.8
CN_ELS	3.67±0.33	3	195±71.0	6.92±0.58	0.61	17.23±1.9
HD_ELS	2.00±0.58	3	180±20.8	7.48±0.40	0.37	11.93±1.3
LW_Org	2.67±0.33	0	0	NA	0.86	7.50±0.92
CS_Org	1.00±0.00	0	0	2.29±0.36	0.48	4.28±0.37
CN_Org	6.67±0.88	0	0	2.99±0.19	1.31	7.90±1.05
HD_Org	7.00±0.00	0	0	3.18±0.53	0.59	5.34±0.74
LW_CG	2.33±0.33	4	225±41.3	8.56±0.49	0.62	7.31±0.92
CS_CG	5.33±0.33	6	168.4±23.8	7.72±0.42	1.22	11.32±1.2
CN_CG	2.00±0.58	2	159.07±25.2	NA	0.5	10.51±1.6
HD_CG	3.33±0.33	6	142.5±27.5	7.61±0.00	0.25	9.54±1.24

2.6 Landscape mapping

For landscape mapping, the best available base map was the Land Cover Map 2007 (Centre for Ecology & Hydrology 2011), which has a minimum mappable unit of 0.5 ha. A comparison with the farm maps created using cropping plans in 2012 showed that 77% of fields and woodland parcels on farms had a relevant land cover class in the Land Cover Map 2007. In Chapter 3, buffers of radius 3 km, 1km, 250 m and 100 m were drawn around sampling points. These buffers were clipped to the following habitat maps: Land Cover map (original version) for the 3 km buffers, Land Cover map (ground-truthed for mass flowering entomophilous crops) for the 1 km buffers and Land Cover map joined with farm habitat map (with roads, rivers and railways digitised using a 1:25 000 scale OS map with minimum mappable unit of 0.01 ha) for the 250 m and 100 m radius buffers.

The Land Cover map was also used to calculate four landscape composition variables within a 1km radius of sampling points, which were: the proportional areas of semi-natural habitat, mass flowering entomophilous crop, organic land, and suburban/urban land. These variables were selected for their potential influence on pollinator communities (semi-natural habitat: Garibaldi *et al.* 2011, mass-flowering crops: Westphal, Steffan-Dewenter & Tscharntke 2003, organic land: Gabriel *et al.* 2010, gardens: Samnegård, Persson & Smith 2011). They were calculated within a 1km buffer drawn around the edge of the farm boundary. A 1 km buffer was chosen because it covers the majority of the foraging ranges of bumblebees and solitary bees in the UK (Osborne *et al.* 2008, Gathmann & Tscharntke 2002). Fields planted with mass flowering entomophilous crops in the 1km buffer surrounding each farm were mapped through ground-truthing and farmer interviews in 2012, 2013 and 2014. The area of semi-natural habitat in the 1km buffer around each farm was mapped using the Land Cover Map 2007, with the following land use types classed as semi-natural habitat: deciduous, conifer, fen marsh and swamp, heather and dwarf shrub, heather grass, acid grassland, calcareous grassland, neutral grassland, rough low-productivity grassland, saltmarsh, scrub and mixed woodland. Data on organic land in the landscape were only available for organic land in Environmental Stewardship (Natural England 2011b). The areas of suburban and urban land in a 1km buffer around each farm were also calculated using the Land Cover Map 2007. There were no significant differences in these landscape composition variables between scheme types across our study sites (Table 2.4).

Table 2.5: Landscape composition differences between schemes (1km radius buffer around each farm in 2013, not including the farm), SNH = semi-natural habitat, MFC = mass flowering entomophilous crop. Friedman Chi^2 test on scheme differences (2 df).

Region	Scheme	SNH (%)	MFC (%)	Organic (%)	(Sub)-urban (%)
Chilterns North	CG	8.13	5.45	0	6.02
	ELS	11.45	3.65	5.68	19.26
	Org	9.35	4.67	0	16.82
Chilterns South	CG	27.52	3.38	0.06	10.41
	ELS	19.85	0.75	0	13.07
	Org	23.57	0	0	16.5
Hampshire Downs	CG	5.54	0	0	0.85
	ELS	19.84	0	0.83	1.53
	Org	7.84	1.8	20.12	2.01
Low Weald	CG	22.62	0.82	0	1.15
	ELS	31.95	0.33	0.02	0.79
	Org	38.6	1.6	11.1	1.68
Chi^2 (p value)		1.5 (0.47)	2.5 (0.28)	1(0.61)	4.5(0.11)

2.7 Scope of sampling

Field surveys were carried out between 2012 and 2014. In 2012, between April and August, data on butterflies and bees were collected over three survey rounds using pan trapping and transects. Between June and July 2012, one sampling round of plant surveys was carried out. In January – March 2013, a winter bird survey was carried out in collaboration with this project (Harrison 2013), over three monthly visits, in the CS, LW and HD regions only due to logistical constraints. Between April and August 2013, data on pollinators, floral resources, pollination services and birds were collected. This included surveys of pollinators over three seasonal rounds using pan traps and transects (as in 2012), and surveys of floral resources and pollination services over one round (July-August). In 2014, the focus shifted towards capturing seasonal variation and so four seasonal rounds of pollinator transect surveys were carried out, along with four seasonal rounds of floral resource surveys. Bird surveys were carried out in 2013 and 2014 with five monthly visits between April and August.

In 2012 and 2013, pan trapping, pollinator transects and plant surveys were carried out at each sampling point. Pollinator transects in 2012 and 2013 were 100 m long at each sampling point. In 2012, there were 10 sampling points per farm in the CN, HD and LW regions and 15 per farms in the CS region. This was to determine the optimal number of sampling points per farm. Species accumulation curves showed that the number of species was still increasing with the number of sampling points between 10 and 15 sampling points (Appendix 5). However, 15 sampling points on every farm was not possible due to logistical reasons, so in 2013, a compromise of 12 sampling points per farm was used. In 2014, only transect surveys were carried out and a total transect length of 1.5 km was surveyed.

Figure 2.3 shows the sampling point design used in 2012 and 2013. The number of sampling points per habitat type was allocated using the proportional sampling strategy. In 2014 the proportion of the total farm transect length was allocated to each habitat according to the proportional sampling strategy. Biodiversity and habitat data from 2012-2014 were used in Chapter 3, pollinator, pollination service and floral resource data from 2013 were used in Chapter 4, and pollinator and floral resource data from 2014 were used in Chapter 5.

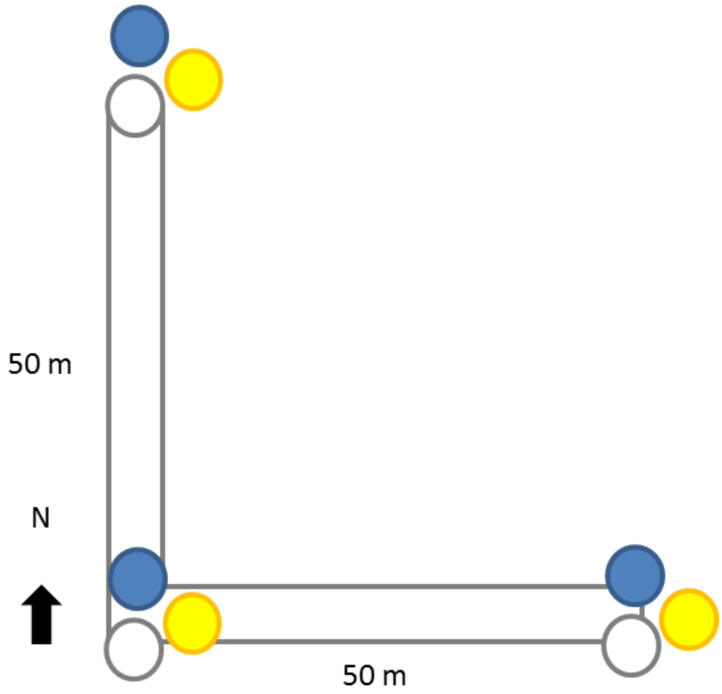

Figure 2.3: Design of pollinator sampling points in 2012 and 2013 (not to scale), showing triplicate pan traps (one blue, one yellow, one white) at three points with a 100 m transect between them

2.8 Plant surveys

In 2012, plants were surveyed in one 1m^2 quadrat at each of the three pan trap points per sampling point (Figure 2.3) and the proportional cover (%) of all plant species was recorded.

2.9 Pollinator surveys

Both pan trapping and transects were used to sample pollinators. Pan traps have high sample coverage, are less subjective than net-sampling, and more likely to sample small bees (Westphal *et al.* 2008). In contrast, transects are more likely to sample large bees and Lepidoptera, as well as allowing flower-visits to be recorded (Popic, Davila & Wardle 2013). Pan traps actively attract insects whilst transects are a passive observational method. Therefore we considered it important to use both methods. Pan traps were made by painting plastic bowls with UV paint to form triplicate sets of one blue, one white and one yellow. All three farms in a region were sampled as close together in time as possible, normally over a period of four days for logistical reasons. Pan traps were placed on the ground and vegetation in a 1m radius surrounding pan traps was flattened. This method was preferable to elevating pan traps using stands for logistical reasons. Each pan trap was half-filled with water to which a couple of drops of washing up liquid were added to reduce surface tension and facilitate the capture of insects. Bees and hoverflies were collected from pan traps after 24 hours and frozen. Other insects caught in pan traps were discarded. After the field season, the frozen bees were recovered and pinned ready for identification. Bees were identified to species using the keys of (Else, In press) for solitary bees and Prŷs-Jones & Corbet (2011) for bumblebees.

The transect method used was based on Pollard walks (Pollard & Yates 1993). Butterflies and bees were recorded to species as far as possible whilst walking at a constant speed of 10m/min. Only insects observed within 2 m either side and in front of the observer were recorded. Wind speed was recorded using an anemometer, cloud cover using visual scale of 'oktas' and maximum temperature using a thermometer. As far as possible, the UK Butterfly Monitoring guidelines for weather conditions for transects were used, restricting survey occasions to when the temperature was over 13°C and between 0900 and 1700 hours. Some bee foraging activity outside these survey hours will have been missed. The temperature was under 13°C on 5 % of transects. The abundance of hoverflies was also recorded. In 2014, five 25 m long transects along hedgerows per farm, were also surveyed for pollinators.

2.10 Bird surveys

The standard Breeding Bird Survey (http:/www.bto.org/volunteer-surveys/bbs), methodology was adapted for this study. Surveyors walked at a steady speed of 25 m/min. Survey days were chosen to avoid persistent heavy rain, poor visibility, and strong winds (exceeding Beaufort Force 4). Observations were assigned to distance categories based on the distance away from the transect line, and only observations within the distance bands 0-25 m and 25-100 m were included in analysis. Transect routes were reversed between visits to minimise the effect of time of day on the birds observed. Summer surveys were carried out by local voluntary ornithologists, who surveyed the same farm all season. A total transect length of 2 km was divided up between habitats using the proportional sampling strategy and surveys were carried out between 6am and 9am. Winter surveys were carried out by Dominic Harrison (Harrison 2013). In winter, a total transect length of 3 km was divided up into 100 m sections, of which two-thirds were allocated to field boundaries, and the remainder to field centres, using a proportional strategy based on areas of habitats (mapped in December 2012). Winter surveys were carried out between 1 hour after sunrise and 1 hour before sunset.

2.11 Phytometer surveys

Phytometers were used to measure pollination services, since they provided a way to capture the pollination service potential created by the overall habitat composition of each farm. Phytometers are standardised plants that are transplanted to new environments during experiments to measure an attribute of the surrounding environmental conditions, such as pollination (Woodcock *et al.* 2014). Seed set of phytometers can be used to measure insect-pollination services if the plants are dependent on insect-pollination and are self-incompatible. Californian poppy (*Eschscholzia californica,* Cham.) was chosen as a phytometer species after the reported self-incompatibility (Cook 1962) was confirmed in field trials carried out before this experiment. Since this species is not found in the wider countryside, our plants represented a standardised amount of experimental pollen. Californian poppies are open-access flowers so can be visited by a wide range of generalist pollinators, including bees and hoverflies. A batch of standardised plants was obtained from a nursery, which were in moisture-retaining compost in pots. The plants were kept in pollinator-exclusion cages before and after the experiment. The experimental period consisted of three weeks of exposure to on farm conditions. Three potted phytometers were placed 50 cm apart at the central sampling point (Figure 2.3), at ten of the sampling stations. Phytometers were watered well on setting out, once during the exposure period and once upon collection. Plants were scored for vigour on setting out and any damage or drought was noted. Due to the need to keep plants away from livestock, plants were sometimes put at field edges behind fences. Where possible plants were arranged in a triangle, but if not possible they were arranged in a line and this was noted. After collection, plants were kept in pollinator exclusion cages until the seed pods were ripe. Seeds were then harvested and counted. Insect visitation to phytometers was not recorded due to time limitations.

2.12 Floral resource surveys

In 2013, the floral resource surveys recorded flower density in July in three 1m^2 quadrats spaced 50 m apart (as in Figure 2.3). Additional species not found in quadrats were recorded on transects running between quadrats (total length 100 m x 1 m). One sampling point in each habitat type was surveyed. The number of floral units per m^2 of plants with open flowers for all insect-rewarding plant species was recorded (species and floral unit types listed in Appendix 6). For compound flowers, such as spikes and capitula, the number of open flowers per floral unit was counted for three typical flowers. In 2014, the floral resource surveys recorded flower density again and this was used to estimate pollen and nectar density. These surveys involved one 1m^2 quadrat being placed at each end of the transect, and the number of floral units being recorded as in 2013. The number of compound floral units dissected to count open flowers was increased to five in 2014, because this was a way of improving the reliability of estimates within the time available. In both years, five random hedgerows were surveyed using 25 m long transects which were 1 m wide and as high as the hedgerow.

2.13 General statistical approach

All data analysis was carried out in R version 3.1.2 (R Core Team 2014). Due to the nested sampling design, mixed effects models from the lme4 package with nested random effects for farm within region were commonly used (Bates *et al.* 2014). Individual analyses are described in more detail in Chapters 3-5.

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Chapter 3: Supporting local diversity of habitats and species on farmland: a comparison of three wildlife-friendly schemes

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Author contributions

Chloe J. Hardman	Planned project, conducted fieldwork to collect data, analysed data and wrote manuscript.
Dominic P.G. Harrison	Conducted fieldwork to collect data on winter birds.
Pete J. Shaw	Advised on winter bird surveys, provided minor edits to manuscript.
Ken Norris	Advised on project design, analysis and structure of manuscript. Provided minor edits to manuscript.
Tim D. Nevard	Advised on project design and provided minor edits to manuscript.
Brin Hughes	Advised on project design, assisted with site selection and provided minor edits to manuscript.
Simon G. Potts	Advised on project design, analysis and structure of manuscript. Provided minor edits to manuscript.

3.1 Summary

1. Restoration and maintenance of habitat diversity has been suggested as a conservation priority in the farmed landscape, but how this should be achieved and at what scale is unclear. This study makes a novel comparison of the effectiveness of three wildlife-friendly farming schemes for supporting local habitat diversity and species richness on 12 farms in England.

2. The schemes were: i) Conservation Grade (CG: a prescriptive, non-organic, biodiversity-focused scheme), ii) organic agriculture, and iii) a baseline of Entry Level Stewardship (ELS: a flexible widespread English government scheme).

3. CG farms supported a quarter higher habitat diversity at the 100 m scale compared to ELS farms. CG and organic farms both supported a fifth higher habitat diversity at the 250 m radius scale compared to ELS farms. Habitat diversity at the 100 m and 250 m scales significantly predicted species richness of butterflies and plants. Habitat diversity at the 100 m scale also significantly predicted species richness of birds in winter and solitary bees. There were no significant relationships between habitat diversity and species richness for bumblebees or birds in summer. This is likely to be due to the scale and/or the way in which habitat diversity was measured.

4. Butterfly species richness was significantly higher on organic farms (50% higher) and marginally higher on CG farms (20% higher), compared with farms in ELS. Organic farms supported significantly more plant species than ELS farms (70% higher) but CG farms did not (10% higher). There were no significant differences between the three schemes for species richness of bumblebees, solitary bees or birds.

5. Policy implications

The schemes that included compulsory changes in management (CG and organic) were more effective at increasing local habitat diversity and species richness of butterflies, compared with the less prescriptive ELS scheme. We recommend that wildlife-friendly farming schemes should aim to enhance and maintain high local habitat diversity, through mechanisms such as option packages, where farmers are required to deliver a combination of several habitats. The lack of detectable positive effects of the CG and organic schemes for bird and bee species richness suggests that either

the sample size in this study was too small to detect effects for these taxa, or farm-level CG and organic management did not change habitat conditions enough to benefit these taxa.

3.2 Introduction

The expansion and intensification of agricultural land is a global threat to biodiversity (Green *et al.* 2005) and biodiversity declines associated with agricultural intensification have been documented for multiple taxa (birds: Donald *et al.* 2006, aculeate pollinators: Ollerton *et al.* 2014, Lepidoptera: Ekroos, Heliölä & Kuussaari 2010, and plants: Kleijn *et al.* 2009). Agricultural intensification reduces the spatial and temporal complexity of habitats (Stoate *et al.* 2001). This reduction in habitat heterogeneity has occurred at multiple spatial scales; for example through reduced crop diversity and hedgerow removal at local scales and homogenisation of land use types at landscape scales (Tscharntke *et al.* 2005). Restoring habitat heterogeneity has been proposed as a "universal management objective" that would increase biodiversity in agricultural systems (Benton, Vickery & Wilson 2003). However, the suitability of this objective has been disputed for low-intensity agricultural landscapes (Batáry *et al.* 2011a). In agricultural landscapes, relationships between habitat diversity and species richness are taxon-specific and scale-dependent (Jeanneret, Schüpbach & Luka 2003, Weibull, Ostman & Granqvist 2003, Gaba *et al.* 2010). Therefore, how habitat diversity should be restored and at what scale are questions that need further research.

In Europe, government-run agri-environment schemes (AES) and private sector environmental certification schemes are important mechanisms for reducing the negative environmental impacts of agricultural intensification. Government AES encompass a range of financial incentives for farmers to undertake low-input extensive farming and/or restoration of particular habitats, species or landscape features (Hart 2010). The effectiveness of AES in conserving and promoting biodiversity has been highly variable; depending on ecological contrast, landscape context and land-use intensity (Kleijn *et al.* 2011). AES appear to be most effective when they create a high ecological contrast (the extent to which the AES management improves habitat conditions for the target group relative to conventional management, Scheper *et al.* 2013). In addition, there is evidence that AES are most effective in simple landscapes (1-20% semi-natural habitat), compared to complex (>20%) landscapes (Batáry *et al.* 2011b).

Environmental Stewardship is an English AES, with a wildlife conservation focus, which accepted applications between 2005 and 2013 (Natural England 2013a). The scheme has two tiers: Entry Level Stewardship (ELS, 5 year agreements) and Higher Level Stewardship (HLS, 10 year agreements in addition to ELS). ELS is a 'broad and shallow' whole-farm scheme, which aimed to maximise geographic coverage. ELS includes management options for boundary features, trees and woodland, historic and landscape features, buffer strips, arable, grassland, crop diversity and soil and water protection. Each option gains a number of points per unit area, and farmers choose how to combine options to achieve an overall 30 points per hectare. The organic version of ELS (OELS) includes the same choice of options and farmers are paid double the conventional rate. In contrast, HLS is a 'narrow and deep' scheme, which is regionally targeted and competitive. HLS contains more complex management options including the creation, restoration and maintenance of priority habitats, such as species-rich semi-natural grassland. ELS covered 64.6% of England's agricultural land area in October 2013, OELS covered 3.4% and HLS covered 13.0% (Natural England 2013b).

Direct comparisons of organic farms with non-organic targeted AES are scarce (but see Marja *et al.* 2014). This research gap was highlighted by Hole *et al.* (2005). Studies examining the different AES in England have shown effectiveness to be variable. Organic farming has been evaluated extensively and a recent meta-analysis showed that it was associated with 30% greater species richness compared to conventional farming (Tuck *et al.* 2014). Benefits of HLS have been observed for birds (Bright *et al.* 2015), whilst ELS has been shown to benefit granivorous passerines in winter, but to have mixed effects during the breeding season (spring/summer, Baker *et al.* 2012). The impacts of ELS for birds and pollinators have been limited by low uptake of the most effective options (Butler, Vickery & Norris 2007, Breeze *et al.* 2014). At a national scale, hedgerow management and low-input grassland together account for half of all points awarded in ELS (Breeze et al. 2014). Farmers did not need to change existing management in 50% of cases for hedgerow options and 81% of cases for low-input grassland options in in order to qualify for ELS payments (Boatman *et al.* 2007).

In addition to governmental AES, farmers can enter ecological certification schemes. One such scheme, which has more stringent habitat management requirements than ELS, is Conservation Grade (CG, http://www.conservationgrade.org). This scheme uses a 'Fair to Nature' protocol that requires 10% of the farm area to be managed solely for wildlife habitat according to a specific formula: 4% pollen and nectar rich habitats, including a grass and native wildflower mix (>1.5%) and a legume mix (<2.5%); 2% wild bird food crops, including at least three seed-producing crops such as barley, triticale, kale or quinoa; 2% tussocky and fine grasses; and 2% wildlife habitat specific to the farm. Pollen and nectar habitats and wild bird food crops require continued management to maintain quality. The additional management costs are met through sales of 'Fair to Nature' branded food products. CG has been implemented since 2004 and currently involves 80 farms, mostly cereal producers in the UK. CG farms had on average 24 times more nectar flower mixture (EF4) and 15 times more wild bird seed mixture (EF2) than farms in ELS alone (Natural England 2013a, proportional area data from 52 CG farms).

The CG protocol was based on evidence from experimental farms that showed significantly higher levels of invertebrates in sown margin mixes compared to the crop (Meek *et al.* 2002) and substantial benefits of pollen and nectar mixed for bumblebees (Carvell *et al.* 2004). More recently, benefits of sown wildflower strips for insects have been demonstrated more widely (Haaland, Naisbit & Bersier 2011) and wild bird food crops have been found to support higher densities of birds in winter compared to controls (Henderson, Vickery & Carter 2004, Hammers *et al.* 2015). Taxon specific studies have been carried out in parallel with our multi-taxa study, using a subset of the same sites. CG farms supported higher densities of granivorous passerines in winter than organic farms (Harrison 2013) and functional diversity of hoverflies on CG farms was slightly higher and less variable between farms (Cullum 2014) compared to organic. Here is the first multi-taxa study of farmer-managed CG farms and how they compare to alternative wildlife-friendly farming schemes.

We compared CG, organic and Entry Level Stewardship, in terms of the extent to which they had higher habitat diversity and species richness of a wide range of taxa. We examined species richness because it is an easily understood and widely used way of measuring species diversity. We focused on spatial rather than temporal heterogeneity and on habitat diversity rather than configuration. We examined habitat diversity at multiple spatial scales, since not doing so would potentially miss important species-landscape effects (Jackson & Fahrig 2015). This analysis also enabled us to check whether scheme type was associated with landscape diversity.

Our research questions were: (1) Does habitat diversity vary between these wildlife-friendly farming schemes at local and landscape scales; (2) At which spatial scale does species richness of different taxonomic groups respond to habitat diversity; and (3) Does species richness differ between farms in the three schemes and if so, how far can this be explained by habitat diversity? We collected spatial data on habitats, along with species richness and abundance data on plants, butterflies, bumblebees, solitary bees and birds in order to answer these questions. We expected farms in the additional schemes (CG and organic) to support higher species richness and habitat diversity than farms only in ELS. We expected taxonomic groups to respond most strongly to habitat diversity at scales similar those at which individuals typically use the landscape. We expected local habitat diversity to be more important on CG and ELS farms than organic farms, since organic crops receive lower or zero synthetic chemical inputs compared to CG and ELS. Therefore, an organic point surrounded by low habitat diversity would be expected to support more species than a non-organic equivalent.

3.3 Methods

3.3.1 Defining spatial scales

We evaluated habitat diversity at four spatial scales: two local scales that largely reflect within-farm management (100 m radius; 3.14 ha and 250 m radius; 19.6 ha), and two larger scales which represent the wider landscape (1 km radius; 314 ha and 3 km radius; 2 827 ha). These radii were chosen because they cover the range of radii at which different taxonomic groups have been found to typically use the landscape: birds, up to 3 km (Pickett & Siriwardena 2011); bumblebees, up to 2 km (Walther-Hellwig & Frankl 2000); solitary bees, up to 600 m (Gathmann & Tscharntke 2002) and butterflies up to 420 m (Merckx & Van Dyck 2002).

3.3.2 Study sites

This study was carried out in southern England on matched triplets of farms to minimise confounding environmental variables. Triplets of sites were matched on region (Joint Character Areas, Natural England 2011), soil type, NSRI 2011), crops and livestock (Chapter 2, Table 2.2), as far as possible. The number of sites fitting these selection criteria was low, but four suitable triplets were found (Figure 3.1). There were no significant differences in landscape composition metrics between scheme types (1 km radius scale, Chapter 2, Table 2.5). The minimum time since scheme entry was 6 years for CG farms and 5 years for ELS farms (with one exception of 2 years). The minimum time since organic conversion started was 13 years. Three-quarters of the CG and organic farms were in HLS, and one organic farm began HLS conversion towards the end of the study. Nationally, 56% of CG, 25% of OELS farms and 24.5% of ELS farms were in HLS in 2013 (Natural England 2013a).

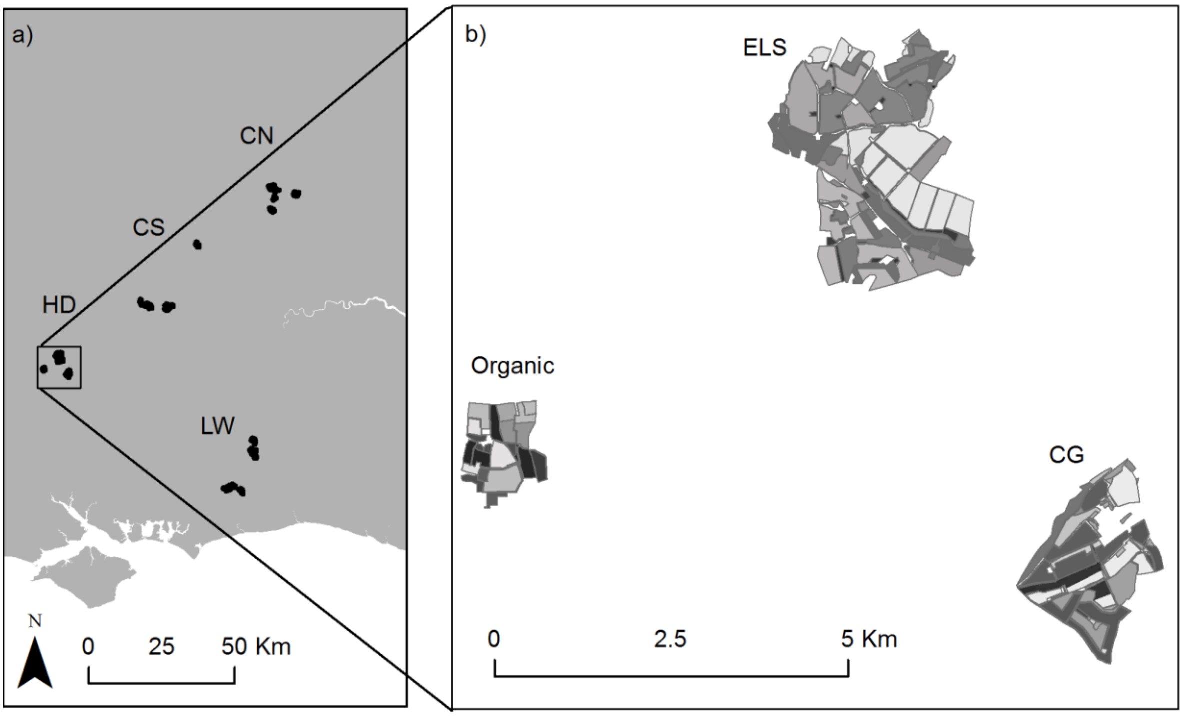

Figure 3.1: Sampling maps showing a) the location of the four regions in southern England: HD=Hampshire Downs, CS=Chilterns South, CN=Chilterns North, LW=Low Weald and b) one region containing a triplet of farms one in each wildlife-friendly farming scheme: ELS = Entry Level Stewardship, CG=Conservation Grade and Organic

Average farm size was 267.5±36.6 ha (mean ±SE) and the average field size was 9.11±0.40 ha. Organic farms had significantly smaller field sizes than ELS farms ($Chi^2(2)=5.43$, $p=0.021$) and significantly lower wheat yields than ELS farms (GLMM $Chi^2(2)= 13.70$, post-hoc tests: CG>Org: $p=0.001$, ELS>Org: $p=0.005$, Chapter 2, Table 2.4). CG farms had a higher number of HLS options per farm than organic farms (Chi^2 test (2) =16.148, p=0.001). However, there were no differences between schemes in the number of ELS options per farm (Chi^2 test (2) =7.319, p=0.292).

3.3.3 Habitat mapping

Farm habitats were mapped by digitising Environmental Stewardship maps and cropping plans using Arc GIS v.10, with a minimum mappable unit of 0.01 ha. The UK Land Cover Map 2007 was used as a base for landscape mapping (Centre for Ecology & Hydrology 2011), which has a minimum mappable unit of 0.5 ha. Ground-truthing methods are detailed in Chapter 2 and on-farm habitat categories are listed in Appendix 2.

3.3.4 Biodiversity sampling strategy

A proportional stratified sampling technique was designed to represent the habitat composition of each farm. If calculated by area alone, Environmental Stewardship options of high biodiversity value covering small areas would be under-represented, therefore areas of AES options were weighted using the points scored in ELS/OELS/HLS (for details see Chapter 2). Sampling stations were plotted randomly according to habitat designations using the 'genrandompnts' tool (Hawthorne L. Beyer 2001).

3.3.5 Habitat diversity calculations

Habitat diversity was calculated using a Shannon diversity index, which emphasises rare habitat types that may be important for sensitive species (Nagendra 2002). To avoid bias in the comparison of habitat diversity between schemes, landscape buffers were drawn around random points. The same number of points was generated as the number of sampling points used for biodiversity surveys. To test correlations between species richness and habitat diversity, buffers were generated around biodiversity sampling stations and clipped to relevant habitat maps.

3.3.6 Biodiversity survey methods

Biodiversity surveys were carried out between 2012 and 2014, between April and August. An additional winter bird survey between January and March 2013 was carried out, but in three of the four regions due to logistical constraints. Sampling effort varied between years, but was always consistent within years, with five sampling rounds for summer birds, three for insects and winter birds and one for plants, at 10-30 sampling points per farm. Butterflies were recorded on transects using UK butterfly monitoring methods (Pollard & Yates 1993), bees were sampled using triplicate pan traps (Westphal *et al.* 2008) and identified to species using keys (solitary bees; Else G., In Press, bumblebees; Prŷs-Jones & Corbet 2011). Birds were sampled along line transects using similar methods to the British Breeding Bird Survey and plants were surveyed in $1m^2$ quadrats at each pan trap sampling point (further method details in Chapter 2).

3.3.7 Statistical analysis

We accounted for the nested design by including farm nested in region as random effects. All generalised linear mixed models (GLMM) were fitted using the package lme4 (Bates *et al.* 2014). Models were checked for overdispersion and residual normality and heteroscedascity. Conditional and marginal R^2 were calculated (Nakagawa & Schielzeth 2013). Likelihood ratio tests (LRT) were used to assess the significance of terms in the models (Zuur *et al.* 2009). Post-hoc simultaneous tests for general linear hypotheses using single step p value adjustments were made to correct for multiple comparisons (multcomp package, Hothorn, Bretz & Westfall 2008). All analyses were performed using R v. 3.1.1 (R Core Team 2014).

3.3.7.1 Wildlife-friendly farming scheme differences in habitat diversity

To test the effect of scheme type and buffer radius on habitat diversity we used a GLMM estimated using ML with Gaussian errors. Buffer radius length was categorical and the interaction between radius and scheme type was examined. Year was a random effect since it represented temporal autocorrelation and did not influence the mean habitat diversity (GLMM LRT for year as a fixed effect, $Chi^2(1) = 2.699$, p=0.100). The nested random effects structure was: Year/Region/Farm/Point since the data included multiple buffers around the same points.

3.3.7.2 Habitat diversity as a predictor of species richness

Species richness data were pooled across sampling rounds. Habitat diversity at each spatial scale was tested as a predictor of species richness of different taxonomic groups in separate GLMM models. Bonferroni corrections were not used, in order to retain statistical power (Nakagawa 2004). Year was a fixed effect since species richness varied significantly between years. For summer bird models, where there were several observers, observer was included as a random effect. For birds and insects, abundance was included as a fixed effect to account for sample size variation. The potentially confounding influence of 1km landscape proportion of mass flowering crop was included in insect models. Proportion of semi-natural habitat in the surrounding landscape was not included because it was significantly correlated with habitat diversity at landscape scales (GLMM 3 km: Estimate: 0.010±0.002, LRT $Chi^2=29.359$, p<0.001, 1 km: Estimate: 0.005±0.001, LRT $Chi^2=8.405$, p=0.004). For butterflies, birds and bumblebees a Poisson distribution was used. For solitary bees and plants, the log-normal Poisson (Elston *et al.* 2001) and negative binomial distributions were used respectively to reduce overdispersion.

3.3.7.3 Effects of wildlife-friendly farming scheme and habitat diversity on species richness

To test for the effect of scheme type on species richness we used GLMM models which included fixed effects for year. The proportion of mass flowering crop in a 1 km radius buffer was included for models on insects. Subsequently, we tested for interactions between scheme type and habitat diversity at the 100 and 250 m scales, then carried out model simplification according to the guidance of Zuur *et al.* (2009). We did not explore interactions between landscape habitat diversity and scheme type because there was not sufficient replication at the landscape scale to draw valid conclusions. By putting habitat diversity and scheme type into models together we could evaluate the relative effects of each variable on species richness.

3.4 Results

3.4.1 Wildlife-friendly farming scheme differences in habitat diversity

Differences in habitat diversity between scheme types varied with spatial scale, with significant differences at local but not at landscape scales (GLMM scheme type x radius interaction LRT: $Chi^2(6) = 38.64$, p<0.001, Figure 3.2, Appendix 7). CG farms supported higher habitat diversity than ELS at the 100 m scale and at the 250 m scale (Post-hoc tests: p=0.021 and p<0.001 respectively). Organic farms supported higher habitat diversity than ELS at the 100 m scale and at the 250 m scale (Post-hoc tests: p=0.109 and p<0.001 respectively).

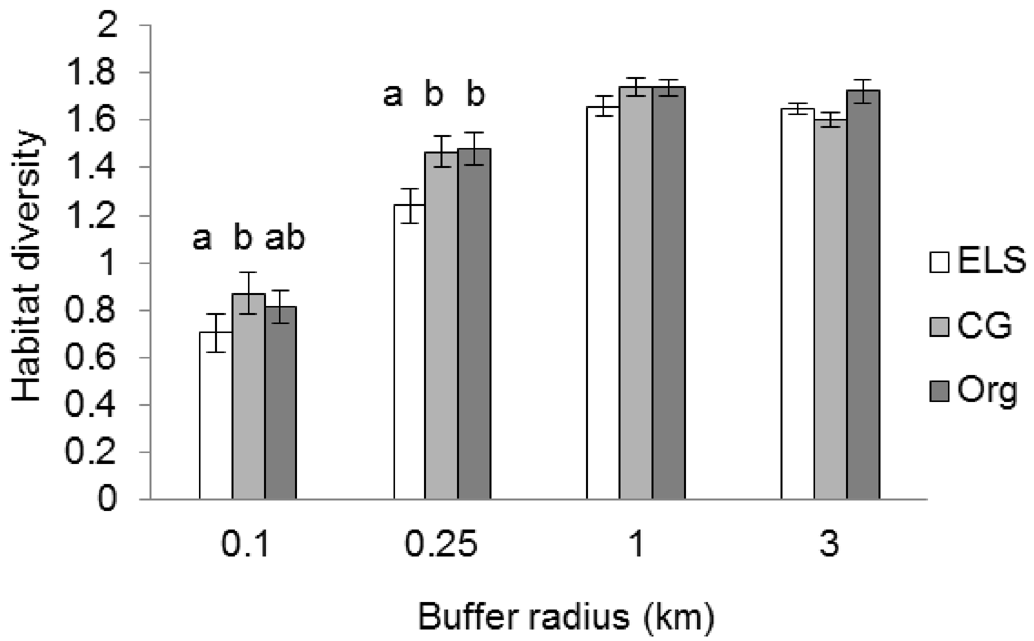

Figure 3.2: Variation in Shannon habitat diversity at different spatial scales for farms in three different wildlife-friendly farming schemes: ELS = Entry Level Stewardship, CG=Conservation Grade, Org=Organic. Means and 95% confidence intervals from the raw data are shown. Letters above bars indicate post-hoc differences between schemes within each buffer radius class. No significant differences were found between schemes in the 1 and 3 km buffer radius classes.

3.4.2 Habitat diversity as a predictor of species richness

During this study, we recorded the following numbers of species: 23 butterflies, 84 solitary bees, 14 bumblebees, 95 birds in summer, 59 birds in winter and 178 plants (of which 123 were insect-rewarding, Baude, M. pers. comm.). Proportional to UK species totals these records represent 39% of butterfly species, 43% of bird species, 64% of bumblebee species and 34% of solitary bee species. Species lists for all sampling years are given in Appendix 8. Relationships between species richness and habitat diversity varied between taxonomic groups (Figure 3.3, Appendices 6 & 8). For butterflies, solitary bees, plants and winter birds, habitat diversity at the 100 m radius scale significantly predicted species richness (butterflies: $p<0.001$, plants: $p<0.001$, solitary bees: $p=0.014$, winter birds: $p=0.012$). Significant positive correlations between habitat diversity at the 250 m scale and species richness were seen for butterflies ($p=0.006$) and plants ($p=0.012$). There was a negative correlation between habitat diversity at the 1km scale and species richness of solitary bees ($p=0.029$). For summer birds and bumblebees, no significant correlations between species richness and habitat diversity were seen at any spatial scale.

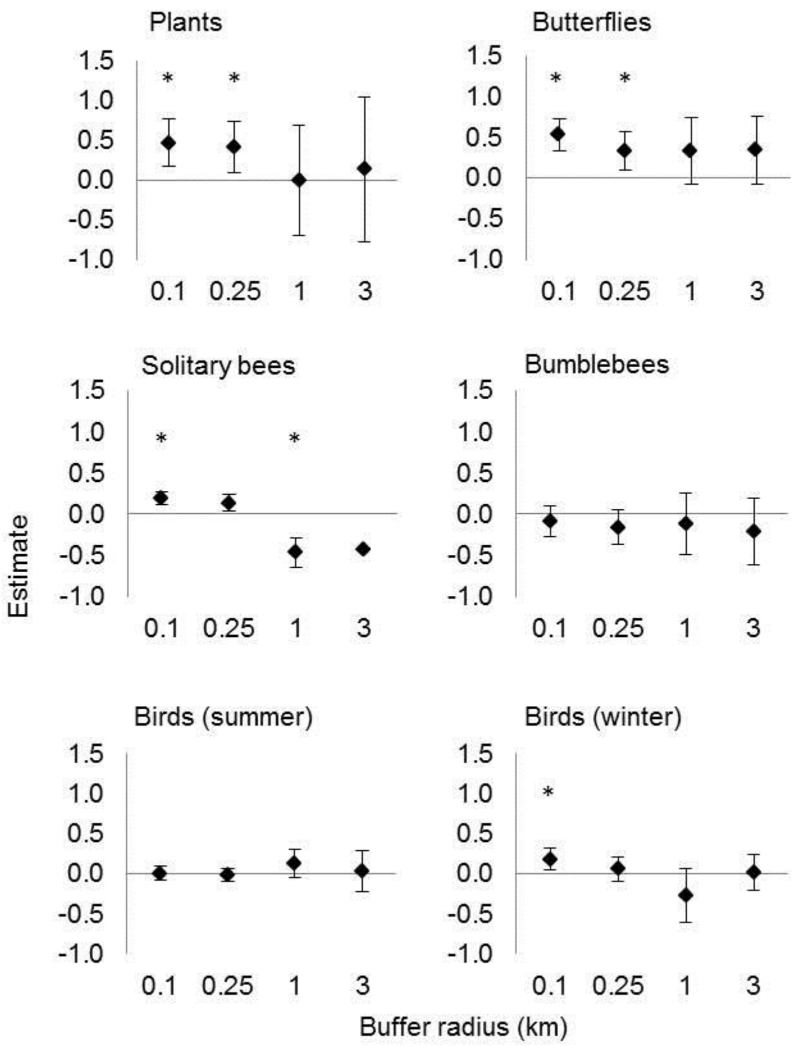

Figure 3.3: Effect sizes (and 95% confidence intervals) from models using habitat diversity to predict species richness, repeated for four spatial scales and six taxonomic groups, with significant results marked with asterisks.

3.4.3 Effects of wildlife-friendly farming scheme and habitat diversity on species richness

The schemes had varying relationships with species richness per sampling point, depending on taxonomic group (Figure 3.4, Table 3.1). Butterfly species richness was 50% higher on organic farms compared to ELS farms (p=0.046) and 20% higher on CG farms compared to ELS farms (p=0.067). Plant species richness on organic farms was 70% higher compared to ELS farms (p=0.013) and 60% higher compared to CG farms (p=0.067). No other significant differences between scheme types were seen. Species richness at the farm scale did not vary between scheme types (Friedman Chi^2 tests: plants, $Chi^2(2)=0.5$, p=0.789; butterflies, $Chi^2(2)=2.6$, p=0.273; bumblebees, $Chi^2(2)=2.923$, p=0.232; solitary bees, $Chi^2(2)=0.5$, p=0.789; summer birds, $Chi^2(2)=2$, p=0.368; winter birds: $Chi^2(2)=2$, p=0.368).

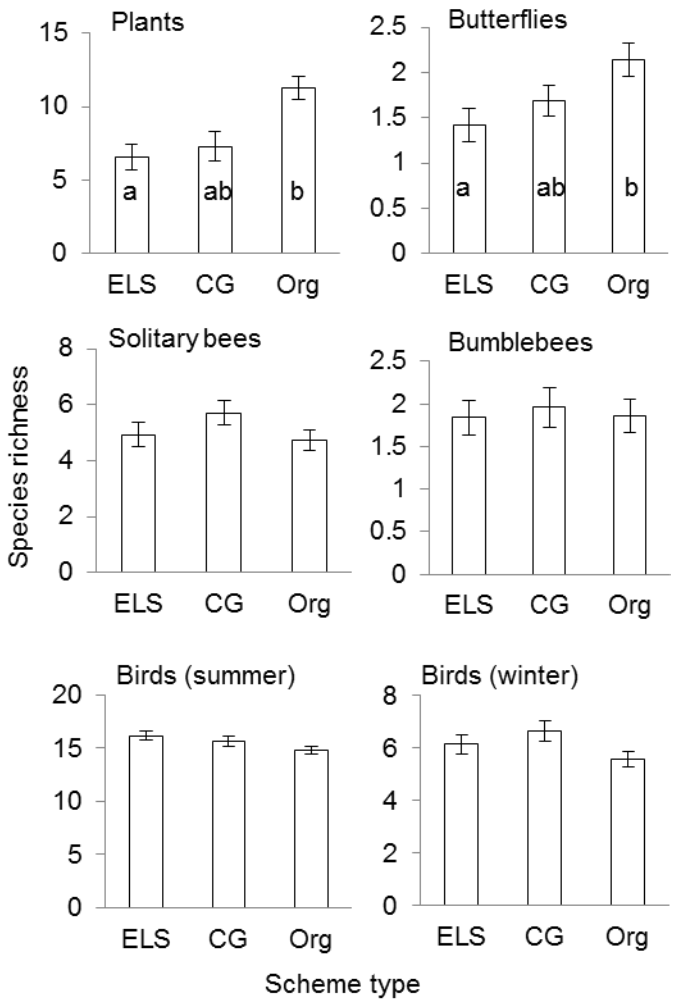

Figure 3.4: Variation in species richness per sampling point pooled across years for farms in three different wildlife-friendly farming schemes: ELS = Entry Level Stewardship, CG=Conservation Grade, Org=Organic. Means and 95% confidence intervals from the raw data are plotted with y-axes scaled appropriately for each taxonomic group.

Table 3.1: Results of generalised linear mixed models (GLMM) testing for differences in species richness between wildlife-friendly farming schemes: CG=Conservation Grade, ELS=Entry Level Stewardship, Org = Organic

Scheme type likelihood ratio test			Post-hoc test		Marginal R^2	Conditional R^2
	Chi^2 (2 df)	P value	Direction	P value		
Plants	**6.678**	**0.035**	**Org>ELS**	**0.013**	0.537	0.552
			Org>CG	(0.067)		
Butterflies	**7.093**	**0.029**	**Org>ELS**	**0.046**	0.936	0.936
			CG> ELS	(0.062)		
Bumblebees	1.577	0.454			0.686	0.686
Solitary bees	1.202	0.548			0.415	0.680
Birds (summer)	1.118	0.572			0.945	0.949
Birds (winter)	1.220	0.543			0.409	0.417

No interactions between local habitat diversity and scheme type were significant in explaining species richness. Testing scheme type and local habitat diversity as predictors of species richness together produced largely the same results as testing independently. The only difference was that for butterflies, where once habitat diversity at the 250 m scale was included in models, the effect of scheme type was no longer significant (LRT Chi^2=5.26, p=0.072, Appendix 7).

3.5 Discussion

The results showed that farms in additional wildlife-friendly farming schemes (CG and organic) supported higher habitat diversity than farms in the 'broad and shallow' ELS scheme. The higher local habitat diversity on CG farms was likely to be due to the greater number of HLS options per farm. Organic agriculture per se does not prescribe non-crop habitat management, but the higher habitat diversity on organic farms could be due to the significantly smaller fields (an organic attribute also found more widely, Norton *et al.* 2009) and/or the HLS scheme. This could be investigated further by including field size as a predictor of species richness in models. The farms in our study met the minimum requirements for the schemes we were interested in (CG, ELS and organic). However farmers can carry out additional wildlife-friendly management beyond the minimum requirements set by these schemes. Three-quarters of the farms in CG and organic schemes carried out additional management as part of the HLS scheme. In interpreting the results we need to be aware that the differences seen in the CG vs ELS and organic vs ELS comparisons may have been amplified by the HLS scheme. Further research with a larger sample size of farms could investigate the individual and aggregate impacts of combined schemes.

We found stronger associations between sampling point species richness and local (100 m or 250 m radius) compared to landscape (1 km or 3 km radius) habitat diversity. These effects depend upon the degree to which land use classifications reflect suitable habitats for species in the area. Had higher resolution habitat maps for the landscape scale been available, positive effects of landscape habitat diversity on species richness may have been apparent; land use maps of relatively larger grain were employed in the present study.

Positive correlations between species richness and local habitat diversity were seen for plants, butterflies and solitary bees. This conformed to our expectations that animal taxa with smaller home ranges would respond more strongly to local scale habitat diversity. Positive effects of habitat heterogeneity on species diversity have been found for plants at the 200 m scale in cereal fields in France (Gaba *et al.* 2010), and for butterflies at the 500 m scale in the UK (Botham *et al.* 2015). Points with high habitat diversity at the 100 m radius scale are often near field edges or in non-crop habitats. Field edges are commonly found to support more species than field centres (e.g. (Gabriel *et al.* 2010). Field edges are likely to have higher plant species richness since they tend to have lower agrochemical exposure and may receive plant propagules from neighbouring habitats (Zonneveld 1995). In addition, bird species richness in winter showed a positive correlation with local habitat diversity, but bird species richness in summer did not. This could be because AES management for winter food resources has a stronger effect than management for breeding season resources (as found by Baker *et al.* 2012). In our study, there could also be a sampling effect, since all summer bird transects were along boundaries due to access limitations, whereas winter bird sampling points also sampled field centres so included more points with low habitat diversity.

The results suggest that landscape moderation of AES effectiveness was occurring, since a negative relationship between solitary bee species richness and landscape habitat diversity at the 1km scale was found. This fits with the intermediate landscape-complexity hypothesis, proposed by Tscharntke *et al.* (2005) and supported by evidence (Batáry *et al.* 2011b), in which AES in simple landscapes are more effective. If we had sampled more triplets of farms in simple landscapes we expect to have seen more significant benefits of the CG scheme. Based on these results and the wider literature (Carvell *et al.* 2011, Scheper *et al.* 2013, Wood, Holland & Goulson 2015), we recommend that the CG scheme targets low diversity landscapes.

The benefits of CG and organic farming for species richness varied between taxa. No effects were seen for bumblebees or summer birds. This is perhaps because bumblebees and birds use the landscape at larger scales than individual farms. Perhaps if the CG or organic schemes were implemented throughout a landscape, positive effects for bumblebees and birds would be found. The limited benefit of organic farming for birds is consistent with Chamberlain, Wilson & Fuller (1999) and Gabriel *et al.* (2010), but in contrast to the findings of Hole *et al.* (2005) and Bengtsson, Ahnström & Weibull (2005), showing how variable the impact of organic farming can be on birds.

Differences between scheme types in butterfly species richness were no longer significant once habitat diversity at the 250 m radius scale was included in models. This suggests that the effect of the organic and CG schemes on butterfly species richness was partly mediated through the effect of habitat diversity. For plants, organic farming remained beneficial even once habitat diversity was taken into account. This was expected due to plant species richness commonly benefitting from organic farming (Tuck *et al.* 2014) due to reduced agrochemical use (Geiger *et al.* 2010).

The three schemes examined are all examples of land-sharing (Phalan *et al.* 2011). However land-sparing offers an opportunity to protect or restore natural habitat and the species that depend on it, by preventing further agricultural land conversion through intensifying yields on existing land (Phalan, Green & Balmford 2014). Further work to examine these schemes in light of land-sparing and land-sharing would involve i) an evaluation of the ecological intensification potential of each scheme (the potential to intensify production using ecosystem services rather than synthetic inputs, Bommarco, Kleijn & Potts (2013)) and ii) an evaluation of how far these schemes support species that benefit from land-sharing (e.g. some butterflies, van Swaay *et al.* 2012). Analysis of trade-offs between production and biodiversity is outside of the scope of this research; but it is worth noting that the CG scheme provided a compromise between supporting yields and biodiversity. CG farms outperformed ELS farms in supporting butterfly species richness and outperformed organic farms on wheat yields by up to 5 tonnes/hectare.

3.5.1 Conclusions and policy recommendations

Our study confirms that increasing local habitat diversity is a valid objective in high-intensity agricultural landscapes, since it is associated with species richness benefits for some taxa. There will be a threshold past which increasing habitat heterogeneity will be detrimental due to shrinking patch size reducing viable populations (Fahrig *et al.* 2011, Redon *et al.* 2014) and the threshold for this effect in AES systems needs further research. Three broad (but not mutually exclusive) mechanisms by which local habitat diversity can be increased are by: i) increasing non-crop habitat diversity (typical of CG, ELS & HLS schemes), ii) increasing crop diversity (Le Féon *et al.* 2013) and iii) reducing the grain of the landscape by reducing field size (Fahrig *et al.* 2015) through restoring hedgerows and field margins.

Recent policy changes that are likely to influence local habitat diversity have occurred in the EU. The Common Agricultural Policy (CAP) reform 2014-2020, made 30% of the 'Pillar 1' direct payments to farmers dependent on three compulsory greening rules: protection of permanent grassland, diversification of crop measures and maintenance of ecological focus areas. Although these measures were designed to increase habitat diversity, the policy is considered to be too dilute to be effective (e.g. Pe'er *et al.* 2014). New AES under 'Pillar 2' are also about to be implemented, such as the English Countryside Stewardship scheme. This scheme will be regionally-targeted, competitive, and include packages of habitat options targeting pollinators and farmland birds (Natural England 2015). The packages are not compulsory, but applications are more likely to be successful if they meet the minimum requirements of a package.

Our results support evidence-based packages of options in schemes (such as CG and the new Countryside Stewardship) and our findings suggest that these should improve habitat diversity and species richness of some taxa beyond that of ELS. The success of the new Countryside Stewardship scheme will depend on the detail of the scheme design, along with the extent of uptake, monitoring, management resources and farmer training. The CG scheme offers an alternative funding model, which could increase the number of farms with packages of wildlife-friendly farming options beyond that of Countryside Stewardship, given sufficient consumer demand and business subscription. We recommend that compulsory, contractually-binding ecological standards should be part of future wildlife-friendly farming schemes, in order to ensure efficient use of funding for biodiversity conservation in intensive agricultural landscapes.

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Chapter 4: Delivery of floral resources and pollination services on farmland under three different wildlife-friendly schemes

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Tim D. Nevard	Advised on project design and provided minor edits to manuscript.
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4.1 Summary

Management that enhances floral resources can be an effective way to support pollinators and pollination services. Some wildlife-friendly farming schemes aim to enhance the density and diversity of floral resources in non-crop habitats on farms, whilst managing crop fields intensively. Others, such as organic farming, aim to support ecological processes within both crop and non-crop habitats. How effective these different approaches are for supporting pollination services at the farm scale is unknown. We compared organic farming with two non-organic wildlife-friendly farming schemes: one prescriptive (Conservation Grade, CG) and one flexible (Entry Level Stewardship, ELS), and sampled a representative selection of crop and non-crop habitats. We investigated the spatial distribution and overall level of: i) flower density and diversity, ii) pollinator density and diversity and iii) pollination services provided to Californian poppy (*Eschscholzia californica*) potted phytometer plants. Organic crop habitats supported a higher density of flowers, insect-wildflower visits, and fruit set of phytometers than CG or ELS crop habitats. Non-crop habitats supported a higher density of flowers and insect-flower visits than crop habitats on CG and ELS farms. Pollination services to Californian poppy were higher on organic farms overall compared to CG or ELS. The species richness of bees and the density of bees and hoverflies did not differ between schemes, at the point or farm level. CG farms received the highest total number of insect-wildflower visits. The findings support organic farming practices that increase floral resources in crop habitats, such as sowing clover or reduced herbicide usage, as mechanisms to enhance pollination services. However trade-offs with other ecosystem services are likely and these are discussed. The findings support the CG scheme as a way of supporting pollinators within farms where high wheat yields are required.

4.2 Introduction

Declines in the abundance, diversity or ranges of flower-feeding insects that pollinate have been documented in Britain (Ollerton *et al.* 2014), China (Xie, Williams & Tang 2008), Europe (Nieto *et al.* 2014), and North America (Cameron *et al.* 2011). Key threats affecting pollinators include habitat loss, agrochemical use, climate change, disease, invasive species and their interactions (Potts *et al.* 2010, Vanbergen & the Insect Pollinators Initiative 2013, Goulson *et al.* 2015, Kerr *et al.* 2015). In addition to species conservation concerns, these declines put pollination services at risk, which are important for 78% of wild plant species in temperate zones (Ollerton, Winfree & Tarrant 2011) and 75% of crop species globally (Klein *et al.* 2007). Demand for crop pollination in Europe has increased faster than honeybee stocks, increasing the dependency on wild pollinators for crop production (Breeze *et al.* 2014b). In Sweden, red clover seed yield has declined and become more variable, most likely to be due to the homogenisation of the bumblebee visitor community (Bommarco *et al.* 2012). Parallel declines in insect-pollinated plants, bees and hoverflies have been documented in the UK and the Netherlands, suggesting that insect-pollination services to wildflowers have declined (Biesmeijer *et al.* 2006). However these declines have slowed since 1990, which may be due to conservation efforts (Carvalheiro *et al.* 2013).

To mitigate declines in pollinators and associated pollination services, the limiting resources or risk factors affecting pollinator populations need to be addressed. Policy responses that benefit flower-feeding insects have so far focused on reversing habitat loss, particularly enhancing floral resources. Floral resources are considered to be a major limiting factor for bee populations (Roulston & Goodell 2011) and have declined over the 20th century in the UK (Carvell *et al.* 2006). Other resources that flower-feeding insects require are nesting sites, shelter and for some taxa such as hoverflies, non-flower food sources for larvae. Areas managed to enhance floral resources tend to support a higher density and/or diversity of pollinating insects (Carvell *et al.* 2007, Haaland, Naisbit & Bersier 2011) and have been associated with higher densities of bumblebee nests (Wood *et al.* 2015). How effective floral resource enhancement is for pollinators depends not only on the density and diversity of flowers, but also on the ecological contrast that the management creates. Ecological contrast describes how far a resource is improved compared to a control and compared to the surrounding landscape (Scheper *et al.* 2013).

It is possible that floral resource enhancement could improve pollination services. Floral resources can influence pollination services through attracting more pollinators to the target plants (Ebeling *et al.* 2008). This is an example of facilitation: when the surrounding floral display attracts pollinators and increases visitation to the target plant. Multi-species plant assemblages have been found to enhance visitation and pollination up to a threshold, above which the surrounding flowers compete with the target species for pollinator visits (Ghazoul 2006). Local weed diversity (Carvalheiro *et al.* 2011), proximity of semi-natural habitat (Garibaldi *et al.* 2011, Martins, Gonzalez & Lechowicz 2015), creation of sown flower strips (Blaauw & Isaacs 2014) and traditional hay meadow management (Albrecht *et al.* 2007) have all been found to enhance pollination services in the local vicinity.

The main tools in Europe for enhancing floral resources in agriculturally dominated landscapes are wildlife-friendly farming schemes, which include both EU-funded governmental agri-environment schemes (AES) and market-funded certification schemes. These schemes vary widely in their objectives and management requirements. Most agri-environment schemes focus on managing land out of production rather than focusing on within-crop practices. For example, the English governmental scheme, Environmental Stewardship (ES), provides a number of options for enhancing floral resources in non-crop habitats. ES had two tiers of schemes: Entry Level Stewardship (ELS), a flexible basic scheme and Higher Level Stewardship (HLS), a competitive scheme targeting regions containing high priority natural features. Farmers chose from a menu of management options which each had a payment rate, which in ELS was calculated using a points system. These schemes can be applied to both conventional and organic agricultural systems. In 2013, ELS covered 64.6% of England's agricultural land area, organic ELS covered 3.4% and HLS covered 18.4% (Natural England 2013). In ELS, the option considered most beneficial for pollinators was sown blocks of legume based nectar flower mixture (Carvell *et al.* 2007, Breeze *et al.* 2014a). HLS had a similar nectar flower mixture, plus options for floristically enhanced grass buffer strips and maintenance, restoration and creation of species-rich grasslands. The adoption of floral resource enhancement options has been higher in HLS (73,126 ha) than in ELS (2,883 ha, (Natural England 2011a), likely due to the wide choice of management options available to ELS participants. This high degree of farmer choice reduced the potential of ELS to provide the greatest benefit to pollinators (Breeze *et al.* 2014a).

Creating minimum management requirements that benefit pollinators is one way of encouraging farmers to implement options that provide the greatest benefits to wildlife. This is the approach taken by Conservation Grade (CG), a biodiversity-focused farming protocol, which is funded through sales of 'Fair to Nature' branded food products (http://www.conservationgrade.org). Farmers are required to provide wildlife habitat on at least 10% of the farmed area, of which 4% must be pollen and nectar rich habitat. Given this protocol, we expect non-crop habitats on CG farms to contain more floral resources, higher local pollinator density and diversity and higher pollination services than non-crop habitats on ELS farms.

Another strategy to make agriculture more wildlife friendly is through organic farming practices. These aim to promote ecological processes that aid production; therefore organic farming applies agroecological management to cropped areas more often than non-organic farming. This includes the use of legumes to build soil fertility and restrictions on pesticide inputs to encourage natural enemies. The spatial difference, within the farm, in the allocation of agri-environmental management between organic and non-organic farms in England is demonstrated by the national patterns of ELS option uptake. For example, organic farms were eight times more likely to undersow spring cereals with a 10% legume mix, and non-organic farms were three times more likely to take a field corner out of management (Natural England 2011a). Furthermore, organic management of crops is associated with a higher diversity and abundance of plants (Fuller *et al.* 2005). Therefore, we expect to find a higher level of floral resource, a higher density and diversity of bees (as found by Holzschuh *et al.* 2007) and a higher level of pollination service in organic crops compared to non-organic crops.

In this study we compared three contrasting wildlife-friendly farming schemes in England: organic farming, Conservation Grade (CG), and Entry Level Stewardship (ELS). ELS was the baseline scheme in which all study farms participated. From here on, farms in ELS only are referred to as ELS, farms in ELS+CG are referred to as CG and farms in organic ELS are referred to as organic. In our study, three-quarters of the CG and organic farms were also in HLS and the implications of this are discussed. By studying farms managed under these schemes, we were able to compare organic and non-organic approaches and prescriptive versus more flexible approaches towards scheme design. This is the first comparison of how whole-farm agri-environment schemes compare in terms of floral resources, pollinator density and diversity and pollination services, using a sampling approach that takes into account the habitat composition of the farm. We aimed to answer two key research questions: 1) How did floral resources, pollinators and pollination services to phytometers vary between crop and non-crop habitats on farms in these three schemes and; 2) How did farm level floral resources, pollinators and pollination services vary between the schemes?

4.3. Methods

4.3.1 Study sites

This study was carried out in July and August 2013 in southern England. Triplets of farms (one in each scheme) were selected that matched as closely as possible in terms of landscape character, as defined by Natural England's National Character Areas, which are designated based on geological, historical, landscape, economic and cultural character (Natural England 2011b), hereafter termed regions. Matching was also based on soil type (NSRI 2011) and production type (the most common commodities were cereals and beef, for more details see Chapter 2, Table 2.1). Four suitable triplets were found (Figure 4.1a). Farming intensity parameters collected during farmer interviews (nitrogen application, number of insecticide products used and stocking density of livestock, Table 2.4) showed no differences between conventional CG and ELS farms. Farm size and number of crops per farm did not differ between schemes (Chapter 2). However farmer reported wheat yields and field sizes measured from maps did differ significantly between schemes, with organic wheat yields being significantly lower and field sizes significantly smaller than CG and ELS (Table 2.4). A high number of our study farms were in HLS (three-quarters of the CG and organic farms). Over 99% of the HLS options by area were for management of non-crop habitats. This means that when interpreting differences between non-crop habitats on organic vs. ELS, and CG vs. ELS farms, we should be aware that the HLS scheme may exaggerate these differences.

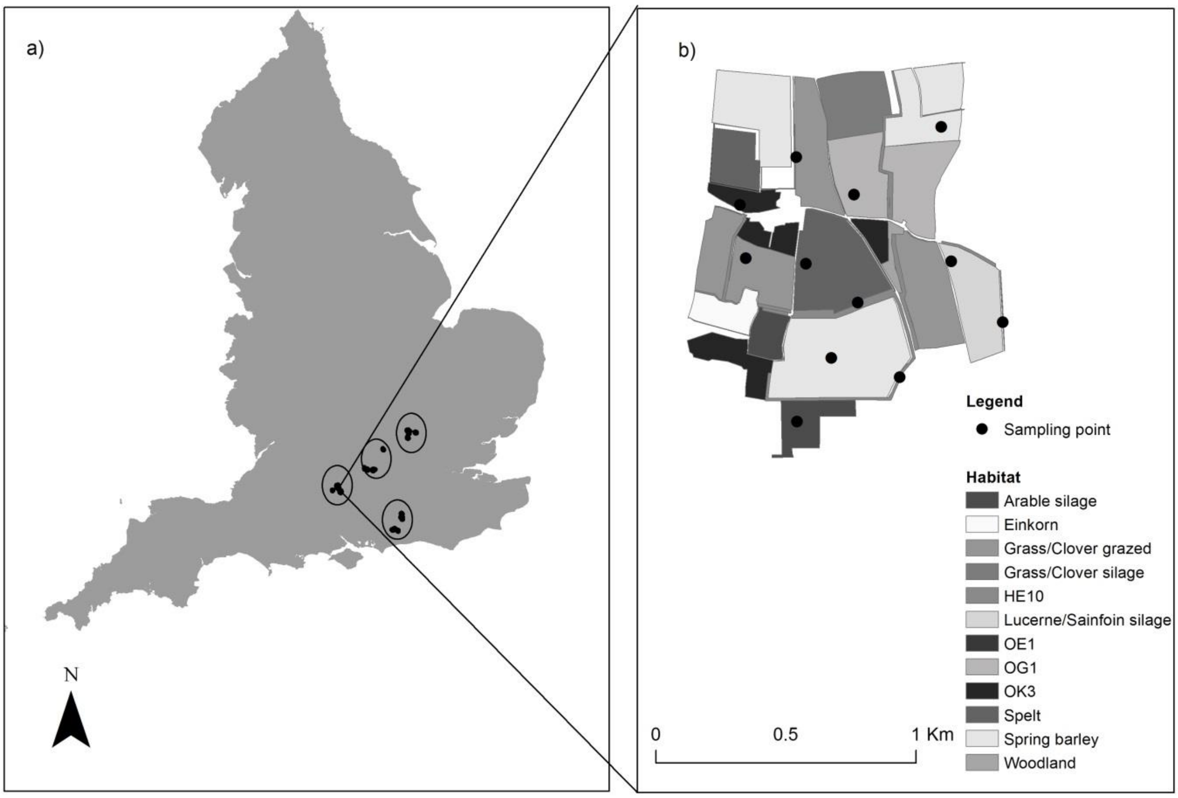


Figure 4.1: a) Map of England showing the location of the twelve study farms (black dots) in four matched regional triplets (ovals), b) map of one organic study farm showing the location of the twelve pollinator sampling points on a habitat map. The legend shows which habitat each sampling point was in, including some habitats classified using their Environmental Stewardship option codes. The crop habitats were arable silage, einkorn, lucerne/sainfoin, spelt and spring barley. The non-crop habitats were grass/clover, HE10: Floristically enhanced grass buffer strips, OE1: 2 m buffer strips on rotational land and OK3: Permanent grassland with very low inputs.

4.3.2 Habitat maps

Farm habitat maps were created in Arc GIS v.10 using cropping plans and Environmental Stewardship (ES) maps (Figure 4.1b). ES habitats include those in ELS and HLS, which cover a range of management options for arable and grassland, boundaries, historic and landscape features, protection of soil and water resources and trees and woodland. Habitat maps were ground-truthed using a handheld GPS enabled PC with Arc Pad software (accuracy ± 4 m). Hedgerows and tree lines were mapped using Google maps aerial images (Google Maps, 2013). There were no significant differences between schemes in habitat composition of the farms when habitats were grouped into broad categories of ES field margin, ES grassland, improved grassland, mass flowering crop, non-mass flowering crop and other (Chapter 2, Table 2.3).

4.3.3 Landscape variables

The landscape scale effects of area of mass flowering crop and semi-natural habitat in a 1km radius have been shown to affect bees and pollination services (Carvell *et al.* 2011, Holzschuh *et al.* 2011). Therefore, these variables were measured through the ground truthing of the Land Cover Map 2007 (Centre for Ecology & Hydrology 2011). There was no significant difference between schemes in the proportion of semi-natural habitat (SNH) or mass flowering crop (MFC) in the 1 km buffers around the farms (SNH: Friedman $Chi^2=1.5$, $p=0.47$), MFC: Friedman $Chi^2=2.5$, $p=0.28$). However, the proportion of semi-natural habitat and mass flowering crop in a 1km radius around each sampling point was highly variable, so was included in pollinator models, to account for the potentially confounding influence of neighbouring off-farm habitat on the pollinator density observed in crop and non-crop habitats on-farm. Two of the landscapes were simple (<20% semi-natural habitat) and two were complex (>20% semi-natural habitat, Chapter 2, Table 2.5).

4.3.4 Floral resource surveys

One floral resource sampling point was surveyed in every habitat type per farm. In addition, five sampling points per farm were randomly allocated to hedgerows, to representatively sample this highly variable linear habitat that is a common field boundary in England. The total number of sampling points at which floral resources were recorded in each scheme was: ELS: 66, CG: 72, Org: 61. Each floral resource sampling point consisted of 1 m^2 quadrats and transects. Only plants considered rewarding to insects (Appendix 6) were recorded. For hedgerows, a column of basal area 1 m^2 and hedge height was surveyed and additional species occurring on the 25 m long x 1 m wide x hedge height transect were recorded. For all other habitats, the number of floral units was recorded in each of three 1 m^2 quadrats. A central quadrat was placed at the randomly allocated point, then another quadrat was placed 50 m north and another 50 m east, with the whole transect fitting within the allocated habitat. Additional insect-rewarding plant species were recorded along the two 50 m x 1m transects between quadrats.

To estimate floral resource availability, we measured the density of open flowers. For composite floral units (defined in Carvell *et al.* 2007), this involved dissecting three typical floral units to count the number of open flowers. The mean number of open flowers per floral unit was multiplied by the number of floral units to estimate open flower abundance per m^2 (flower density). The average flower density per species across the three quadrats was taken and the density per m^2 of additional species recorded on transects was added. For points with open flowers, the Shannon index was used to calculate flower diversity. Only sampling points in non-crop habitats had sufficient open flower species for diversity analysis. A diversity index was used because the relative density of species surrounding the focal plant is likely to influence whether facilitation of pollination occurs (Ghazoul 2006). The main assumptions in these floral resource estimations are: i) that the distribution of flowers in each habitat was homogeneous, and therefore the sampling plots are representative of the whole habitat area, ii) that the number of open flowers in three floral units was representative of the wider population.

4.3.5 Pollinator surveys

For pollinator surveys, a proportional stratified sampling design was used to represent the composition of habitats on the farm. The area of each habitat on each farm was calculated in Arc GIS. Then a weighting system was used to give areas of land in Environmental Stewardship (ES) a greater representation in the proportional stratified sample. If stratified solely by area, small areas of high value for biodiversity may have been missed. The habitats not in ES were given a weighting of 1, whereas the ES habitats were weighted using the following equation: ES points or payment per ha/ (85 x 0.9). This equation was used because the lowest number of points that any of the ES options on these farms earned per ha was 85. Therefore the lowest scoring ES option had a weighting of 1.05 and the weighting for other options increased proportionally up to the highest scoring option which earned 485 points and received a weighting of 6.34. The proportion that each habitat's weighted area made of the summed weighted habitat areas for each farm was used to assign the twelve sampling points to habitats (further details in Appendix 4). These points were then randomly plotted within habitats using the 'genrandompnts' tool (Beyer 2001, Figure 4.1b).

We focused on the density and species richness of bees and hoverflies, which are the main functional groups of pollinators in Europe (Albrecht *et al.* 2012). For our phytometer species, bees are considered to be the most important pollinator guild (Cook 1962), but hoverfly visits have also been observed (Wickens, J., personal communication). Pollinator sampling points consisted of three pan trap sampling points 50 m apart and a 100 m observation transect between them, arranged as for floral resource surveys.

Observation transects were used to assess bee and hoverfly density and wildflower visitation over a constant sampling area. This method is recommended by Popic, Davila & Wardle (2013) for studying bee-flower interactions. Transects 100 m long were walked at a constant speed over a period of 10 minutes, and wild bees and honeybees (*Apis mellifera* L.) were observed within 2 m either side and in front of the observer and recorded to the most accurate taxonomic level as possible. Specimens not easily identified in the field were collected with a hand net for later identification under the microscope using keys. Species level identification was achieved for 88% of bee observations on transects. *Bombus terrestris* (L.) and *B. lucorum* agg. workers were recorded as *B.terrestris/lucorum* because they cannot be reliably distinguished in the field. Wind speed was recorded using an anemometer, cloud cover using visual scale of oktas and maximum temperature using a thermometer. As far as possible, the UK Butterfly Monitoring guidelines for weather conditions for transects were used (Pollard & Yates 1993). The frequency and species identity of bee-flower visits on transects was recorded.

At each pan trap sampling point, triplicate blue-white-yellow UV painted pan traps were set containing dilute soap solution. This method was used to assess bee species richness since this is considered less subjective than net sampling for small solitary bees (Westphal *et al.* 2008). Contents of pan traps were collected after 24 hours. All three farms in a landscape were sampled as close together in time as possible, normally over a period of four days for logistical reasons. Bees were frozen and then identified to species using the keys of (Else, In Press) for solitary bees and (Prŷs-Jones & Corbet 2011) for bumblebees. Hoverfly density, but not species richness was assessed due to time constraints.

4.3.6 Pollination service surveys

Ten of the twelve pollinator sampling points also had phytometers present. Phytometers are potted plants that are self-incompatible and insect pollinated. Californian poppy (*Eschscholzia californica,* Cham.) plants were used as phytometers to measure pollination services. Phytometers have been shown to be a consistent and cost effective method for measuring pollination services (Woodcock *et al.* 2014). Californian poppy was chosen because it is an ornamental species not found in the natural environment. This allowed us to standardise the availability of pollen, which is important because it allows us to measure insect pollination services in a way that is not affected by the distribution of a particular native plant species in the landscape. Californian poppy is an open-access flower accessible by a wide range of pollinators and so can be used as proxy of ambient pollination services. Flowers are bowl shaped and petal colour was pale yellow. Californian poppy has a mean petal width of 2.7 cm and flowers which provide only pollen (Cook 1962). Anthers are 1.8 cm long with a linear form and can survive for several days after petals have dehisced (Cook 1962). Pollen grains are large (29.5-32 – 30-35 microns) and spherical (Cook 1962). In field trials carried out before this experiment, the reported self-incompatibility (Cook 1962) of Californian poppy was confirmed as well as the feasibility to grow in large quantities in pots (Coston, D., pers. comm.).

Phytometer sampling points were allocated using the same proportional stratified sampling design used for pollinator surveys. The proportion of phytometer points in crop habitats was 53.6 % (ELS), 38.0 % (CG) and 47.0 % (Org). Phytometers were placed 50 cm apart at the central point. Phytometers remained in pots which were partly sunk into the soil. Surrounding vegetation was flattened within a 1 m radius to allow access to flowers by pollinators and prevent shading of the phytometers. Phytometers were watered well on setting out, once during the exposure period and once upon collection.

On setting out, phytometers were classified using a three point plant vigour score based on a visual appraisal of health. Where livestock were in fields, phytometers were placed at field edges behind fences. Where possible plants were arranged in a triangle, but if not possible they were arranged in a line. Phytometers were exposed on-site for three weeks, after which they were collected and any damage or drought was noted. They were then left in pollinator exclusion cages whilst fruit ripening occurred. Fruit set, defined as the proportion of nodes which contained at least one developed seed, along with the number of seeds per fruit were counted.

4.3.7 Data analysis

Sampling points were divided into crop and non-crop habitats to further investigate differences between schemes, since organic farming affects the cropped areas of the farm, whereas the majority of the ELS and CG schemes are focused on non-cropped areas. Crop habitats were defined as fields reseeded annually with a crop other than grass, as part of an arable rotation. Grassland (including grass/clover mixes), hedgerows, field margins, and other non-production areas were classified as non-crop habitats. Improved grassland was not classified with crop habitats as 'production area' because the differences between organic and non-organic systems are expected to be largest in arable fields. This expectation is because a meta-analysis found a higher species richness of pollinators associated with organic farming in croplands compared to grasslands (Scheper *et al.* 2013).

To compare floral resources, pollinators and pollination services among schemes we used generalised linear mixed effects models (GLMMs) from the package lme4 (Bates *et al.* 2014) with nested random effects (farms within regions). The probability of presence of floral resource, pollinators and pollination service at the ten proportionally allocated sampling points were modelled using GLMMs with binomial distributions, with scheme as a predictor variable. The contribution of different habitats to farm level total numbers of flowers was compared between schemes using Friedman, Kendall-Babington Smith tests, because the data was from a blocked design, was non-normal and had a small sample size.

Flower density was log+1 transformed and modelled using a GLMM with Gaussian errors. For flower density models, heteroscedascity of residuals could not be reduced, so estimates and SE values are reported from post-hoc tests as the p values were considered unreliable. Flower diversity was analysed using a GLMM with a Gamma error distribution since it was positive continuous data. Total floral resource at the farm scale was estimated by multiplying the habitat flower density by the habitat area, summing across habitat types, and dividing by total farm area. Area of hedgerows was estimated using length multiplied by a mean width of 1.93 m (data from 14 hedges in Berkshire and Oxfordshire, Garratt, M.P. pers. comm.).

In order to reduce overdispersion, the GLMMs for density of bees and hoverflies used a log-normal Poisson distribution (Elston *et al.* 2001) and for species richness of bees used a negative binomial distribution. The covariates temperature, wind, cloud, proportion of mass flowering crop and proportion of semi-natural habitat in 1km buffer around sampling points were include in pollinator models. Number of bee species per scheme was rarefied to the minimum number of individuals per scheme using the rarecurve function in the vegan package (Oksanen *et al.* 2015).

Full pollination service models included plant vigour score, proportion of semi-natural habitat and mass flowering crop in a 1 km radius around sampling points, scheme type, and distance to nearest field edge. The latter variable was included to account for the potentially confounding influence of phytometers needing to be moved to the edge of fields to avoid livestock and farm operations more on some farms than others. Survival in crop vs. non-crop habitats was marginally significantly different between schemes (Non-crop habitats, Org: 61, CG: 59, ELS: 35, Chi^2 (2) = 5.70, p=0.058). Therefore, distance to nearest surviving phytometer (log transformed) was included in models to account for the potential confounding effect of scheme on phytometer mortality. Fruit set was modelled using a binomial GLMM and sampling point was included as a random effect. Due to excess zeros and overdispersion in the number of seeds per plant data, a zero inflated negative binomial (ZINB) model (Zuur *et al.* 2009) was used. Data were summed at the sampling point level, because random effects could not be incorporated into ZINB models. The full model included a term for the number of surviving nodes at each sampling point. For testing correlations between flower density and fruit set, a binomial error distribution was used. For testing correlations between flower density and seed set, both variables were log+1 transformed and a Gaussian error distribution was used.

Likelihood ratio tests (LRT Chi^2) were used to test for the significance of scheme and the interaction of habitat type (crop/non-crop) with scheme. We applied post-hoc simultaneous tests for general linear hypotheses (from the multcomp package, Hothorn, Bretz & Westfall 2008), using contrast matrices to test for differences between crop and non-crop habitats within each scheme type and between schemes within each habitat type. Data analysis was carried out using R version 3.1.2 (R Core Team 2014).

4.4 Results

4.4.1 Spatially differentiated results

4.4.1.1 Spatial distribution of floral resources between habitats

The proportion of sampling points with insect-rewarding plants present was higher on organic compared to ELS farms, (LRT Chi^2 (2) = 9.552, p=0.008, Post-hoc test: Org>ELS: 0.001, Figure C.1). However the proportion of sampling points with bees, hoverflies, insect-flower visits or fruit set present did not vary between schemes (Appendix 12).

The contribution of each broad habitat category to the estimated total number of flowers at the farm scale is shown in Figure 4.2. Significant differences in mean proportions were found for AES margin habitats (Friedman, Kendall-Babington Smith S = 8, p = 0.0046), due to particularly low contributions from AES margins on organic farms. In addition, the proportion of flowers from 'other' habitats differed significantly between schemes (S = 6, p = 0.037), due to a high proportion of flowers from tree planting areas and woodland on CG farms. Other habitat categories did not show differences between schemes in the proportion of flowers from different habitat categories (AES grass: S = 3.125, p=0.213, Cereal: S=1.5, p=0.5556, Hedge: S=0.125, p=1, Improved grass: S= 0.875, p=0.7778, MFC: S=2.625, p=0.3333). ELS farms varied widely in the spatial distribution of floral resources, with one having a particularly large area of floristically dense grassland due to clover having being drilled into improved grass for silage (farm maps of floral resource density supplied in Appendix 13).

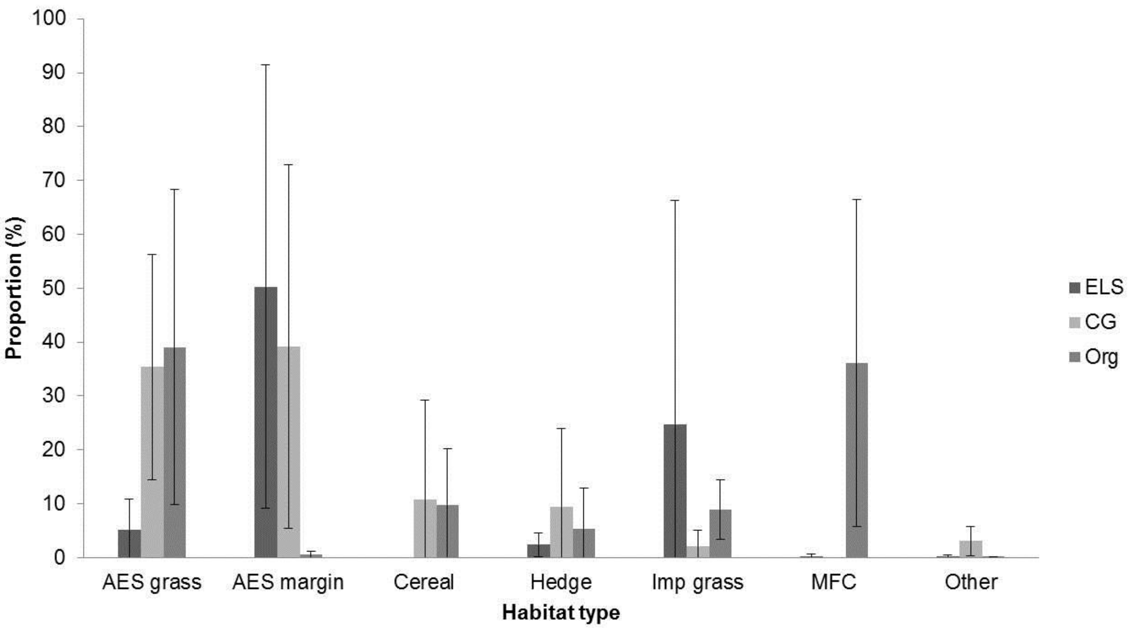
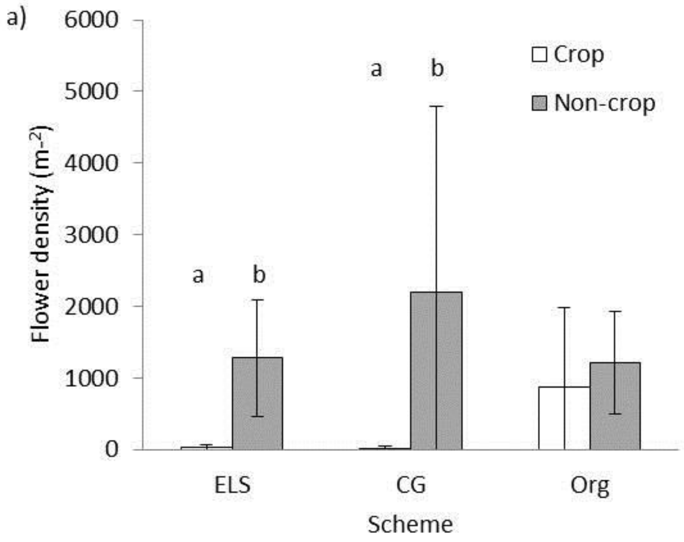


Figure 4.2: The proportion of total flowers (%) contributed by each habitat type to the total farm level flower abundance on farms in three different wildlife-friendly farming schemes (mean and SE across four farms per scheme). ELS = Entry Level Stewardship, CG = Conservation Grade, Org = organic, ES = Environmental Stewardship, Imp. grass = improved grass, MFC = mass flowering crop and other = fallow, tree planting, woodland, game cover.

The sampling points with the highest flower density in each scheme were all non-crop habitats: CG: field corner, ELS: grass/clover ley and organic: low-input grassland. The plants which contributed the most to each of these habitats were: CG field corner; 96% *Tripleurospermum inodorum* L. Sch.Bip. (scentless mayweed), ELS grass/clover ley; 97% *Trifolium pratense* L. (red clover) and organic low input-grassland; 75% *Leucanthemum vulgare* Lam. (oxeye daisy).

A range of organic crop habitats had open floral resources present, including cereals (arable silage, einkorn, spelt, barley oats and wheat), and mass flowering crops (lucerne, lucerne/sainfoin silage, clover and field beans, Figure 2). The three plants with the highest open flower density in organic crop habitats were *Tripleurospermum inodorum, Trifolium repens* L. (white clover) and *Sinapis arvensis* L. (charlock). In organic crop fields, 84% of insect-rewarding flowers were from non-sown species. The most common sown species with open flowers were white clover (9%) and lucerne (6%).

4.4.1.2 Differences between crop and non-crop habitats in flower density and diversity
There was a significant interaction between scheme and habitat type in explaining variation in flower density (LRT $Chi^2(2) = 8.357$, p=0.015, Figure 4.3a, Appendix 14). Post-hoc tests revealed that flower density was higher in non-crop habitat than in crop habitats on ELS (Estimate ±SE: 3.31 ±0.74) and CG farms (3.59 ±0.79). Crop habitats supported a higher flower density on organic farms compared to ELS (3.72 ±1.18) or CG farms (3.71 ±1.14). There were no significant differences between schemes in flower Shannon diversity in non-crop habitats (LRT Chi^2 (2) = 0.360, p=0.835, Figure 3b).



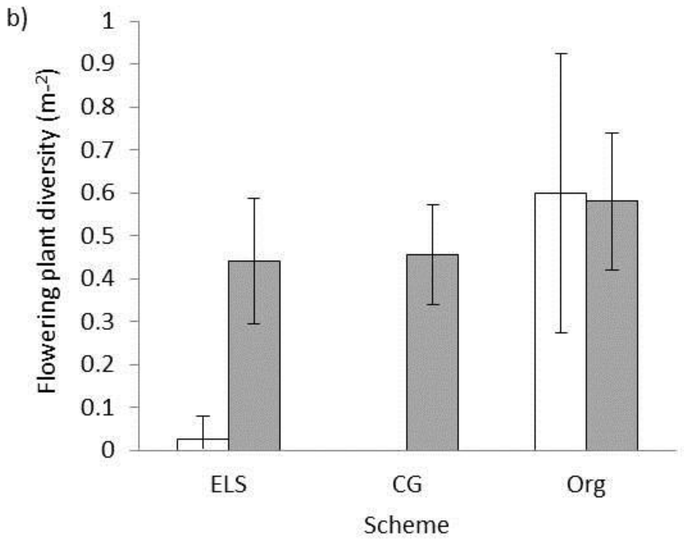


Figure 4.3: Bar plots showing mean flower density (a) and flowering plant Shannon diversity (b) in crop and non-crop habitats on farms in three different wildlife-friendly farming schemes (ELS = Entry Level Stewardship, CG = Conservation Grade, Org = Organic). Error bars show 95% confidence intervals. Letters 'a' and 'b' indicate significant differences between crop and non-crop habitats within schemes.

4.4.1.3 Differences between crop and non-crop habitats in pollinator density and diversity

There were no significant interactions between scheme and habitat type (crop or non-crop) in explaining bee species richness (LRT Chi^2 (2) = 0.366, p=0.833, Figure 4.4a), hoverfly density (LRT Chi^2 (2) = 1.082, p=0.582, Figure 4.4b) or bee density (LRT Chi^2 (2) = 4.161, p=0.125, Figure 4.4c). There was a significantly higher density of bees (LRT Chi^2 (1) = 16.60, p<0.001) and species richness of bees (LRT Chi^2 (1) = 4.707, p=0.030) in non-crop habitats than in crop habitats overall. Habitat type did not have a significant independent effect on hoverfly density (LRT Chi^2 (1) = 0.162, p=0.688).

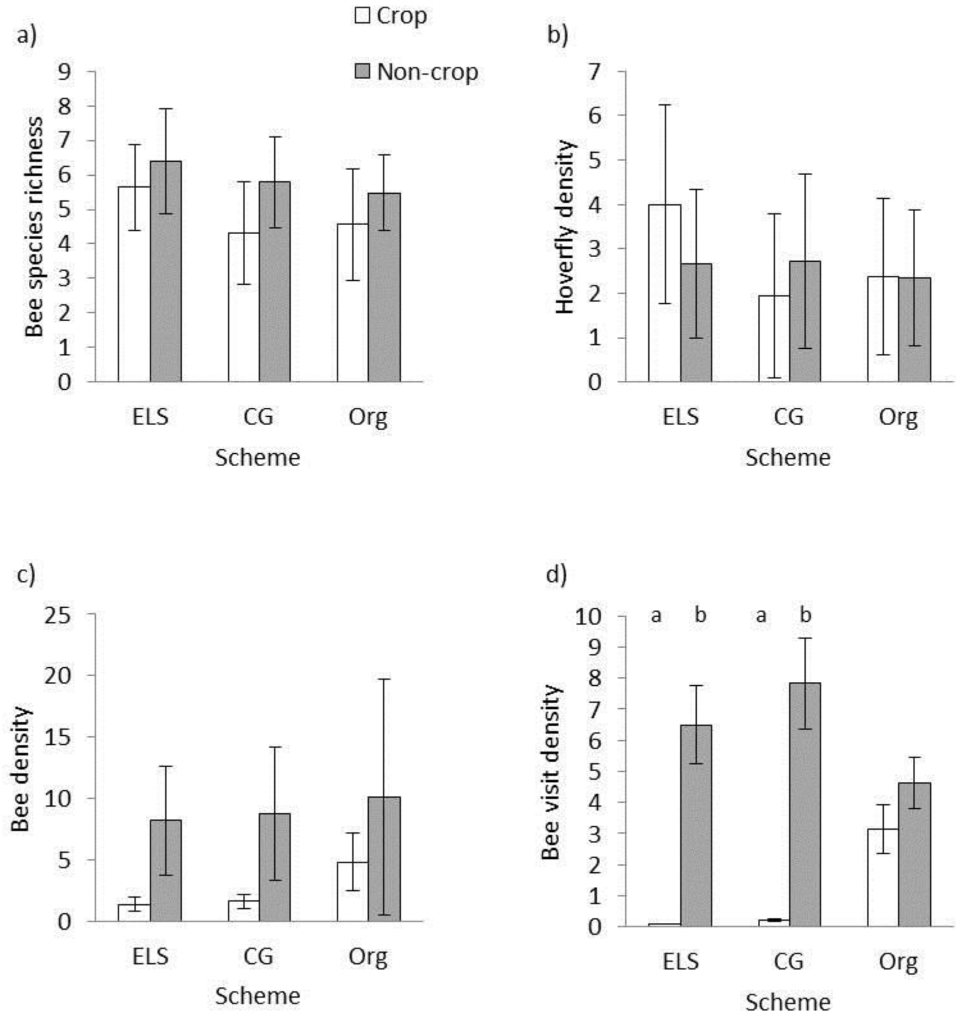


Figure 4.4: Bar plots showing means with error bars showing 95% confidence intervals for a) bee species richness, b) hoverfly density, c) bee density and d) bee-flower visit density, recorded on twelve transects, each 100 m long and 2 m wide, in crop and non-crop habitats on farms in different wildlife-friendly farming schemes: ELS =Entry Level Stewardship, CG =Conservation Grade and Org =Organic. Letters 'a' and 'b' indicate significant differences between crop and non-crop habitats within schemes.

4.4.1.4 Differences between crop and non-crop habitats in insect-wildflower visitation

There was a significant interaction between scheme and habitat type in explaining density of wildflower visits made by bees (LRT $Chi^2(2) = 11.65$, p=0.003, Figure 4.4d). Post-hoc tests revealed that on CG and ELS farms there were significantly more bee visits to wildflowers in non-crop compared to crop habitats (CG: p<0.001, ELS: p<0.001) whereas on organic farms there were no significant differences between crop and non-crop habitats (p=0.292). There were insufficient data on density of hoverfly visits to be analysed.

4.4.1.5 Differences between crop and non-crop habitats in pollination services

There was an interaction between scheme and habitat type in explaining fruit set of phytometers (LRT Chi^2=10.79, p=0.005, Figure 4.5a). Post-hoc tests revealed that organic crop habitats supported significantly higher fruit set than CG crop habitats (p<0.001) or ELS crop habitats (p<0.001). In addition, ELS non-crop habitats supported significantly higher fruit set than ELS crop habitats (p= 0.022). There was no significant interaction between habitat type and scheme in explaining seeds per node per phytometer plant (LRT Chi^2 = 1.018, df=2, p=0.601, Figure 4.5b).

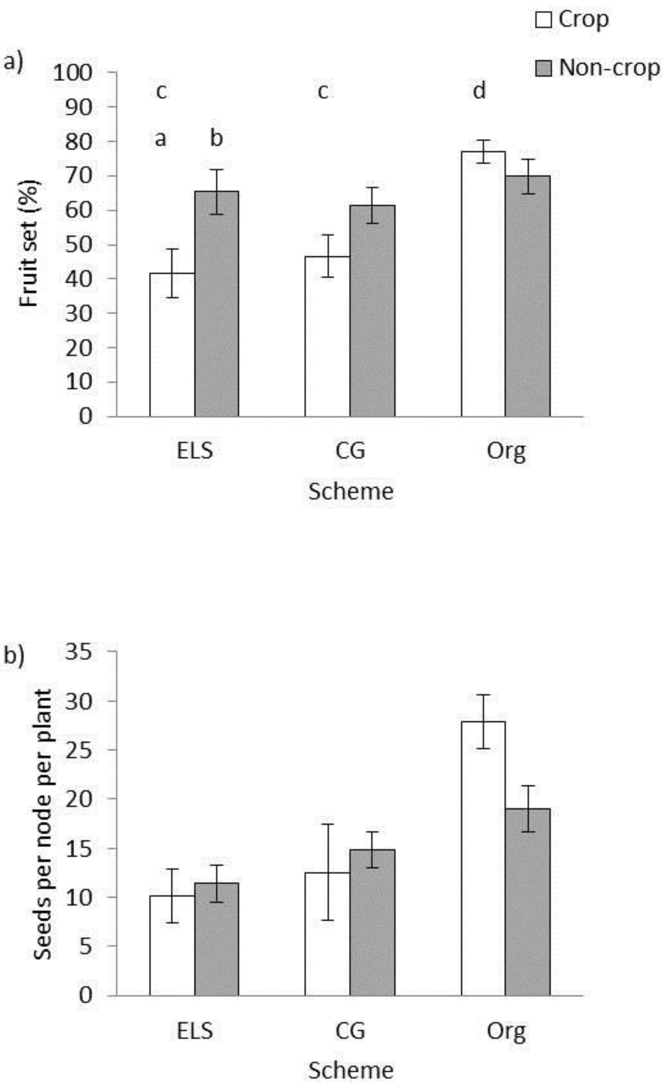


Figure 4.5: Bar plots showing means for pollination service measured as fruit set and seeds per node per phytometer plant recorded in crop and non-crop habitats on farms in three different wildlife-friendly farming schemes (ELS = Entry Level Stewardship, CG = Conservation Grade, Org = Organic). Error bars show 95% confidence intervals. Letters 'a' and 'b' indicate significant differences between crop and non-crop habitats within schemes and letters 'c' and 'd' indicate significant differences between schemes within crop habitats.

4.4.2. Farm level results

4.4.2.1 Flower density

Flower density at the farm scale did not differ significantly between schemes (Friedman Chi^2 = 1.5, df = 2, p-value = 0.472). The gamma diversity (total species richness per farm) of open flowering plants did not vary significantly between schemes (Friedman Chi^2=2, df=2, p=0.368).

4.4.2.2 Pollinator density and species richness

In pan traps we recorded 52 bee species, and on transects we recorded 925 bee individuals and 386 hoverfly individuals. CG farms showed a weak tendency towards supporting a higher density of bees on transects at the farm level, once an outlier with a particularly high density of honeybees on restored organic heathland was removed, (Org=235, CG=283, ELS=243, Chi^2(2)=5.214, p=0.074). ELS farms supported a higher density of hoverflies overall (Org=113, CG=116, ELS=157, Chi^2(2)=9.394, p=0.009). At the point level, there were no significant differences in bee density (LRT Chi^2 (2)=0.04, p=0.98) or hoverfly density (LRT Chi^2 (2)=0.523, p= 0.77) between schemes.

There was no significant difference in the total species richness of bees recorded in pan traps between schemes (Org=36, CG=28, ELS=43, $Chi^2(2)$=3.159, p=0.206). Rarefaction reduced differences between schemes (Estimated species richness: ELS: 42.2 ± 0.869, Org: 34.3 ± 1.21, when rarefied to the same level as CG: 28 species, 552 individuals). At the point level, there were no significant overall differences between schemes in bee density (LRT Chi^2 (2)=0.04, p=0.98), bee species richness (LRT Chi^2 (2)=4.38, p=0.219) or hoverfly density (LRT Chi^2 (2)=0.523, p= 0.77).

4.4.2.3 Insect-wildflower visitation

The sum total number of wild bee visits to flowers on transects differed significantly between schemes, with CG farms supporting the highest number of wild bee-flower visits ($Chi^2(2)$ =8.603, p=0.014, CG =217, ELS=160, Org=190) once the outlier was removed (one sampling point in organic restored heathland with a high density of honeybees). The top three habitats for insect visitation density (visits per 100 m by 4 m transect) were a naturally regenerated managed field corner on a CG farm (EF1), a floristically enhanced margin on an organic farm (HE10), and a field margin with a high density of *Centaurea nigra* L. (common knapweed) on an ELS farm. The majority of insect-wildflower visits were carried out by wild bees (66%), followed by honeybees (20%), and hoverflies (14%). The red-tailed bumblebee *Bombus lapidarius* (L.) made up 61% of all wild bee visits to wildflowers. Plants which received particularly high numbers of visits were *Erica tetralix* L. (cross-leaved heather, mostly visited by *Apis mellifera* at the heathland restoration point), *Centaurea nigra*, *Cirsium arvense* (L.) Scop. (creeping thistle) and *Chamerion angustifolium* (L.) Holub (rosebay willowherb).

4.4.2.4 Pollination service

Survival of phytometers varied between schemes (Number of surviving phytometers per scheme: Org: 97, CG: 89, ELS: 72, Chi^2 (2) = 13.4, p=0.002). Survival was influenced by drought, damage by farm machinery and herbicide spraying. Farm type had a marginally significant effect on farm level of fruit set per plant (Mean fruit set (%) ± SE: Org = 72.5 ± 2.9, CG = 56.6 ± 3.6, ELS = 51.9 ± 4.4, LRT $Chi^2(2)$ = 5.773, p=0.056) and organic farms supported higher fruit set than ELS and CG (Post-hoc test: Org>ELS, p=0.011, Org>CG, p=0.021). Seeds per node per plant was not significantly affected by scheme Chi^2 (2)=3.034, p=0.219).

Floral resource density had a significant positive effect on fruit set (LRT $Chi^2(1)$ = 164, p<0.001), but only explained 16% of the variation (marginal R^2 = 0.159, conditional R^2 = 0.205). Variation in seeds per node per plant was not significantly related to surrounding flower density (LRT $Chi^2(1)$ = 1.288, p=0.257).

4.5. Discussion

4.5.1 Spatial distribution of floral resources, pollinators and pollination services

On organic farms, we found that a greater proportion of the farm had floral resources present in July and August, since both crop and non-crop habitats delivered floral resources. The greater density of flowering plants in organic crop fields was consistent with other studies (Fuller *et al.* 2005, Holzschuh, Steffan-Dewenter & Tscharntke 2008). Pollination service and bee-wildflower visits were higher in organic crop fields compared to non-organic crop fields. This is in line with findings that organic farming disproportionately benefits insect-pollinated plants (Gabriel & Tscharntke 2007, Power, Kelly & Stout 2012, Batáry *et al.* 2013). However, in contrast to other studies (Rundlöf, Nilsson & Smith 2008, Holzschuh *et al.* 2007), we did not find a higher species richness or density of bees in organic crop fields. This may be because the pan trap and transect methods intercepted pollinators flying through the habitat, rather than only recording pollinators using the habitat. The moderating effect of landscape context could also explain the low effect size for organic farming on species richness and density of bees in our study. Positive effects of organic farming on bee abundance and species richness have been found in homogeneous landscapes (>60% arable land) but not in heterogeneous landscapes (15-16% arable land) in Sweden (Rundlöf, Nilsson & Smith 2008). In our study the proportion of arable land in a 1km radius buffer around our farms was 7-

36%, which is relatively low compared to the Swedish study. This will have reduced the ecological contrast in floral resources that the schemes created compared to the surrounding landscapes.

CG and ELS farms supported a significantly higher density of flowers and insect-wildflower visits in non-crop habitats compared to crop habitats, which was consistent with the findings of (Pywell *et al.* 2005). We expected non-crop habitats on CG and organic farms to have higher floral resource densities than those on ELS farms, since three-quarters of the CG and organic farms had HLS scheme managed non-crop areas. (Wood, Holland & Goulson 2015) found higher floral abundance on HLS farms implementing flower-rich margin options compared to ELS farms not implementing such options. However, flower density was not higher in CG compared to ELS non-crop habitats in our study. This appears to have been because some of the ELS farms in our study supported high non-crop densities of floral resource in habitats such as field corners (EF1), buffer strips (EE3), and improved grass/clover leys. However, after field surveys, one ELS farm removed the arable buffer strips (EE3) which contributed a high density of *Centaurea nigra* and insect-flower visits. This demonstrates the vulnerability of habitats in flexible schemes such as ELS, compared to more prescriptive schemes such as CG and longer-term agreements such as HLS.

4.5.2 Farm level of floral resource, pollinators and pollination services

Farm level floral resource provision and pollinator diversity did not differ significantly between schemes, contrary to expectations. However, CG farms supported a significantly higher overall number of bee-flower visits, showing that the more prescriptive pollinator management was successfully attracting foraging bees. This emphasises the importance of prescriptive non-crop habitats, in addition to organic farming as measures to help reverse species declines in agricultural ecosystems.

Our results suggest that the benefits of organic farming for pollination services were displayed more by the enhancement of local floral resources than by enhancement of the local density and/or diversity of pollinators. Our results concur with those of Power & Stout (2011) who found that organic farms supported a higher floral abundance and higher level of pollination service to hawthorn (*Crataegus monogyna* Jacq.). Facilitation of pollination services by nearby floral resources has also been found for weeds in sunflower crops (Carvalheiro *et al.* 2011) and uncultivated areas next to oilseed rape crops (Morandin & Winston 2006).

4.5.3 Implications for management

Our study took place in the later stage of the pollinator season in the UK, after the majority of the mass flowering crop (oilseed rape) had flowered. This time of year tends to be when bee populations are most limited by floral resource (Persson & Smith 2013). Our results emphasise the importance of managed non-crop habitat areas (such as floristically enhanced margins which received the highest density of insect visits in this study) and organic crop areas in providing floral resources for pollinators at this time of year. Chapter 5 will examine how the relative contributions of different habitats in the farmed landscape changes throughout the season.

Organic farming supported an ecosystem service (pollination) to a greater extent than non-organic wildlife-friendly farming schemes in our study. Organic farming is an example of ecological intensification: the shift towards managing ecosystem services to support agricultural production and away from synthetic inputs (Bommarco, Kleijn & Potts 2013). This type of management will result in trade-offs and synergies for different ecosystem services. We found enhanced pollination services at the farm scale on organic farms and a greater floral resource in organic crop habitats. The management practices which are likely to have contributed (legume cropping and reduced herbicide use) are likely to create synergistic benefits for soil fertility (Watson *et al.* 2002) and weed seed predation (Diekötter *et al.* 2010). Management practices commonly used in organic farming, such as reduced herbicide use and sowing clover, are likely to be beneficial in non-organic systems for supporting pollination services at both farm and landscape scales.

When considering management for pollination services, it is important to consider trade-offs with other ecosystem services. Wild plants in crop fields could enhance ecosystem services (pollination, pest control by natural enemies, nitrogen fixation) or provide disservices to crop production (competition for resources with the crop, supporting pests). Determining economic thresholds for weed tolerance in different crops is an important area of future research, and one factor to take into account is the pollinator dependence of the crop (Deguines *et al.* 2014). There are potentially opposing effects of weeds on yields for insect-pollinator-dependent vs. independent crops (Bretagnolle & Gaba 2015). Although our study was not designed to look at yields, farm intensity data collected through farmer interviews revealed that organic winter wheat yields were significantly lower than CG and ELS (winter wheat tonnes/ha mean ± SE , ELS: 7.00 ± 0.23, CG:8.04 ± 0.30, Org: 3.06 ± 0.17, Appendix 15). Larger sample sizes show the yield gap for winter wheat in England and Wales averaged 50% between 2009-2014 (Moakes, Lampkin & Gerrard 2015, full list of reports in Appendix 15). Where farm management aims to support high wheat yields and pollinators within the same farm, our results suggest the CG scheme is likely to be more appropriate.

Deciding which wildlife-friendly farming scheme individual farms should enter is a process that needs to be spatially optimised at both landscape and national scales. Factors to consider include landscape level biodiversity and food production targets, starting conditions and the productivity of the land. Spatial targeting is being used for both tiers in the new Countryside Stewardship scheme which is replacing Environmental Stewardship (Natural England 2015) and this process has potential to be improved through better data and models. Our study stimulates further research questions on which schemes or management practices will optimise pollination services to specific crops and stimulates debate about potential trade-offs between managing for insect-pollinator dependent and independent crops. This will involve consideration of how best to facilitate crop conspecific pollen transfer and reduce potential pollen competition between crop plants and co-flowering species (Schüepp, Herzog & Entling 2014).

4.6 Conclusion

Our research has explored three contrasting approaches towards management of biodiversity and ecosystem services in agricultural landscapes. The most holistic approach (organic) supported the highest level of pollination service to potted Californian poppy plants, and the most prescriptive non-organic approach (CG) supported the highest farm level density of insect visits, but these were more concentrated in non-crop areas. The basic, flexible approach (ELS) still supported high flower densities in non-crop habitats and a similar farm level pollination service to potted Californian poppy plants to the CG scheme. Our work furthers the understanding of how different habitat elements under contrasting wildlife-friendly farming schemes support potential pollination services.

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Chapter 5: Seasonal supply of floral resources for pollinators on farms in three different wildlife-friendly schemes

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5.1 Summary

1. The loss of floristically-rich habitats through agricultural intensification is an important factor contributing to bee declines. We expect there to be a temporal mismatch between floral resource supply and demand from bees in agriculturally intensive landscapes, due to the expansion of early-flowering oilseed rape crops and the reduction of late-flowering meadows, but this has not been quantified.

2. This paper is the first to estimate seasonal pollen and nectar supply at the farm-scale and compare it between farms in three different wildlife-friendly farming schemes: Conservation Grade (a prescriptive nature-friendly certification scheme, CG), organic farming, and a baseline Entry Level Stewardship (ELS) scheme. We surveyed four matched triplets of farms in southern England, four times through the season. We also collected data on bee-flower visitation and compared our estimates of pollen supply to estimates of pollen demand for six important crop-pollinating bee species.

3. We found that at the farm scale, the total nectar density was significantly higher on organic farms (by 450%) compared to ELS farms and was 110% higher on CG farms compared to ELS farms. Total pollen density was 80% higher on organic farms and 60% higher on CG farms compared to ELS farms. The total visit density was significantly higher on organic farms (by 190%) compared to ELS farms and 100% higher on CG farms compared to ELS farms.

4. Hedgerows and mass-flowering crops supported particularly high floral resource densities at both local and farm scales. Agri-environment scheme grasslands and organic cereals supported high floral resource densities overall, when scaled up to the farm scale.

5. Pollen density was higher on organic farms late in the season compared to CG and ELS farms. When comparing estimated pollen supply with maximum estimated pollen demand, organic farms were the only farms where supply exceeded the maximum estimated demand in late summer.

6. *Synthesis and applications*

We recommend that farms in non-organic schemes improve provision of floral resource later in the season, such as through the use of clover leys, reduced herbicide applications and floristically enhanced field margins. Our findings also support the restoration of hedgerows as a space-efficient way of providing floral resources in intensively managed agricultural landscapes.

5.2 Introduction

Bees play an important role in pollinating crops (Kleijn *et al.* 2015) and wild plants (Ollerton, Winfree & Tarrant 2011). Widespread declines in wild bees (Williams *et al.* 2009, Ollerton *et al.* 2014) and managed honeybees (Potts *et al.* 2009) have highlighted the need for global pollinator conservation policy responses (Gilbert 2014). Bees are threatened by habitat loss and fragmentation, climate change, disease, parasites, invasive species and agrochemicals (Potts et al., 2010) and these factors are likely to be having complex interactive effects (Vanbergen *et al.* 2013).

The loss of floral resources is often cited as one of the main factors contributing to bee declines (Ollerton *et al.* 2014, Goulson *et al.* 2015). Agricultural intensification, over the 20th century in the United Kingdom, resulted in a decline in both quality and quantity of wildflower-rich habitats such as unimproved grasslands (Fuller, 1987) and hedgerows (Garbutt & Sparks 2002). Key foraging plants for bumblebees have declined over time both in frequency (between 1978 and1998) and range (1930–1969 compared to 1987–1999, Carvell et al., 2006). There is evidence that plants that depend upon bee pollination have declined more than plants that do not in the UK and the Netherlands (Biesmeijer *et al.* 2006).

Since foraging resources are recognised as a limiting factor for bee populations (Roulston & Goodell 2011), measures to increase the availability of nectar and pollen are recommended (Pywell *et al.* 2005). Arable and improved grassland areas are important in providing foraging resources for bees because of their large national area (25% coverage of UK land area each (Morton *et al.* 2011) and because of the increase in pollinator dependent crops (Aizen et al., 2009, Breeze et al., 2011). Agri-environment schemes (AES) have been employed to reverse negative environmental effects of agricultural intensification and they represent the highest conservation expenditure in Europe (Batáry *et al.* 2015). Through AES, farmers are paid to manage land in a more environmentally sensitive way. The new AES in England (Countryside Stewardship) includes a specific option package targeting pollinators (Natural England 2015). This was one of the policy responses to the English 'National Pollinator Strategy', launched in 2014 (DEFRA 2014). The strategy includes specific actions that farmers can take to help wild pollinators, in order "to provide the right resources for pollinators where they are most needed" and to add more "high-quality flower rich habitats" across the country (DEFRA 2014).

Supply of pollen and nectar needs to meet demand in terms of quantity and quality, and be provided at the right spatial scale, in accessible flowers and at the right time of year. We currently do not know exactly what the demands of different insect pollinator species are. However, evidence shows that a continual supply of floral resources throughout a pollinators flight period is important for reproductive success (Williams et al., 2012). Most pollinator activity in the UK is between March and October. Many solitary bee species have shorter flight periods than bumblebees (UK solitary bee flight periods: 2–10 months, bumblebees: 5-12 months, Roberts, S.P.M., unpublished data). For solitary bees with flight periods of only two months, such as *Andrena niveata,* the timing of floral resource supply is critical for adult survival and reproduction. For bumblebees, the early season is a critical time because the future of the colony depends on queens accessing sufficient floral resources. The mid-season is important for colony growth and the late season supports the activity of newly emerged reproductives (Prŷs-Jones & Corbet 2011). Initial estimates of pollen demand throughout the season have been made for six important crop pollinators, by multiplying pollen demand per larva (mm^3) by the number of bees reared per colony or nest and the density of nests or colonies per 100 ha (Dicks *et al.* 2015). These estimates showed pollen demand peaking in August. Declines in both early season and mid-late season bumblebee forage plants have been recorded

(Carvell *et al.* 2006a), but it is not clear at which point in the season resources are in shortest supply relative to demand.

Field trials aiming to find management options for providing floral resources for bumblebees found that margins sown with a pollen and nectar mix (agricultural legumes and grass) were most effective at enhancing the density of foraging bumblebees (Carvell *et al.* 2007). The pollen and nectar mix contained significantly higher foraging densities of *Bombus lapidarius* and *B. pascuorum* compared to other margin types and three declining *Bombus* spp. (*B. ruderatus, B. ruderarius* and *B. muscorum*) were also observed foraging in the pollen and nectar mix. Based on this research, a nectar flower mixture (EF4) was included as an option in the most widespread AES in England, Entry Level Stewardship (ELS). This mixture must include at least four nectar-rich plants, such as *Trifolium pratense* (red clover), *Trifolium hybridum* (alsike clover), *Lotus corniculatus* (bird's-foot-trefoil), *Onobrychis viciifolia* (sainfoin), *Malva moschata* (musk mallow) or *Centaurea nigra* (common knapweed), (Natural England 2012). However due to the high degree of flexibility over which management options to choose, the uptake of the EF4 option has been relatively low (5% of agreement holders chose this option, Natural England 2013a), so the ELS scheme has not realised it's maximum potential benefit for pollinators (Breeze *et al.* 2014).

Research on the effectiveness of agri-environmental management to supply floral resources has so far largely focused on individual options, such as blocks of sown flowers. Although these blocks have been up to 1 ha in size (Carvell *et al.* 2015), AES typically operate at the farm scale (average farm size in England: 87.8 ha, (DEFRA, 2015) and foraging resources have been found to affect nest density of bumblebees at landscape scales (314 ha, Knight et al., 2009). This highlights a need to evaluate the impact of different AES at larger scales and to take into account the habitat context in terms of composition of the farmed landscape, including cropped areas, grasslands and linear features such as hedgerows.

In this study we compared floral resource supply between three farm-scale AES in England which all aim to some extent to support pollinators through the provision of floral resources. Conventional ELS was our baseline scheme, which covered 65% of England's agricultural area in 2013 (Natural England 2013c). We compared conventional ELS with organic ELS. Organic agriculture is widely supported throughout Europe (Batáry *et al.* 2015) due to its emphasis on maintaining and increasing ecological health. Greater species richness of plants and pollinators has been found on organic compared to non-organic farmland (Tuck *et al.* 2014). We compared these two schemes with a third more prescriptive, non-organic scheme: Conservation Grade (CG, http://www.conservationgrade.org). This market-funded ecological certification scheme has a 'Fair to Nature' protocol in which farmers must manage 10% of their farm for wildlife, including 4% of the farm area as pollen and nectar rich habitat. To ensure a diversity of floral resources are provided, at least 1.5% of farm area must be grass and wildflower mix, while up to 2.5% can be legume-based pollen and nectar mix. An additional scheme present on some farms was Higher Level Stewardship (HLS), which is the more targeted and competitive government scheme in England.

In this study we investigated the effect of three different wildlife-friendly farming schemes on the dynamics of pollen supply, nectar supply and bee visitation across the season both at local and farm scales. Our specific questions, predictions and reasoning are outlined here.

1) How does the local density of pollen and nectar (estimated from flower density) and bee-flower visitation vary between habitat types and scheme types through the season? We expected the density of floral resources and visitation to be higher in AES margin, AES grass and hedgerow habitats on CG farms compared to ELS farms. This is because the CG protocol includes advice on hedgerow management as well as management of field margins and grasslands which make up the 4% pollen and nectar rich farm area. We also expected the density of floral resources and visitation to be higher in cereal habitats on organic farms than on farms in ELS or CG. This is because organic farms do not use herbicides and may undersow cereals with a legume mix. We expected the local

density of floral resources and visitation to be higher in hedgerows earlier in the season and higher in AES margins later in the season. This is because hedgerows in the UK typically comprise of early-flowering species (March – June) such as *Prunus spinosa* (blackthorn) and *Crataegus monogyna* (hawthorn). By contrast, AES margins are enhanced by sowing flower mixtures, which typically include late-flowering species (July – September) such as *Leucanthemum vulgare* (oxeye daisy) and *Centaurea nigra* in grass and wildflower mixtures, and agricultural legumes such as *Trifolium pratense* in pollen and nectar mixes.

2) Which plants supplied the highest density of floral resource and visitation at the local scale? We expected sown agricultural legumes (such *Trifolium pratense*, *Lotus corniculatus* and *Onobrychis vicifolia*), which are part of pollen and nectar mixes to make particularly large contributions to local floral resource density, because they have been included in seed mixes for this reason.

3) How does the farm scale density of pollen, nectar and bee-flower visitation vary between scheme types through the season? This question investigates the floral resource provision that the composition of habitats on each farm creates. We expected the farm scale floral resource to be higher on CG and organic farms compared to ELS. This is because the CG farm protocol requires 10% of farm area to be managed as pollen and nectar rich habitat and organic farms tend to support more insect-pollinated plants (Batáry *et al.* 2013).

4) How do the estimates of pollen supply compare with estimates of pollen demand through the season?

5) Which plants supplied the highest density of floral resource and visitation at the farm scale? We predicted that habitats which have large areas (such as low-input grasslands and mass-flowering crops) would make large contributions to farm scale floral resources. Therefore we expected plants typical of these habitats such as *Trifolium repens* (white clover) and *Brassica napus* (oilseed rape) to make large contributions at the farm scale.

5.3 Methods

5.3.1 Site selection

In order to compare the three wildlife-friendly farming schemes, we searched for triplets of farms, matched as far as possible on crops and livestock, soil type (NSRI 2011) and landscape character (National Character Area profiles, defined by a unique combination of landscape, biodiversity, geodiversity, history, and cultural and economic activity, Natural England 2011). We found four suitable triplets (Chapter 2, Figure 2.1). A habitat map was created for each farm by digitising cropping plans and Environmental Stewardship maps (Chapter 2, Figure 2.2). The areas of each habitat on each farm were calculated using Arc GIS v.10.1. The proportional areas of broad habitat categories and the density of hedgerows did not differ between schemes (Chapter 2, Table 2.3). Three-quarters of the CG farms and three-quarters of the organic farms were also in HLS and one organic farm started HLS conversion during the study. The proportional area of land in mass flowering crop in a 1km radius around the farms did not differ between schemes (Friedman Chi^2 = 0.5, df = 2, p-value = 0.78).

5.3.2 Sampling strategy

On each farm, a set of transects of total length 1.5 km were surveyed, sub-divided proportionately according to weighted habitat areas. Weights were based on the number of points the habitat earns in ELS or HLS (further method details in Chapter 2) and were assigned in order to better capture small areas of high quality floral resource within the survey. The minimum transect length was 10 m. The starting point for each transect within the designated habitat was assigned randomly in ArcGIS to remove any systematic bias towards habitat edges or centres. Three-dimensional linear habitats (hedgerows) were also surveyed, by randomly selecting five hedgerows per farm and surveying transects 25 m long along each hedgerow. Four sampling rounds were carried out in 2014. The dates of sampling were: first round,14th April to 29th May; second round, 30th May to 25th

June; third round: 26th June to 17th July; fourth round, 22nd July to 13th August. These sampling rounds covered the peak period of pollinator activity in the UK, but missed the early spring activity (February/March) and the late summer – autumn activity (late August-September). Each farm was sampled once per round and each region was sampled in the same order within each round.

5.3.3 Floral resource surveys

Quadrats of $1m^2$ were placed at both ends of transects and the number of floral units (defined in Appendix 6) was recorded for each flowering plant species that had open flowers. Additional flowering plant species that were not recorded in quadrats were recorded on transects (1m wide) running between quadrats, with an estimate of the number of floral units. Floral units were either single flowers or compound flowers (multi-flowered stems as described in Carvell et al., 2007). For compound flowers, the number of open flowers per floral unit was estimated by selecting five representative floral units and dissecting them. This was repeated on each farm during each survey round. For hedgerows, the number of floral units in the entire column (1 m wide) above the transect was estimated. Plant identifications were made in the field (following Rose 2006) and accepted Latin names were checked using The Plant List (2013).

5.3.4 Pollinator surveys

Transects were walked at a steady speed of 10 m/min. Pollinator transects were 4 m wide to maximise records and be within netting distance of the observer. Surveys were carried out during the optimal times of day and weather conditions as far as possible (Pollard & Yates 1993), which was between 9am and 5pm, in temperatures over 13°C, with low wind and no rain. The order in which transects were walked was changed each visit to minimise the effect of time of day. All bees observed on transects were recorded to species as far as possible. Solitary bees and unknown bumblebees were collected with a hand net for identification in the lab using microscopes and taxonomic keys (solitary bees: Else, G. in press, bumblebees: Prŷs-Jones & Corbet 2011). If bee-flower visits were observed on transects, the bee and plant species involved in the visit and the number of separate visits to floral units was recorded (separate visits being those that the bee had to fly between to make). The workers of *Bombus terrestris* (L.) and *B. lucorum* agg. were recorded as *B.terrestris/lucorum* due to their unreliable identification in the field.

5.3.5 Local scale density calculations

To calculate flower density of each species, the number of floral units per m^2 was multiplied by the mean number of open flowers per floral unit from that sampling site and day. Flower density for species found in quadrats was calculated by averaging the density across the two quadrats. Flower density for the additional species found on transects was calculated by dividing by transect length. To estimate nectar and pollen density for each species, flower density was multiplied by nectar sugar content (µg / 24 hrs) and pollen volume (mm^3) per flower (Table 5.1). Where pollen and nectar values were missing, a substitute value from the nearest related species was found using (Stace 2010, Appendix 17). Then pollen and nectar density values from all plant species found in the habitat were summed to get an estimate of pollen and nectar density per habitat per farm in each sampling round. Equation 1 summarises how pollen density per habitat (PH) was calculated, and the equivalent calculation was carried out for nectar. If there are S species in a habitat, PH is the sum of the *i*th species product of pollen volume per flower (PF), flowers per floral unit (FFU), and floral units per habitat (FUH). Being a product, this calculation will incur error propagation (sources of error described in Appendix 18). In proportion to the mean, standard errors were higher for PF and NF (pollen and nectar content per flower) than for flowers per floral unit (FFU) or floral units per habitat (FUH, Appendix 19).

$$PH = \sum_{i}^{S} PF_i \times FFU_i \times FUH_i \qquad (1)$$

Visit density was calculated by dividing the number of visits by the transect area (length x width), since the transect lengths were proportionally allocated to habitats (further details in Chapter 2 and Appendix 4).

Table 5.1: Sources of pollen and nectar values and number of plant species for which these sources were used, sampling methods for the Baude *et al.* dataset are in Appendix 16

Source	**Pollen**	**Nectar**
Baude *et al*. (unpublished) field data¶	105	115
(Müller *et al.* 2006) field data	2	0
Genus average	47	33
Literature	1	2
Substitute*	56	32
Gillespie, M. trait-based model (unpublished)	0	29

¶Database as of December 2013 *Listed in Appendix 17

5.3.6 Farm scale density calculations

We multiplied each habitat pollen and nectar density (per m^2) by the habitat area, and summed these values for each farm. For hedgerows the footprint area was calculated by multiplying the length by the mean width (1.93 m, data from 14 hedgerows in the study region, Garratt. M., pers. comm.). Then we calculated the density of pollen and nectar per 100 ha farmland by dividing the farm total amount of pollen or nectar by the farm area (ha) and multiplying by 100.

5.3.7 Statistical analysis

For analysis purposes, habitats were assigned to one of the following categories: AES grass, AES margin, improved grass, cereal, mass-flowering crop, hedgerows and other (Chapter 2, Table 2.2). Habitats classed as 'other' were those which were not part of the schemes and were often unique to certain farms (woodland, fallow, game cover crops and tree planting areas). To test our specific hypotheses about contrasts between factor levels, we conducted post-hoc tests (simultaneous tests for general linear hypotheses using single step p value adjustments based on the joint normal or t distribution of the linear function from the multcomp package, Hothorn, Bretz & Westfall 2008). Model residuals were checked for normality and homoscedascity. All statistical analyses were conducted in R version 3.1.2 (R Core Team 2014).

5.3.7.1 Local density analysis

Due to the nested study design, for analysing local scale density, mixed effects models from the lme4 package (Bates *et al.* 2014) were used, with farm nested within region as a random error term. Variable significance was tested using likelihood ratio tests (LRT, Zuur *et al.* 2009). A Gaussian error distribution was used and nectar density was log+1 transformed and visit density was square-root transformed to improve normality. Temperature, wind and cloud were included in visitation models. The interaction between habitat type (factor with 7 levels), round (factor with 4 levels), and scheme type (factor with 3 levels) was included as a fixed effect.

5.3.7.2 Density of floral resource from individual plants at the local scale

The average density of pollen, nectar and visitation per m^2 for each plant species for each farm was calculated. Then the average across all farms was used to determine the five plant species with the highest density.

5.3.7.3 Farm density analysis

To test for differences between scheme types through the season we modelled the total farm density (n=48, 12 farms over 4 rounds) as a function of the interaction between round and scheme type. This was a mixed effects model with Gaussian errors and a random term for region.

5.3.7.4 Comparing pollen supply and demand

Dicks et al. (2015) estimated pollen demand for six important crop pollinator species including three bumblebees and three solitary bees (*Andrena spp.*). Here we used pollen demand values for the April to August period only and we moved the pollen demand values to be one month earlier than in Dicks et al. (2015). This is to take account for the majority of the pollen demand of a bee occurring during the pupal and larval phases, which start approximately one month before adults emerge (Prŷs-Jones & Corbet 2011). Nectar demand estimates were not available.

5.3.7.5 Contributions of habitats at the farm scale
The interactive effects of scheme type, habitat type and round were tested on farm-scale estimates of pollen and nectar density (n=48) using mixed effects models with Gaussian errors and random effects for farm nested in region. Pollen and nectar density were log+1 transformed and visit density was square-root transformed to improve model fit.

5.3.7.6 Density of floral resource from individual plants at the farm scale
The density of pollen, nectar and visitation per m^2 for each plant species was scaled up to the farm scale by multiplying by the area of the habitat in which it was recorded. The total amount (of pollen, nectar or visitation) per plant species per farm was summed then divided by farm area and multiplied by 100 to standardise to density per 100 ha.

5.4 Results
In total, we encountered 211 insect-rewarding plant species of which 70 were visited by bees. We observed 10 bumblebee species and 22 solitary bee species foraging. The majority of visits were made by bumblebees (76%), with one species *Bombus lapidarius* (L.) making 40% of all visits. The density of pollen, nectar and visitation were all significantly correlated (Appendix 20).

The number of insect-rewarding plant species with open flowers varied between rounds and scheme types (GLM LRT, scheme: Chi^2=15.4, p<0.001, round: Chi^2=45.7, p<0.001, Appendix 21). Post-hoc tests revealed that the species richness of open flowers was lower on ELS farms than CG (p=0.001) or organic (p=0.044) and on all schemes was lower in round one than round two, three or four (p<0.001 in all cases).

5.4.1 Local scale density
The habitats supporting the highest local scale pollen density across all scheme types and rounds were hedgerows, other (woodland, fallow, game cover crops and tree planting areas) and mass flowering crops (mean ± SE, hedgerows: 111 +-39, other: 74+-32, MFC: 35+-10 mm^3 per m^2). The same top three habitats supplied the highest local scale nectar density (mean ± SE, hedgerows: 42+-12, other: 78 +-47, MFC: 49+-25 mg per m^2 per 24 hrs). The effect of habitat type varied with round and scheme (Table 5.2). Post-hoc tests revealed that the pollen density in hedgerows was significantly higher earlier in the season, a trend not seen for nectar. In contrast the nectar density of AES margins was higher later in the season. Organic cereal fields supported a higher pollen and nectar density than ELS cereal fields and a higher nectar density than CG cereal fields at the local scale. Bee visitation at the local scale did not significantly differ between scheme types or habitat categories (Table 5.2), however round and temperature both had significant effects. Post-hoc tests revealed that visit density at the local scale was higher in round two than round three.

Table 5.2: Results of general linear mixed effects models (GLMM) on local scale density of pollen, nectar and visitation as a function of an interaction between habitat type, wildlife-friendly farming scheme type and seasonal round, with the results of likelihood ratio tests (LRT) and post-hoc tests specified by hypotheses.

	GLMM LRT	Chi^2	df	P	Post-hoc tests	Est	SE	P	
Pollen density	Scheme * Round	36.3	28	0.136					
	Habitat * Round	59.7	42	0.037					
					R1 hedgerow > R4 hedgerow	2.10	0.59	0.003	**
					R1 AESm > R4 AESm	0.44	0.64	0.996	
					R1 MFC > R4 MFC	0.94	0.83	0.912	
					R1 AESg < R4 AESg	<0.01	0.64	1.000	
		64.5	36	0.002					
	Habitat * Scheme				CG AESm < ELS AESm	0.04	0.67	1.000	
					CG AESg > ELS AESg	0.05	0.76	1.000	
					CG hedgerow > ELS hedgerow	0.73	0.64	0.911	
					Org cereal > CG cereal	1.40	0.92	0.676	
					Org cereal > ELS cereal	2.13	0.66	0.011	*
Nectar density	Scheme * Round	47.3	42	0.266					
	Habitat * Round	72.4	54	0.05					
					R1 hedgerow > R4 hedgerow	1.33	1.35	0.960	
					R1 AESm < R4 AESm	3.46	0.75	<0.001	***
					R1 MFC > R4 MFC	1.16	1.41	0.987	
					R1 AESg < R4 AESg	0.73	0.87	0.984	
		105.8	48	<0.001					
	Habitat * Scheme				CG AESm < ELS AESm	0.35	0.61	0.999	
					CG AESg > ELS AESg	0.13	1.02	1.000	
					CG hedgerow > ELS hedgerow	0.12	1.18	1.000	
					Org cereal > CG cereal	4.60	1.46	0.014	*
					Org cereal > ELS cereal	4.71	0.87	<0.001	***
Visit density									
	Habitat * Round	45.0	51	0.709					
	Habitat * Scheme	31.7	44	0.917					
	Scheme * Round	30.8	39	0.821					
	Temperature	7.80	1	0.005					
	Round	8.28	3	0.041	R4 > R1	<0.01	0.01	0.975	
					R4 < R2	0.01	0.01	0.536	
					R4 > R3	0.01	0.01	0.559	
					R3 < R2	0.03	0.01	0.039	*
					R2 > R1	0.02	0.01	0.219	
					R3 < R1	<0.01	0.01	0.874	

5.4.2 Density of floral resource from individual plants at the local scale

At the local scale, the top plants in terms of nectar, pollen and visit density (Table 5.3) included several hedgerow plants: *Acer pseudoplatanus* (sycamore)*, Crataegus monogyna* and *Rubus fruiticosus agg.*(bramble) as well as a mass-flowering crop (*Brassica napus*, oilseed rape) and an arable weed (*Tripleurospermum inodorum,* scentless mayweed). Some plants with particularly local high density of floral resource were only found on one or two farms, such as *Hyacinthoides non-scripta* (bluebell) and common *Calluna vulgaris* (heather). Some of the top plant species in terms of local visit density were not top species for local pollen or nectar density, such as *Glechoma hederacea* (ground-ivy) and *Cirsium vulgare* (spear thistle).

Table 5.3: The top five plants in terms of density of pollen, nectar and visitation, at both local (per m^2) and farm (per 100 ha) scales (density values in Appendix 24)

		Pollen	Nectar	Visitation
Local scale	1.	*Acer pseudoplatanus*	*Crataegus monogyna*	*Rubus fruiticosus agg.*
	2.	*Crataegus monogyna*	*Tripleurospermum inodorum*	*Glechoma hederacea*
	3.	*Hyacinthoides non-scripta*	*Acer pseudoplatanus*	*Taraxacum agg.*
	4.	*Calluna vulgaris*	*Calluna vulgaris*	*Cirsium vulgare*
	5.	*Brassica napus*	*Brassica napus*	*Trifolium pratense*
Farm scale	1.	*Hyacinthoides non-scripta*	*Tripleurospermum inodorum*	*Rubus fruiticosus agg.*
	2.	*Crataegus monogyna*	*Trifolium pratense*	*Cirsium vulgare*
	3.	*Fumaria officinalis*	*Trifolium repens*	*Trifolium repens*
	4.	*Ranunculus repens*	*Crataegus monogyna*	*Taraxacum agg.*
	5.	*Brassica napus*	*Taraxacum agg.*	*Trifolium pratense*

5.4.3 Farm scale density

The farm scale density of nectar and visitation was significantly higher on organic farms than farms in CG (p=0.040, p=0.013) or ELS (p<0.001, p<0.001, Figure 5.1, Appendix 22). The farm scale density of pollen was significantly higher on organic farms compared to ELS farms in round 4 only (p=0.035, Figure 5.2, Appendix 22). Visit density at the farm scale was significantly lower in round 1 than all other rounds (p<0.001 in all cases, Appendix 22). If we scale up our estimates of pollen and nectar density to the entire utilisable agricultural land area (UAA) in England, and assume the estimates are only representative of organic land in HLS (since three of the four organic farms in this study were in HLS), then organic HLS land (which makes up 0.8% UAA), is providing the same amount of nectar as 7% UAA managed under ELS and the same amount of pollen as 2% UAA managed under ELS.

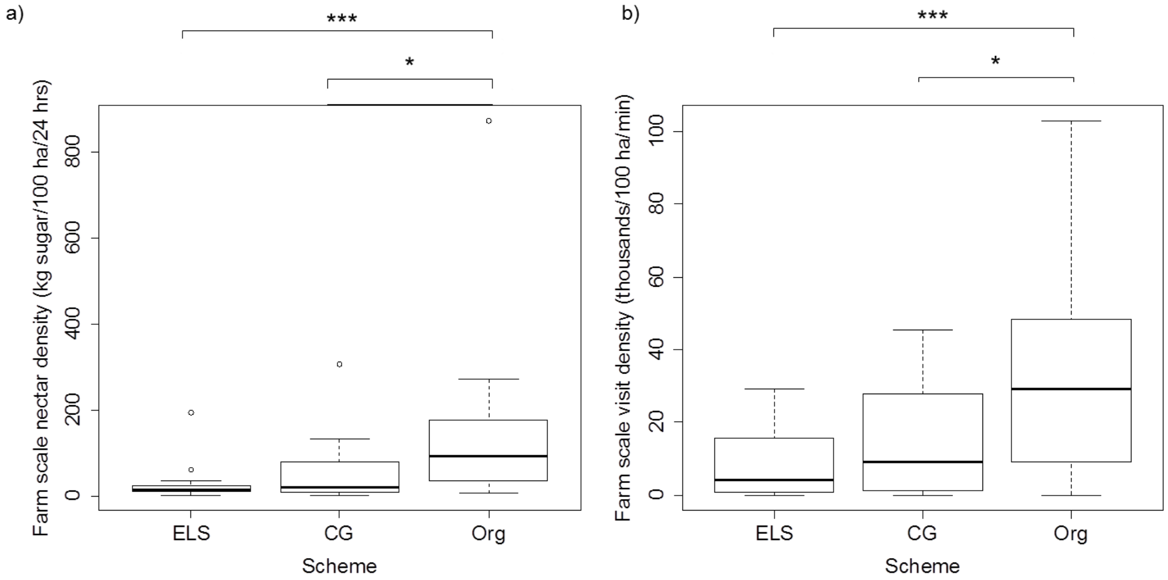

Figure 5.1: Boxplots showing differences between three wildlife-friendly farming schemes in a) farm scale nectar density and b) farm scale visit density

5.4.4 Comparing pollen supply and demand

By comparing estimates of pollen supply with pollen demand (Figure 5.2), we can see that pollen demand increases between April and July, whereas pollen supply drops. Using the low estimate of pollen demand, all farms (except one ELS farm in round 4) supplied sufficient pollen during all four sampling rounds. However if we use the high estimate, only the organic farms supplied sufficient pollen in round 4.

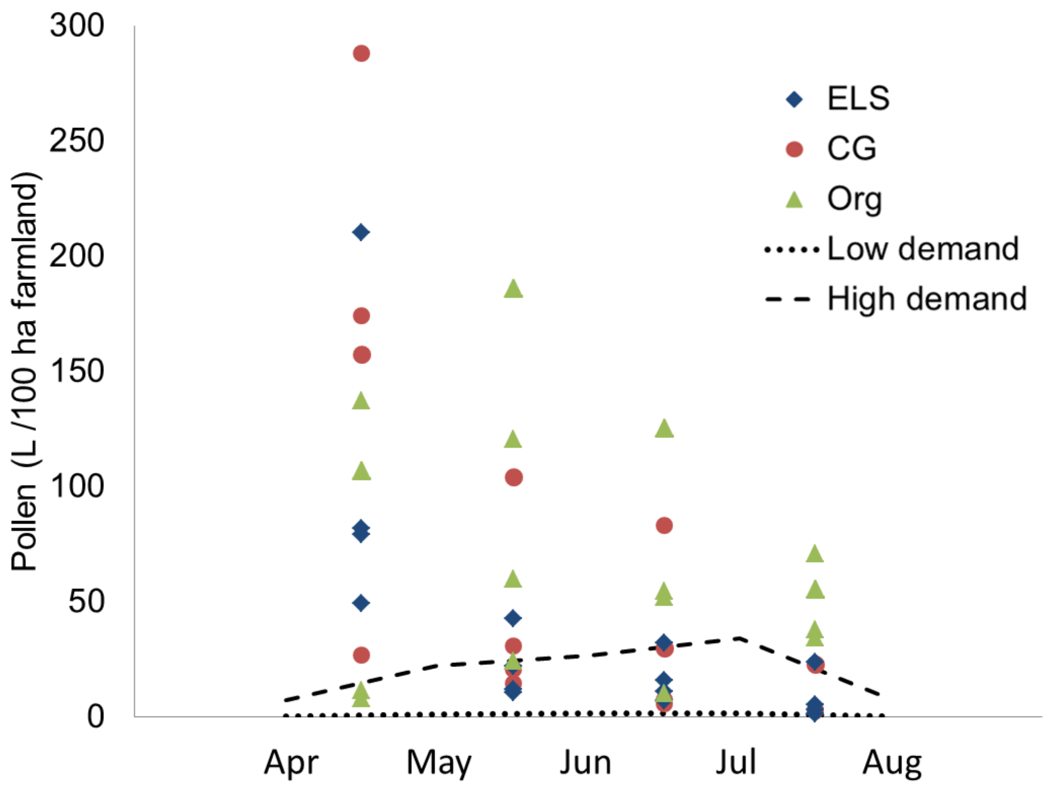

Figure 5.2: Estimates of pollen supply and demand on twelve farms in three wildlife-friendly farming schemes (CG=Conservation Grade, ELS=Entry Level Stewardship, Org=Organic) throughout the season

5.4.5 Habitat contributions to farm scale density

The three habitats with the highest farm scale density of pollen across all scheme types and rounds were: 1) AES grass, 2) other (particularly woodland dominated by *Hyacinthoides non-scripta*) and 3) hedgerows. For nectar the habitats with the highest farm scale density were 1) other (particularly fallow dominated by *Tripleurospermum inodorum*), 2) cereal and 3) mass-flowering crop. Figure 5.3 shows the variation in farm-scale density of pollen, nectar and visitation between habitats, schemes and rounds. The figure shows that on organic farms, the density of pollen, nectar and visitation was spread more evenly between different habitat types. There was a significant interaction between habitat type and scheme in explaining pollen density (Appendix 23). Post-hoc tests revealed that organic cereal habitats supported a higher pollen density than CG or ELS cereal habitats ($p<0.001$ in both cases). For farm-scale nectar density, the effect of habitat type varied with scheme and round, and the effect of scheme varied with round. Post-hoc tests revealed that the nectar density of cereal habitats was higher on organic farms compared to farms in ELS or CG in round 4 (Appendix 23). There were significant interactions between habitat type, scheme and round in explaining visit density at the farm scale, but the post-hoc tests for the hypotheses of interest were not significant (Appendix 23).

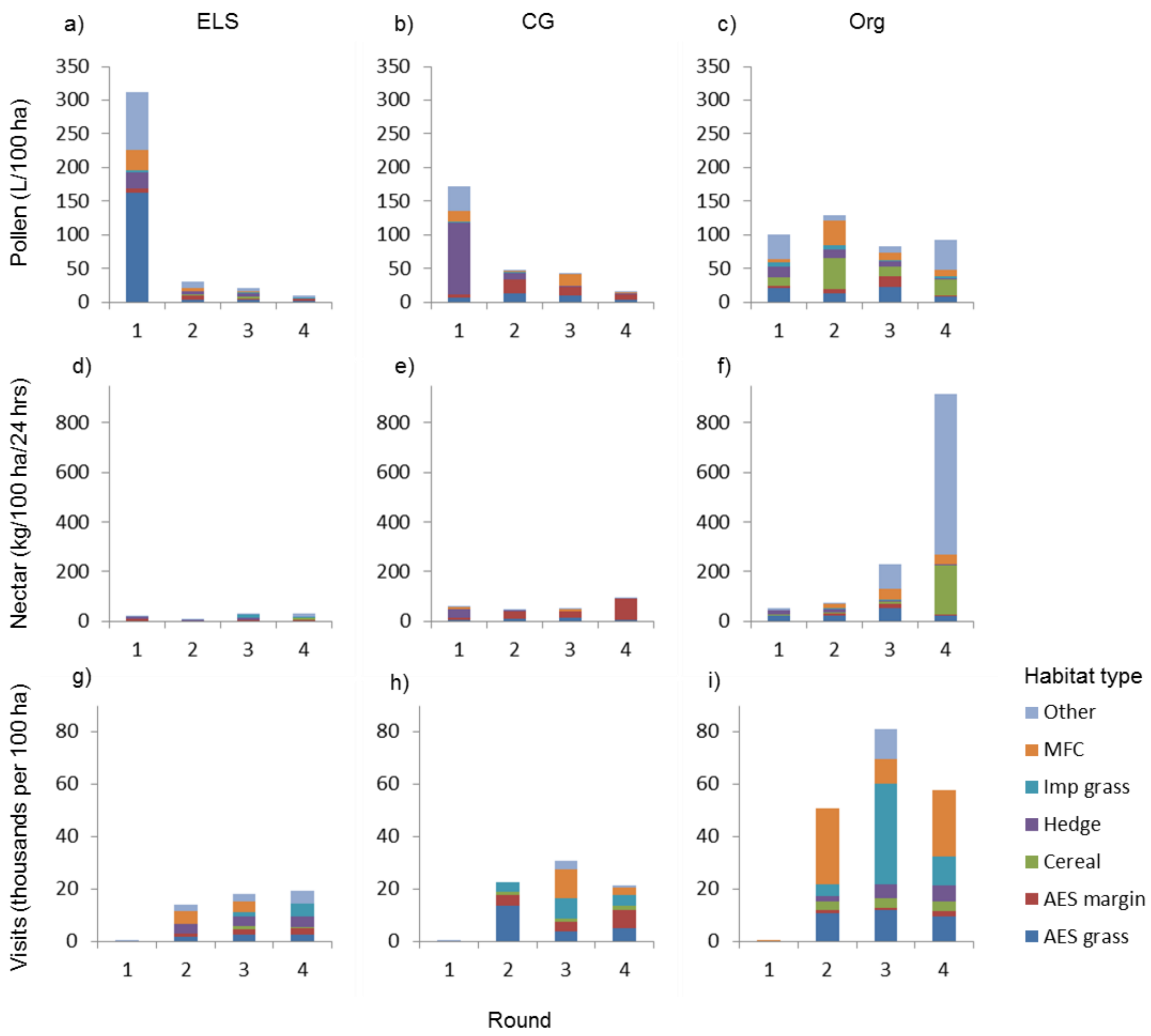

Figure 5.3: Mean farm scale (per 100 ha) density of pollen, nectar and visitation across four sampling rounds in different habitat types on farms in three different wildlife-friendly farming schemes. Sampling round 1 = April-May, 2= May-June, 3=June-July and 4=July-August. CG=Conservation Grade, ELS=Entry Level Stewardship, Org=organic, Other=fallow, woodland, game cover and tree planting, MFC=mass-flowering crop, Imp grass=improved grass, AES=agri-environment scheme.

5.4.6 Density of floral resource from individual plants at the farm scale

Scaling up to the farm scale increased the density of floral resource from plants in grassland and crop habitats (Table 5.3). These included the mass-flowering crops *Brassica napus* (oilseed rape), *Trifolium pratense* and *Trifolium repens* (red and white clover), which supported a particularly high density of nectar and visitation at the farm scale. Also the grassland species *Ranunculus repens* (creeping buttercup) and *Taraxacum agg.*(dandelion) appeared in the top five only when estimates were scaled up to the farm scale. *Tripleurospermum inodorum* was the top contributing plant to nectar density at the farm scale, contributing large amounts of nectar to cropped habitats including a fallow field on an organic farm (classed as 'other') as well as cereal and mass-flowering crop habitats.

5.5 Discussion

5.5.1 Farm-scale floral resource supply and bee-flower visitation

This paper is the first attempt to quantify floral resource supply at the farm scale. Compared to the low estimates of pollen demand, all CG and organic farms provided sufficient pollen through the season, but one ELS farm did not. CG farms did not support significantly higher densities of floral resources or visits than ELS and this appeared to be due to considerable variation in delivery between CG farms. However, CG and organic farms outperformed ELS in delivering a greater species richness of insect-rewarding plants. Overall, organic farms outperformed CG and ELS in terms of delivering higher late-season pollen, higher overall nectar and more bee-flower visits at the farm-scale.

Organic farming is commonly found to benefit insect-pollinated plants (Gabriel and Tscharntke, 2007, Power et al., 2012, Batáry et al., 2013) and pollinators (Holzschuh et al., 2008, Tuck et al., 2014). As predicted, organic cereal habitats provided a higher density of floral resource than non-organic cereal habitats. The mechanism by which organic agriculture benefits plants is likely to be through a combination of restricted herbicide use (Rundlöf, Edlund & Smith 2010) and a lack of synthetic nitrogen (Kleijn *et al.* (2009). Our study provides strong evidence that organic agriculture benefits pollinators by increasing the amount of foraging resource, but an additional mechanism by which organic farming benefitted bees could be the lack of insecticide use on these farms (since pesticides such as neonicotinoids have been found to have negative effects on bumblebees and solitary bees in the field (Rundlöf *et al.* 2015)). Three-quarters of our organic farms were in HLS, which may have exaggerated the differences we have recorded between organic and ELS. However three-quarters of the CG farms were also in HLS, so the differences between organic and CG farms are likely to be due to the organic standards. Despite covering a small proportion of the agricultural land area in England, our study suggests that organic HLS land makes a large contribution to landscape level floral resources.

Contrary to expectations, it was the late-season period when pollen supply dropped below demand, particularly on ELS farms. Pollen from hedgerows declined over the season and the late season flowers in other habitats, such as AES margins and grass were not sufficient to maintain pollen density. Late summer is an important time of year for the production of new reproductive bumblebees. The exact timing varies between species and in the UK bumblebee species tend to start male production between May and August and finish between September and November. Declines in late-season floral resource and associated declines in bumblebee abundance have been recorded in simplified landscapes in Sweden, where the area of ley (often containing clover), area of permanent pasture and herbaceous flower abundance were key variables determining late season bumblebee abundance (Persson & Smith 2013). In England, field margins sown with pollen and nectar mix have been designed to supply late season floral resource and have performed well in supporting bumblebees when compared to other field margin types (Pywell *et al.* 2005). Surprisingly AES margins were not a top habitat at the local or farm scale in our study. This suggests that the quality and quantity of pollen and nectar mixes should be improved in the wider landscape. The only plant species recommended in the EF4 pollen and nectar mix that was a top contributor to floral resource was *Trifolium pratense,* but this was in large part due to its prevalence on organic farms.

The importance of different habitats for supplying floral resources in the farmed landscape depended on the spatial and temporal scale at which they were being examined. As predicted, hedgerows supplied a high density of floral resource and this was important at both local and farm scales. There was some complementarity between hedgerows and AES margins in the timing at which floral resources peaked, with hedgerow resources declining as AES margin resources increased. The contribution of 'other' habitats was surprisingly high. These were habitats which were not included in agri-environment schemes and were specific to individual farms. One organic farm which had left an arable field fallow had a particularly high density of nectar from *Tripleurospermum inodorum*. This illustrated how management decisions that affect whole fields can have large effects on the total floral resource at the farm scale. The process of scaling up increased the importance of habitats which cover large areas such as grass, mass-flowering crop and cereals. This was particularly important on organic farms which had around 20% of farm area as AES grass (Chapter 2, Table 2.3) and had cereal habitats that supported a higher floral resource than on non-organic farms. The top five plants in terms of pollen, nectar and visitation were quite different at local and farm scales (Table 5.3). This reflects the patchy distribution of some pollen and nectar rich plants.

5.5.2 Uncertainty in estimates and future directions

Our estimates of pollen and nectar supply come with a large degree of uncertainty, as do the estimates of pollen demand (Dicks *et al.* 2015). Both supply and demand estimates suffer from error propagation due to the product equations used in estimation. Standard errors could not be estimated here due to incomplete data on the variance of each variable in the floral resource calculations. We did not have sufficient data to quantify variation in floral resource density within individual plant species and habitats through the season and between sites. Important next steps will involve exploring the sensitivity of the supply and demand estimates to changes in the various parameters. Expanding the pollen demand estimates to include a greater range of bee species will also be an important topic for future research.

Our results suggest that collecting further data on pollen and nectar contents of plant species is an important area of future research, because this was a source of particularly high variance. Collecting data on pollen and nectar quality will also be very important. The list of insect-rewarding plant species is likely to be revised as new data comes to light on bee diets. Further work will involve identifying the plants frequently used by bees, by analysing pollen from pollen sacs (e.g. Carvell *et al.* 2006b) and quantifying the pollen densities provided by these plants. Species that are mainly wind-pollinated may be added. Floral resource estimates from trees and hedgerows in this study were likely to be less accurate than those from other habitats, due to the difficulty in counting the number of flowers in tall hedgerows. Also, some early season pollen sources will have been missed in this study due to the first round of sampling taking longer than planned.

In this study we made several assumptions. By scaling up from transects to the farms, we assumed that the density on transects represented the density from the whole habitat, and that we sampled all the habitats on the farm that would support pollen, nectar and visits. In reality, the distribution of pollen, nectar and visits will have been patchy and though our sampling strategy was thorough, some important foraging habitats will have been missed, such as road verges. We assumed that open flowers contained 100% of the pollen that they contained upon first opening, whereas in reality some of this will have been depleted. We assumed plants providing high densities of pollen and/or nectar would be beneficial to bees. In reality, there are morphological, phenological and nutritional constraints over what foraging resources insects use, along with different preferences. For example, bumblebee species have been recently discovered to vary in their ability to exploit high and low quality pollen sources (Somme *et al.* 2014). High sugar concentrations in nectar can hinder insect feeding because the nectar is so viscous (Harder 1986), so plants with very high nectar concentrations will not necessarily be the most attractive to bees. Taking into account accessibility of flowers and phenology, the time of year when pollen is most limiting may change. Future work to estimate nectar demand would allow us to evaluate the extent to which farms in different schemes supply sufficient nectar. Extending such research on floral resource supply and demand to non-bee flower-visitors, such as Diptera and Lepidoptera, will also be important.

This study provides an insight into the spatio-temporal dynamics of floral resources within the farm, but landscape scale dynamics are also very important. A better understanding of the interactive effects of floral resources on pollinators between farms and the surrounding landscape and between successive years is developing (Riedinger et al., 2015, Scheper et al., 2015). Further work to apply floral resource estimates to larger landscape areas across multiple years will enhance our understanding of these processes. Evidence that floral resource enhancement on farms has population level benefits for some bumblebee species has recently been found (Wood *et al.* 2015), however the extent to which this approach will benefit all pollinators is debatable, since some may be more limited by nesting resources.

5.5.3 Management applications

Improving late summer floral resources on ELS and CG farms could be achieved by increasing the area of AES margin or AES grass and/or by improving the density of resource provided on the existing area. Floristically enhanced field margins need careful management to promote high quality and this typically involves cutting or grazing in April and September each year, followed by completely re-seeding after 3 years. There is strong evidence showing that flower strips in both croplands and grasslands had a positive effect on species richness of pollinators (Scheper *et al.* 2013), as did naturally regenerated grass field margins and extensive grasslands. In grasslands, summer resting periods in cutting and grazing regimes are important management tools for prolonging the seasonal continuity of floral resources (Woodcock *et al.* 2014).

Our study suggests that the farm scale gains in floral resource and bee visitation to changing management of cropped areas could be large. This could include incorporating clover leys into the farm rotation or reducing herbicide use. Fields of red clover increased bumblebee population persistence in agricultural landscapes by providing floral resources when bumblebee colonies are producing new males and queens (Rundlöf *et al.* 2014). Reducing the use of herbicides will support a larger species pool of plants, which makes it more likely that at any one time a rewarding plant is available for generalist bees to forage on. Large-scale herbicide reduction programmes are predicted to have beneficial effects for pollinators (Bretagnolle & Gaba 2015). However this approach may need spatial targeting, since a European meta-analysis showed that organic farming was found to be beneficial for pollinators in croplands but not in grasslands (Scheper *et al.* 2013).

Farm management should aim to ensure seasonal continuity of resources to support bumblebee and solitary bees throughout their life cycles. Ensuring that a range of different habitats provide floral resources is one way of achieving this. This means that agricultural activity on one habitat (e.g. cutting or harvesting), will not eliminate the entire floral resource provided by the farm. The greater spread of floral resources between different habitats on organic farms in this study is likely to have provided complementarity in floral resources, reducing the dramatic pulses and gaps in resource supply commonly found in intensive agricultural landscapes (Mandelik *et al.* 2012).

Hedgerows emerged as a space-efficient way of supplying floral resource in intensively-farmed landscapes. They provided early-season pollen from *Crataegus monogyna* and supported late-season bee visits to *Rubus fruticosus agg*. Hedgerows have been a popular way of enhancing pollinators in California, because they do not require land to be taken out of production (Morandin & Kremen 2013). How hedgerows are managed has an important effect on their value for bees and reducing cutting from annually to once every three years doubles the abundance of flowers (Staley *et al.* 2012).

5.5.4 Conclusion

In this study we aimed to quantify the supply of pollen and nectar and the density of bee-flower visits at the farm-scale for farms in different wildlife-friendly farming schemes. We explored seasonal variation in floral resources and the contribution of different habitats and plants. The results have shown that organic farming supported higher density of nectar and bee-flower visits, and that late-season pollen resources are likely to be insufficient on non-organic farms. The findings suggest that non-organic wildlife-friendly farming schemes need to increase provision of floral resources later in the season.

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Chapter 6: Discussion

6.1 Study aims

The aim of this thesis was to compare the effectiveness of three contrasting wildlife-friendly farming schemes, Entry Level Stewardship (ELS), Conservation Grade (CG) and organic farming, for supporting biodiversity and pollination services. This was a novel comparison that improved our understanding of the effectiveness of prescriptive non-organic schemes compared to organic agriculture. Habitat diversity, floral resources and species richness of several taxonomic groups were measured at both farm scales and sub-farm scales. The proportional stratified sampling design took into account farm habitat composition. The study included a first attempt at quantifying the seasonal supply of floral resources at farm scales.

The first research question (Chapter 3) asked **how effective the three wildlife-friendly farming schemes were in supporting a diversity of habitats and species**. To evaluate species diversity we collected data on plants, butterflies, solitary bees, bumblebees, and birds in winter and summer. The spatial scale at which habitat diversity most strongly correlated with species richness of these taxonomic groups was a knowledge gap we also explored.

The second research question (Chapter 4) asked **how the schemes compared in their spatial provision of floral resources, pollinators and pollination services**. We focused on pollination as an example of an ecosystem service, because it has a close link with biodiversity, it is important for global food production and terrestrial ecosystem function, and it is currently a major policy focus. We compared the schemes in terms of how effectively they supported floral resources, pollinators and pollination services. The novelty in our approach was to examine spatial variation by sampling in proportional stratified design that reflected the entire habitat composition of the farm (crop and non-crop habitats).

The third research question (Chapter 5) asked **how the seasonal supply of floral resources and the density of bee-flower visitation varied between schemes**. In answering this question we estimated supply of pollen and nectar at the farm scale and compared it with estimated pollen demand from the literature. This is an important emerging area of research because policymakers are interested in how much flower-rich habitat is needed to support pollinators.

6.2 Synthesis of key findings

Chapter 3 revealed that CG and organic farms supported higher local habitat diversity than farms only in ELS. Local habitat diversity was most significantly correlated with the species richness of plants and butterflies of all the taxa tested. Butterfly species richness was significantly higher on organic farms and marginally higher on CG farms. Plant species richness was significantly higher on organic farms. Bird species richness in winter showed a significant positive correlation with local habitat diversity but did not differ between scheme types. Solitary bee species richness showed a significant positive correlation with local scale habitat diversity and a significant negative correlation with landscape scale habitat diversity.

An emerging theme was the effectiveness of organic farming in supporting a diversity of plants and an abundance of insect-rewarding flowers. Organic farms supported a higher species richness of plants (Chapter 3) and a more even spatial distribution of floral resources (Chapter 4). Crop habitats on organic farms supported a higher density of floral resources than on CG or ELS farms and similar differences were found for insect-flower visits and pollination services (Chapter 4). CG farms supported higher plant species richness than ELS when a wider seasonal period was surveyed (Chapter 5 compared to Chapter 4). However the total number of insect-flower visits was higher on both CG farms (Chapter 4) and organic farms (Chapter 5) compared to ELS. Species richness of bees did not show a significant response to scheme type (Chapters 3 & 4). Pollination services were highest on organic farms overall (Chapter 4).

When examining pollen supply and demand, only organic farms provided sufficient pollen to meet the estimated maximum demand in late summer (July/August, Chapter 5). Organic farms were estimated to supply higher densities of nectar compared to CG and ELS. Hedgerows and mass-flowering crops made particularly important contributions to supplying pollen and nectar. When scaled up to the farm scale, habitats which covered large areas such as AES grass and organic cereals increased in importance as floral resource providers.

6.3 Interpretation of key findings

6.3.1 Habitat diversity

Our results suggest that flexible schemes (such as ELS alone) will tend to support a lower diversity of habitats and species compared with farms in more prescriptive schemes (such as CG) or farms under organic management. The ELS scheme was sufficiently flexible that farmers could choose options where they largely continued existing management. In contrast the CG and organic schemes required farmers to change management. CG farmers are required to create a range of different habitat blocks, including some with specific sown plant mixtures. We categorised non-crop habitats using Environmental Stewardship options, since this approach was applicable across all farm types. The CG schemes in our study supported a higher number of habitat types (when classified as HLS options) compared to organic farms. This is likely to be representative of the 56% of CG farms nationally that are in HLS. Even the CG farms not in HLS are expected to have higher habitat diversity due to the requirements of the CG protocol. Organic farms had significantly smaller fields than farms in CG or ELS, which is the most likely explanation for the higher habitat diversity on organic farms compared to ELS. Organic farming typically involves diverse crop rotations and mixed farming which are facilitated by several small fields rather than a few large ones (Hole *et al.* 2005). Therefore, despite not including creation of a range of habitat blocks in its definition, organic farming is likely to maintain or increase habitat diversity.

6.3.2 Species diversity

The most sensitive taxonomic groups to variation in scheme type and local habitat diversity were butterflies and plants (Chapter 3). Other studies have found butterflies and plants to respond very quickly to changes in farm management (Jonason *et al.* 2011). Plant-feeding taxa were found to benefit more strongly from organic cereal farming than predatory taxa across 28 European studies covering farmland birds, spiders, ground beetles, butterflies and moths (Birkhofer *et al.* 2014). Bumblebees and birds showed no significant relationships with local habitat diversity or scheme type in our study, probably due to the larger scales at which they forage compared to butterflies (Chapter 3). Higher habitat diversity (measured at 1, 9 and 25 km^2 spatial scales) was associated with higher abundances of birds for 66-75% of the farmland species examined (Pickett & Siriwardena 2011). However some specialist and declining farmland bird species were more common in less diverse landscapes. This highlights a more general point: the scale and extent of habitat diversity enhancement that policy aims for depends on the conservation target.

6.3.3 Spatial variation in floral resources

A greater variety of habitats contributed to providing floral resources on organic farms, including crop habitats. By contrast, on non-organic farms, crop habitats had very low floral resource provision in late summer (Chapters 3 and 4). These results suggest that organic arable farming could make an important contribution to landscape scale conservation, by providing floral resources on a large scale, and providing a less hostile matrix for pollinators to travel through. There is evidence that landscapes with a higher proportion of organic crops sustain higher density and species richness of bees in fallow strips in Germany (Holzschuh, Steffan-Dewenter & Tscharntke 2008). Landscapes with more organic farms tend to support higher weed diversity on conventional farms within the same landscape (Rundlöf, Edlund & Smith 2010**,** Henckel *et al.* 2015). Landscapes with a high proportion of organic farming have been found to support higher species richness of multiple taxonomic groups compared to landscapes with a low amount of organic farming (Gabriel *et al.* 2010)**.**

6.3.4 Spatial variation in pollinators

By sampling in all habitats, we revealed a difference in the spatial distribution of insect-flower visits. Organic farms had a more even distribution of insect-flower visits across both crop and non-crop habitats (Chapter 4). This agrees with findings from Germany in which the density and diversity of flower-visiting bees was higher in organic than in non-organic cereal fields (Holzschuh *et al.* 2007). Organic farms supported the highest density of bee-flower visits in 2014 when scaled up to the farm-level (Chapter 5), whereas CG farms supported the highest number of insect-flower visits on the total transect length in 2013 (bees and hoverflies, Chapter 4). Due to the different methodologies used to answer the different research questions (Chapters 4 and 5), and the limited number of years available, it is not possible to make multi-year inferences about variation in insect-flower visitation between schemes.

With the higher diversity, density and more even coverage of floral resources on organic farms (Chapters 4 and 5), we may expect that there would have been a higher diversity and density of insect pollinators overall (Chapters 3 and 4). However this was not the case. This probably reflects the mobile nature of insect pollinators, particularly large-bodied bees (Greenleaf *et al.* 2013), which were using habitat at a larger spatial scale than single farms. This could also have been a methodological constraint since transect and pan trapping methods did not just record insects using the habitat, but could have recorded insects flying between other habitats outside the farm boundary, making it difficult to examine the influence of farm management.

6.3.5 Spatial variation in pollination services

We found that organic farms supported a higher level of pollination service overall compared to farms in ELS or CG (Chapter 4) and that organic crop fields supported a higher pollination services than CG or ELS crop fields. Pollination service was correlated with local floral density in our study, and the local density of flowers was also found to be an important correlate of visitation to phytometers in a study in Sweden (Ekroos *et al.* 2015). These results suggest that the enhanced pollination service on organic farms was mediated by the higher local density of flowers. Our results suggest that organic farms play an important role in facilitating pollination services to wildflowers. This fits with evidence showing a higher prevalence of insect-pollinated plants on organic farms (Batáry *et al.* 2013).

6.3.6 Seasonal floral resources and insect-flower visits

Although the pollen demand estimates of Dicks *et al.* (2015) still contain a high degree of uncertainty, our results suggest that organic farms are more likely to meet pollen demands of important crop pollinators than ELS or CG farms, particularly late in the summer. This means that there is an opportunity for non-organic farms to improve delivery of late summer floral resources. Scaling up to the farm scale increased the contribution of habitats that cover large areas, such as AES grass, mass flowering crops and cereals. This suggests that schemes should consider the upscaling potential of different management options for pollinators and perhaps encourage options which are likely to deliver large areas of floral resources in late summer. The contribution of floral resources from AES margins was lower than expected, so this could be a focal habitat for management to improve floral resource provision.

6.4 Recommendations

6.4.1 Management recommendations

6.4.1.1 Maximising habitat diversity

Based on our results, we recommend that farmers aim to maximise habitat diversity in order to provide a full complement of resources for a range of species (Chapter 3). This can be done by varying management practices and seed mixes between field margins. Some margins could be sown with perennial wildflower species, as found in traditional hay meadows, and others with the more common and less diverse legume based ‘nectar flower’ mix prescribed in ELS. Higher habitat diversity could also be achieved through diversifying crop rotations or by restoring hedgerows and sowing field margins to create smaller fields and increase the area of non-crop habitat.

6.4.1.2 Improving spatial coverage of floral resources

Weeds in organic cereal fields emerged as important habitats for providing late season floral resources (Chapter 5) and supporting a more even distribution of pollination services (Chapter 4). There is potential to increase weed populations in agroecosystems whilst still achieving high yields, through carefully managed herbicide-reduction programmes (Bretagnolle & Gaba 2015). Along with supporting pollinators, this could have additional benefits, such as reducing herbicide-resistance in weeds and supporting natural enemies. However a further understanding of the potential ecosystem disservices that such as programme may provide, such as yield loss due to pernicious weeds, needs to be developed (Wood *et al.* 2015). Our results also indicated that habitats which cover large areas such as AES grass and mass flowering crops can make large contributions at farm scales to total floral resource provision. Therefore incorporating floristically-enhanced pastures or legume leys into crop rotations is encouraged.

6.4.1.3 Improving seasonal continuity of floral resources

Our results showed that farmers in the CG and ELS schemes could improve the supply of pollen in July/August (Chapter 5). The supply of floral resource from AES margins and AES grass habitats was lower than expected (Chapter 5, Fig.3, Table A.6). The quality and/or quantity of pollen and nectar rich habitats could be improved through farmers following management guidelines more closely (e.g. Natural England 2011), particularly cutting in June to promote late season flowering. Seed mixes may need revising to include more pollen-rich plants which flower in late summer. Red clover leys could be incorporated into crop rotations, which have been shown to benefit bumblebees in Sweden (Rundlöf *et al.* 2014). In addition, hedgerows and field margins should not all be cut at once, in order to help maintain seasonal continuity of floral resources.

6.4.2 Policy recommendations

6.4.2.1 Option packages

The results of this study support schemes which include compulsory option packages (combinations of habitat management options), such as the CG scheme. Option packages should increase habitat diversity and this is likely to be associated with a higher species richness of plants, butterflies, solitary bees and winter birds (Chapter 3). The new mid-tier Countryside Stewardship scheme in England gives preference to applicants who agree to deliver habitat prescriptions from the "Wild Pollinator and Farm Wildlife Package". This package includes complementary habitat options that provide foraging, nesting and shelter resources for pollinators and farmland birds.

6.4.2.2 Organic farming

Based on the higher floral resource provision and pollination service potential found on organic farms, continued support for organic farming through agri-environment schemes is recommended. The possibility of including more organic-style management options into the non-organic AES is an area that future policy could explore. One option in the new Countryside Stewardship mid-tier which appears to fit the recommendations of this study particularly well is "legume and herb-rich swards" for pastoral and mixed farms. This option involves planting a mix of legumes, grasses, herbs and wildflowers which can be grazed. It must contain a minimum of 10% red clover and requires a cutting regime which aims to provide late season foraging resource for bumblebees (Natural England 2015). This option is likely to improve late season pollen supply, which our study showed was potentially limited on non-organic farms. Pesticide use is not permitted on the swards, which is likely to benefit pollinators since pesticides such as neonicotinoids have been found to have lethal and sub-lethal effects on bees (Goulson *et al.* 2015, Rundlöf *et al.* 2015). Neonicitinoids may be present in pollinator foraging resources created on arable farms since these compounds have been found to persist in soil and be present in field margin vegetation next to arable crops (Krupke *et al.* 2012).

6.4.2.3 Spatial scale

Coordination of agri-environment schemes at landscape scales seems wise, based on a lack of significant effects of local habitat management on bumblebees and birds found in this study, and evidence from the wider literature. A third of important farmland species in England are estimated to operate at scales larger than the average farm size (McKenzie *et al.* 2013). Analysis of spatial species turnover of bees (the change in species composition between sites) showed that a 50 km^2 area as the scale at which turnover was steepest (equivalent to a 4 km radius, Rollin *et al.* 2015). This led the authors to conclude that for French landscapes, this is the size of spatial unit at which conservation efforts (such as maximising the area of semi-natural habitat) should be focused on. Furthermore, landscape composition was found to be more important than farm management in explaining variation in bird abundance across 16 landscapes in England (Gabriel *et al.* 2010). Countryside Stewardship could achieve landscape scale implementation of AES, because it has encouraged collaborative applications. Uptake of the collaborative schemes has not yet been published, but interviews in Britain in 2012 showed that 75% of farmers across three survey areas were willing to participate in collaborative schemes (McKenzie *et al.* 2013). How widespread and effective collaborative schemes will be remains to be seen.

6.6 Methodological constraints

6.6.1 General study design

This study was limited by a low number of farm-level replicates of each scheme type, which made the sample size low at the farm-scale, which was a particular limitation in evaluating effects of the scheme on taxa with large ranges (such as bumblebees and birds). The study aimed to compare CG farms with organic and ELS, which made finding suitable matched triplets very difficult (Chapter 2). If the study had focused on one two-way comparison (either CG vs. ELS, or organic vs. ELS), then the number of farm-level replicates could have been higher. However one advantage of our study design was that it allowed within-farm variation to be explored in detail. The first year of sampling showed more within-farm variation in bee species richness than between farms or between regions (Appendix 20). Therefore we maximised the number of sampling points within each farm, rather than maximising the number of farms or regions. This allowed us to make detailed inferences about the floral resources provided by the various habitats within each scheme and how these varied in space and time.

6.6.2 Site selection

It is possible that greater benefits of the CG scheme compared to ELS would be found if a larger number of paired sites (CG vs. ELS) were sampled. Also, it is possible that a larger impact of the CG scheme would have been found if more homogeneous landscapes had been sampled, since we found a higher species richness of solitary bees on farms in more homogenous landscapes (Chapter 3). This study was carried out in southern England and the patterns observed may differ in other parts of the UK and Europe with different land use histories. Additionally, we were sampling in HLS target areas (Chilterns, North Wessex Downs and South Downs) and the presence of HLS schemes on the CG and organic farms may have exaggerated the differences seen between CG vs. ELS and organic vs. ELS.

6.6.3 Habitat diversity at landscape scales

The effects of landscape habitat diversity on species richness are likely to have been underestimated in this study. This is because landscape scale habitat diversity was quantified at a coarser scale than local scale habitat diversity (land use maps with a minimum mappable unit of 0.5 ha). Also the maximum buffer radius used was 3 km, but positive effects of landscape habitat diversity on insect-pollinated plant species richness have been found at the 5km spatial scale (Power, Kelly & Stout 2012). Our study was not designed to quantify the effects of landscape habitat diversity on farm or landscape scale species richness.

6.6.4 Pollinator surveys

We used two methods to survey pollinators (pan traps and transects with net sampling), because the methods are generally thought to complement each other. Pan traps are known to under-sample bumblebees and solitary bees in the genus *Colletes* (Roulston, T'ai H., Smith, Stephen A. 2007). Transects are better for recording bumblebees, and give information on the use of floral resources by bees (Popic, Davila & Wardle 2013). However transects suffer from more observer bias than pan traps (Westphal *et al.* 2008), and are likely to under-record solitary bees. The amount of observer error in the transect surveys is likely to have declined throughout the multiple years of this study, due to improved observer experience. However, between-year comparisons were not made and pan trap surveys were carried out in addition to transects, so this is not thought to have compromised the reliability of the results. This study did not explicitly examine the effect of the previous year's floral resources on pollinators, which is a factor that has been found to be important in other studies (Potts *et al.* 2003, Riedinger *et al.* 2015).

6.6.5 Pollination services

Phytometers provide a general measure of pollination service potential; however they do not give us information about specific pollination services to crops, or wildflowers. The species that we used was an open access flower not naturally found in the environment. It is likely to have been used by generalist pollinator species such as short-tongued bees or hoverflies. It may have been more likely to be used by pollinator species with a greater preference for novel plants. There is some concern over the use of phytometers due to their flowers being potentially more attractive when located in a floristically-poor surrounding habitat. However our data did not show any indication of this being the case, since pollination service was positively correlated with local flower density (Chapter 4).

6.7 Further work

With more resources, a larger study could be carried out which includes farms in HLS only and farms not in Environmental Stewardship at all, to investigate the individual and combined effects of wildlife-friendly farming schemes currently in place in England. Ideally, we would use a before-after-control-impact design to evaluate the impacts of schemes. This would involve sampling a number of matched pairs of sites that had not yet entered schemes, then randomly assigning scheme entry to one site in the pair. Sampling would be carried out before and after scheme entry. This approach may be possible for looking at the effects of individual management options (e.g. Scheper *et al.* 2015), but for whole-farm schemes it is not feasible.

It would be interesting to test how far the different schemes influence the farmer's motivations and how far this influences choice of options and quality of habitat created. The CG scheme involves advice upon joining the scheme, as well as biannual visits to other CG farms. At these "CG Technical Updates", farmers hear a series of talks on the latest agri-environmental policy and management news and scientific research. Farmers take it in turn to host the training days, giving them a chance to view habitats on other CG farms, talk with advisors and compare notes on management techniques. Whether this process results in higher motivation and better quality habitat creation remains to be tested for CG farmers compared to ELS farmers. Evidence from ELS farmers growing nectar flower strips and wild bird seed mixtures shows that more experienced farmers produce habitats with greater floral and seed resources (McCracken *et al.* 2015). This study also highlighted that wildlife-friendly motivations and an understanding of the challenges involved in habitat management were important for successful habitat delivery. Both of these attributes are likely to be higher in CG farmers due to their attendance at farmer training events.

To extend the comparison further, it would be interesting to look at the contributions to food production that farms in each scheme make. This work would attempt to quantify the calories, protein and profit that each farm produces. Such a comparison would need to be long-term to take into account the more complex crop rotations involved in organic farming (Norton *et al.* 2009). It would involve including all the food products that a farm produces, since organic farms often produce a diverse array of products. It would need a larger sample size, and better matching of farms in terms of production types, than was achievable in this study. However such a study would reveal whether CG farming offers the best compromise in terms of supporting both high-yielding farming and biodiversity. This would allow a better analysis of the trade-offs between biodiversity and yields which may be occurring within these farming systems. Additionally, a cost-benefit analysis could be carried out of the wider economic and environmental impacts of the various management suggestions that have been suggested for supplying floral resources.

Developing our understanding of wildlife foraging resource supply and demand in agroecosystems would be particularly interesting, and relevant to informing policy. For bees, the estimates of pollen demand could be improved by including more bee species and better representing colony dynamics. Estimates of pollen supply could be improved extending sampling to more plant species and more populations. A better understanding of the plant species used by bees for pollen will be an important next step in improving the relevance of the pollen supply estimates. It is possible that the high early season pollen supply is from flowers that are not accessible to the bees which are flying at this time. Estimates of nectar supply will also be important for understanding the extent to which floral resource provision in agricultural landscapes is meeting demand.

Models that include foraging resource estimates have been found to outperform habitat models in explaining responses of birds to AES management (Ponce, Bravo & Alonso 2014). The provision of bird foraging resources on CG, ELS and organic farms could be investigated by collecting data on seeds, fruits and chick food invertebrates. Further information on habitat use by birds would provide a better insight into how far the different schemes support birds. For example territory mapping could be carried out over several years, to gather data on breeding densities for priority farmland bird species on farms in the different schemes.

I have focused on floral resources, which are considered to be a key limiting factor controlling bee populations, but nesting site abundance and incidental risks such as tillage, predators, parasites and pesticides are also likely to be important and are currently understudied (Roulston & Goodell 2011). An investigation of the extent to which difference schemes provide nesting resources for both bees and birds will be an interesting area of future research. For many species of solitary bee, bare ground is an important nesting resource (Potts *et al.* 2005,Hopwood 2008) and there is evidence that digging shallow bays to create bare earth provides nesting habitat for a range of solitary bees in England (Gregory & Wright 2005). Experiments to determine the potential benefits of including such options in new AES will be an important area of future work.

For pollinators and pollination services, there are various directions in which further study could develop. A longer-term study of pollinator foraging and the spatio-temporal dynamics of floral resource provision would be interesting. Initial evidence suggests that the history of crop rotation is important for solitary bees (Le Féon *et al.* 2013), so the longer term impacts of organic farming systems on pollinators deserve more investigation. Given the detailed species-level data on bee communities collected in this study, an interesting next step would be to analyse whether the wildlife-friendly management carried out on organic and CG farms tends to benefit pollinators with certain functional traits. There is evidence to show that the pollinators most sensitive to land-use intensity increases are those “with a narrow diet breadth, large body size, solitary behaviour, and a preference for non-floral food resources” (Rader *et al.* 2014) and it would be interesting to see how far farms in wildlife-friendly farming schemes support species with these traits.

For the pollination service data, further work could use a spatially explicit analysis to try to understand what the key habitat correlates of pollination service were. This could include distances to specific habitats, or presence of certain other plants nearby which were attracting potential pollinators of the phytometers. To provide information about pollination services to specific crops, a study examining the impact of the CG scheme on oilseed rape pollination would be particularly interesting. Sown flower strips can enhance pollination services in neighbouring crops (Blaauw & Isaacs 2014). If the pollen and nectar rich field margins could enhance pollination services to oilseed rape, reductions in nitrogen application might be achievable whilst maintaining yield (Marini *et al.* 2015). This would be an example of ecological intensification (Bommarco, Kleijn & Potts 2013).

6.8 Concluding remarks

This study has compared different wildlife-friendly farming strategies within the UK. Taking a global perspective, land-sparing has an important role to play in biodiversity conservation, by restricting further conversion of wildlife habitat to agricultural land (Phalan *et al.* 2011). However, our study focused on wildlife-friendly farming, which makes up the largest biodiversity conservation spending in Europe (Batáry *et al.* 2015). We found considerable benefits of organic farming for supporting plant diversity, butterfly diversity, foraging resources for pollinators and pollination service potential. Our results indicate that schemes which result in higher local habitat diversity are likely to have biodiversity benefits, particularly for plants and butterflies. Based on our findings we make recommendations for management and policy. Encouragingly, many of our recommendations are already part of the new mid-tier Countryside Stewardship scheme launched this year. This suggests that Countryside Stewardship should be more effective than ELS in delivering a greater diversity of habitats and quantity of foraging resources for pollinators and birds. However, as with all wildlife-friendly farming schemes, it will need careful implementation, monitoring and adaptive management to ensure it delivers cost-effective biodiversity conservation in agricultural landscapes.

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Appendices

Appendix 1: The years that each farm started in ELS (Entry Level Stewardship), OELS (Organic Entry Level Stewardship), HLS (Higher Level Stewardship), CG (Conservation Grade) or organic conversion

Farm	Scheme			
	(O)ELS	HLS	CG	Organic conversion
LW_CG	2009	2009	2006	
CS_CG	2005 (renewed in 2010)		2004	
CN_CG	2010	2012	2006	
HD_CG	2009	2009	2006	
LW_ELS	2007	2014		
CS_ELS	2010			
CN_ELS	2007			
HD_ELS	2007			
LW_Org	2007	2007		1999
CS_Org	2010	2012		1997
CN_Org	2007	2013		1998
HD_Org	2011	2011		1999

Appendix 2: List of on farm habitat categories, including descriptions of ELS, HLS and OELS codes

Habitat	Description
Farm map/cropping plan	
2m buffer	Grass buffer strip 2 metres wide
6m buffer	Grass buffer strip 6 metres wide
Arable silage	
Barley and peas	
Barley and peas and grass	
Clover	
Einkorn	
Fallow	
Game cover	
Grass/clover grazed	
Grass/clover silage	
Hedgerow	
Lucerne/sainfoin silage	
Maize	
Mustard	
One year fallow	
Peas	
Poppy	
Scrub	
Spring barley	
Spring beans	
Spring linseed	
Spring oats	
Spring wheat	
Stubble	
Tree planting	
Two year fallow	
WBC	Wild bird crop
Winter barley	
Winter beans	
Winter oats	
Winter OSR	Winter oil seed rape
Winter rye	
Winter spelt	
Winter spelt	
Winter wheat	
Woodland	
ELS codes	
EE3	6m buffer strips on cultivated land
EF1	Management of field corners
EF2	Wild bird seed mixtures
EF2NR	Wild bird seed mixtures (normal rotation)
EF4	Nectar flower mixture
EF7	Beetle banks
EK1	Take field corners out of management (on improved grassland)
EK2	Permanent grassland with low inputs
EK2/Tree planting	Permanent grassland with low inputs/Tree planting

EK3	Permanent grassland with very low inputs
HLS codes	
HC7	Maintenance of woodland
HD2	Take out of cultivation archaeological features that are
HE10	Floristically enhanced grass buffer strips (non-rotational)
HE3	6 m buffer strips on cultivated land
HF1	Management of field corners
HF13	Uncropped, cultivated areas for ground-nesting birds on arable
HF2NR	Wild bird seed mixture (normal rotation)
HF4	Nectar flower mixture
HK10	Maintenance of wet grassland for wintering waders and
HK15	Maintenance of grassland for target features
HK16	Restoration of grassland for target features
HK2	Permanent grassland with low inputs
HK3	Permanent grassland with very low inputs
HK6	Maintenance of species-rich, semi-natural grassland
HK7	Restoration of species-rich, semi-natural grassland
HK8	Creation of species-rich, semi-natural grassland
HO1	Maintenance of lowland heathland
HO2	Restoration of lowland heathland
OELS codes	
OE1	2m buffer strips on rotational land
OE3	6m buffer strips on rotational land
OF1	Management of field corners
OF2	Wild bird seed mixture
OG1	Undersown spring cereals
OK2	Permanent grassland with low inputs
OK3	Permanent grassland with very low inputs

Appendix 3: Number of sampling points per habitat per farm per year for pollinator surveys. Farm codes are regions (LW=Low Weald, CN=Chilterns North, CS=Chilterns South, HD=Hampshire Downs) and schemes (CG=Conservation Grade, ELS = Entry Level Stewardship, Org = Organic ELS).

Year	Farm code	Broad habitat category	Specific habitat category	Number of sampling points
2012	CN_CG	Non-MFC	Winter barley	1
2012	CN_CG	MFC	Winter beans	1
2012	CN_CG	AES margin	EF2	1
2012	CN_CG	Improved grass	Grass	1
2012	CN_CG	AES margin	HD2	1
2012	CN_CG	AES margin	HF1	1
2012	CN_CG	AES grass	HK16	1
2012	CN_CG	MFC	Peas	3
2012	CS_CG	AES margin	EE3	1
2012	CS_CG	AES margin	EF4	1
2012	CS_CG	AES margin	EF1	1
2012	CS_CG	Improved grass	Grass	3
2012	CS_CG	MFC	Linseed	1
2012	CS_CG	Non-MFC	Winter barley	1
2012	CS_CG	Non-MFC	Winter oats	1
2012	CS_CG	MFC	Winter OSR	2
2012	CS_CG	Non-MFC	Winter wheat	3
2012	CS_CG	Other	Woodland	1
2012	HD_CG	AES margin	EF2	1
2012	HD_CG	AES margin	HF12	1
2012	HD_CG	AES margin	HF13	1
2012	HD_CG	AES grass	HK8	1
2012	HD_CG	Non-MFC	Winter oats	1
2012	HD_CG	MFC	Winter OSR	1
2012	HD_CG	AES margin	EF4	1
2012	HD_CG	Non-MFC	Spring barley	1
2012	HD_CG	Non-MFC	Winter wheat	1
2012	HD_CG	Other	Woodland	1
2012	LW_CG	Non-MFC	Winter wheat	2
2012	LW_CG	Non-MFC	Winter oats	1
2012	LW_CG	Other	HC7	1
2012	LW_CG	AES margin	HE3	1
2012	LW_CG	AES grass	HK10	2
2012	LW_CG	MFC	Winter OSR	1
2012	LW_CG	AES margin	EF2	1
2012	LW_CG	AES margin	EE3	1
2012	CN_ELS	AES margin	EF1	1
2012	CN_ELS	AES margin	EF2	1
2012	CN_ELS	Non-MFC	Winter oats	1
2012	CN_ELS	MFC	Winter OSR	2
2012	CN_ELS	Non-MFC	Winter wheat	5
2012	CS_ELS	AES margin	EF1	1
2012	CS_ELS	AES margin	EF2NR	1
2012	CS_ELS	Improved grass	Grass	4
2012	CS_ELS	Non-MFC	Maize	1

2012	CS_ELS	MFC	Winter OSR	2
2012	CS_ELS	MFC	Poppy	2
2012	CS_ELS	Non-MFC	Winter wheat	4
2012	HD_ELS	AES margin	EE3	1
2012	HD_ELS	AES grass	EK3	2
2012	HD_ELS	Improved grass	Grass	1
2012	HD_ELS	MFC	Mustard	1
2012	HD_ELS	Non-MFC	Winter wheat	4
2012	HD_ELS	Other	Woodland	1
2012	LW_ELS	AES margin	6m buffer	3
2012	LW_ELS	Improved grass	Grass	1
2012	LW_ELS	Improved grass	Grass for silage	2
2012	LW_ELS	Non-MFC	Winter oats	1
2012	LW_ELS	Other	Overwinter stubble	1
2012	LW_ELS	Non-MFC	Winter wheat	1
2012	LW_ELS	Other	Woodland	1
2012	CN_Org	MFC	Clover	1
2012	CN_Org	AES margin	OE3	1
2012	CN_Org	AES margin	OF1	1
2012	CN_Org	AES grass	OK3	1
2012	CN_Org	MFC	Spring beans	1
2012	CN_Org	Non-MFC	Spring oats	1
2012	CN_Org	MFC	Winter beans	1
2012	CN_Org	Non-MFC	Winter spelt	1
2012	CN_Org	Non-MFC	Winter wheat	2
2012	CS_Org	Improved grass	Grass	3
2012	CS_Org	AES grass	HK15	2
2012	CS_Org	AES grass	HK16	1
2012	CS_Org	AES grass	HK6	1
2012	CS_Org	AES grass	HK7	2
2012	CS_Org	AES grass	HK8	1
2012	CS_Org	Non-MFC	Winter wheat	3
2012	CS_Org	Other	Woodland	2
2012	HD_Org	Improved grass	1st year ley	1
2012	HD_Org	Improved grass	2nd year ley	1
2012	HD_Org	Improved grass	3rd year ley	1
2012	HD_Org	Improved grass	Grass	1
2012	HD_Org	AES margin	HE10	1
2012	HD_Org	AES grass	OK3	1
2012	HD_Org	Non-MFC	Spelt	1
2012	HD_Org	Non-MFC	Spring barley	1
2012	HD_Org	Non-MFC	Winter oats	1
2012	HD_Org	Non-MFC	Winter wheat	1
2012	LW_Org	MFC	Barley and peas	1
2012	LW_Org	AES grass	HO1	1
2012	LW_Org	AES grass	HO2	2
2012	LW_Org	AES grass	HK10	1
2012	LW_Org	AES grass	HK6	1
2012	LW_Org	Improved grass	Grass	3
2012	LW_Org	AES grass	OK3	1
2013	CN_CG	Non-MFC	Barley	1

2013	CN_CG	AES margin	EF2	1
2013	CN_CG	Improved grass	Grass	1
2013	CN_CG	AES margin	HD2	1
2013	CN_CG	AES margin	HE3	1
2013	CN_CG	AES grass	HK15	1
2013	CN_CG	AES grass	HK16	1
2013	CN_CG	AES grass	HK17	1
2013	CN_CG	Non-MFC	Wheat	4
2013	CS_CG	Non-MFC	Winter barley	1
2013	CS_CG	AES margin	EF1	1
2013	CS_CG	AES margin	EF4	1
2013	CS_CG	Improved grass	Grass	2
2013	CS_CG	MFC	Winter OSR	1
2013	CS_CG	Non-MFC	Spring oats	1
2013	CS_CG	Non-MFC	Winter wheat	4
2013	CS_CG	Other	Woodland	1
2013	HD_CG	AES margin	EE3	1
2013	HD_CG	AES margin	HE3	1
2013	HD_CG	AES margin	HF13	2
2013	HD_CG	AES margin	HF4	1
2013	HD_CG	AES grass	HK7	1
2013	HD_CG	AES grass	HK8	2
2013	HD_CG	Non-MFC	Spring barley	1
2013	HD_CG	Non-MFC	Winter oats	1
2013	HD_CG	MFC	Winter OSR	1
2013	HD_CG	Other	Woodland	1
2013	LW_CG	AES margin	EE3	1
2013	LW_CG	AES grass	EK2	1
2013	LW_CG	Other	HC7	1
2013	LW_CG	AES margin	HF2NR	1
2013	LW_CG	AES grass	HK10	3
2013	LW_CG	Non-MFC	Maize	3
2013	LW_CG	Non-MFC	Spring oats	1
2013	LW_CG	Non-MFC	Winter oats	1
2013	CN_ELS	AES margin	EF1	1
2013	CN_ELS	AES grass	EK2	1
2013	CN_ELS	AES grass	EK3	1
2013	CN_ELS	Non-MFC	Winter oats	4
2013	CN_ELS	Non-MFC	Winter barley	1
2013	CN_ELS	Non-MFC	Winter wheat	4
2013	CS_ELS	Non-MFC	Winter barley	2
2013	CS_ELS	AES margin	EF1	1
2013	CS_ELS	AES margin	EF2NR	1
2013	CS_ELS	Improved grass	Grass	3
2013	CS_ELS	Non-MFC	Maize	1
2013	CS_ELS	MFC	Poppy	1
2013	CS_ELS	MFC	Winter OSR	1
2013	CS_ELS	Non-MFC	Winter wheat	2
2013	HD_ELS	AES margin	EE3	1
2013	HD_ELS	AES grass	EK3	3
2013	HD_ELS	Other	Fallow	2

2013	HD_ELS	Improved grass	Grass	1
2013	HD_ELS	Non-MFC	Spring barley	1
2013	HD_ELS	MFC	Winter OSR	2
2013	HD_ELS	Non-MFC	Winter wheat	1
2013	HD_ELS	Other	Woodland	1
2013	LW_ELS	AES margin	EE3	3
2013	LW_ELS	Other	Fallow	1
2013	LW_ELS	Improved grass	Grass	4
2013	LW_ELS	Non-MFC	Spring oats	1
2013	LW_ELS	Non-MFC	Spring wheat	1
2013	LW_ELS	Other	Woodland	2
2013	CN_Org	MFC	Clover	1
2013	CN_Org	AES grass	EK1	1
2013	CN_Org	Other	Fallow	1
2013	CN_Org	AES margin	OE3	1
2013	CN_Org	AES margin	OF1	1
2013	CN_Org	Non-MFC	Spring oats	2
2013	CN_Org	Non-MFC	Spring wheat	4
2013	CN_Org	MFC	Winter beans	1
2013	CS_Org	Improved grass	Grass	4
2013	CS_Org	AES grass	HK15	1
2013	CS_Org	AES grass	HK16	1
2013	CS_Org	AES grass	HK6	1
2013	CS_Org	AES grass	HK7	2
2013	CS_Org	Non-MFC	Wheat	1
2013	CS_Org	Other	Woodland	2
2013	HD_Org	MFC	Arable silage	1
2013	HD_Org	Improved grass	Grass/clover grazed	2
2013	HD_Org	AES margin	HE10	2
2013	HD_Org	MFC	Lucerne/Sanfoin silage	1
2013	HD_Org	AES margin	OE1	1
2013	HD_Org	MFC	OG1	1
2013	HD_Org	AES grass	OK3	1
2013	HD_Org	Non-MFC	Spelt	1
2013	HD_Org	Non-MFC	Spring barley	2
2013	LW_Org	MFC	Barley and peas	1
2013	LW_Org	Improved grass	Grass	3
2013	LW_Org	AES grass	HK10	1
2013	LW_Org	AES grass	HK6	1
2013	LW_Org	AES grass	HO1	1

Appendix 4: Further details on stratified proportional sampling design

This section describes the method for allocating sampling points (pollinator sampling points with pan traps and 100 m long transects in 2012 and 2013) and sections of transects (for bird surveys and pollinator transects in 2014). Sampling points were allocated to habitat types in proportion to the area of each habitat type on the whole farm, with habitat areas weighted according to the number of points or pounds assigned in the Environmental Stewardship Schemes. This approach avoided the sample being heavily dominated by productive areas, which dominate in terms of actual land area, and provided greater focus on the areas of the farm managed for biodiversity. Each habitat management option is assigned a value (number of points in ELS and a number of pounds in HLS) in Environmental Stewardship. The values are designed to reimburse the farmer for costs of carrying out management and income foregone. We made the assumption that the options with higher values assigned were of higher benefit to biodiversity, since they involved more costly management changes deemed worthwhile by Natural England, likely to results in a greater change in habitat conditions for wildlife compared to less costly management changes. Weightings for each habitat (W_h) were calculated as follows: habitats not in Environmental Stewardship options (ES) were given a weighting of 1 and ES habitat options were given a weighting calculated using the formula:

$W_h = V_h / (85 \times 0.9)$.

Where V_h is the value of each habitat (points in ELS or pounds in HLS). This gives the lowest scoring ES option (EK2: Low input grassland: 85 points) a weighting of 1.05, and other areas in proportion to this, giving the highest scoring ES option (HE10: Floristically enhanced margin: £485) a weighting of 6.34.

Example 1: Sampling points in 2013

In 2013, the number of sampling points out of 12 for each farm assigned to each habitat (N_{hf}) was calculated using the formula below, where A_{hf} is the area of the habitat on the farm. The lengths were rounded to the nearest integer and allocated in order starting with the highest ranking habitat until all 12 points were allocated.

$N_{hf} = A_{hf} * W_h / \sum(A_{hf} * W_h))*12$

A worked example for one farm (CS_CG) is shown below:

Habitat name	Area A_{hf} (ha)	Value V_h (points)	Weight W_h	Weighted area $W_h * A_h$	Proportion $A_h * W_h / \sum(A_h * W_h)$	Proportion * 12	Number of sampling points
Winter	129.7967	0	1	1297966.	0.304	3.6474	4
Grass	58.8741	0	1	588740.4	0.1379	1.6544	2
EF1	8.2483	400	4.9536	408583.5	0.0957	1.1482	1
Woodland	39.6433	0	1	396432.4	0.0929	1.114	1
EF4	6.5605	450	5.5728	365597.1	0.0857	1.0274	1
Winter OSR	36.2218	0	1	362217.3	0.0849	1.0179	1
Winter	30.1118	0	1	301117.4	0.0706	0.8462	1
Spring oats	20.2255	0	1	202254.1	0.0474	0.5684	1
Winter	19.4704	0	1	194703.7	0.0456	0.5472	0
EE3	3.0846	400	4.9536	152793.1	0.0358	0.4294	0

Example 2: Transect lengths in 2014

The proportions of transects of total length 1500 m for each farm assigned to each habitat (L_{hf}) were calculated using the formula below, where A_{hf} is the area of the habitat on the farm. The lengths were rounded to the nearest 10 m and transects over 300 m long were split into two and assigned to different fields to ensure that they fitted into fields.

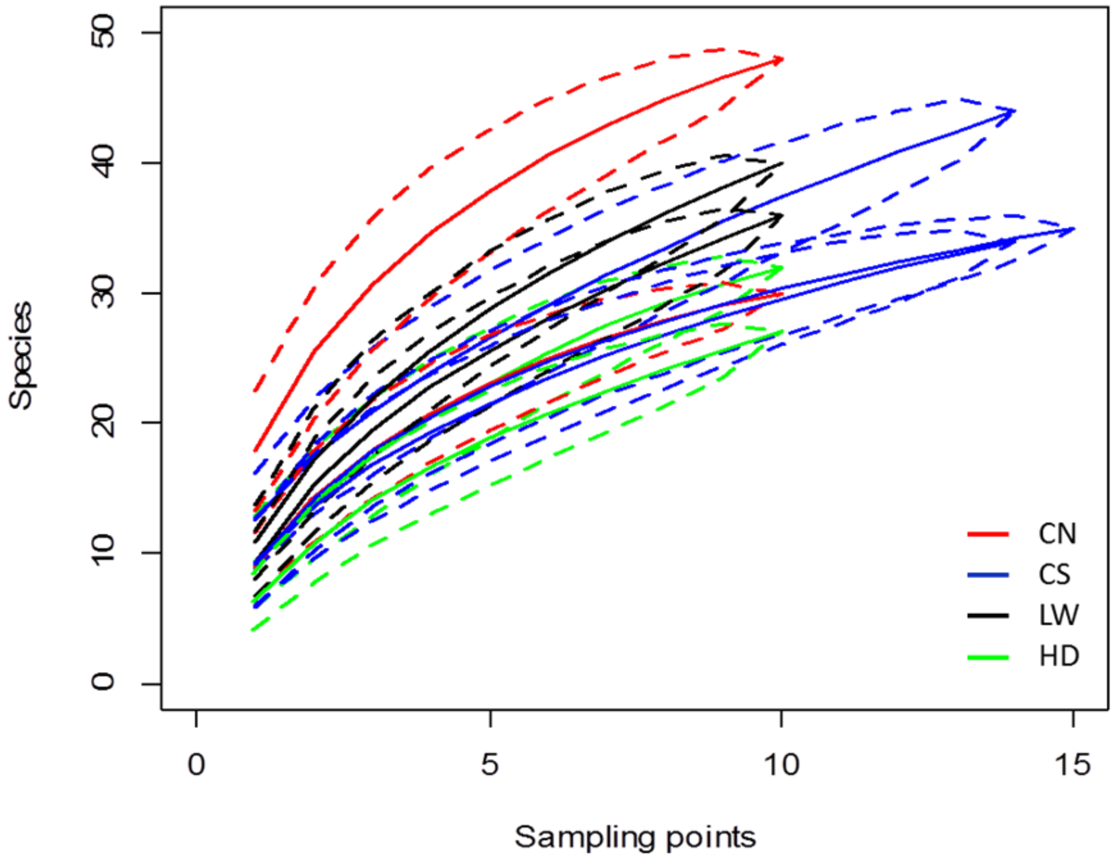
$L_{hf} = A_{hf} * W_h / \sum(A_{hf} * W_h))*1500$

A worked example for one farm (CS_ELS) is shown below:

Habitat name	Area A_{hf} (ha)	Value V_h (points)	Weight W_h	Weighted Area $W_h * A_h$	Proportion $A_h * W_h / \sum(A_h * W_h)$	L_{hf} (m)
EF4	1.40	450	5.573	7.7900	0.0237	35.5
EF2NR	2.82	450	5.573	15.6972	0.0477	71.5
EF1	3.30	400	4.954	16.3275	0.0496	74.4
Poppies	40.78	0	1	40.7827	0.1238	185.7
OSR	65.25	0	1	65.2545	0.1981	297.2
Grass	81.46	0	1	81.4628	0.2474	371.0*
Winter wheat	101.87	0	1	101.8662	0.3093	464.0¶

*Split into two transects of length 185.5 m ¶ Split into two transects of length 232.0 m.

Appendix 5: Species accumulation curves for wild bees by sampling point for the twelve study farms, coloured by region



Appendix 6: List of insect-rewarding plant species recorded in 2013 and 2014

Species	Floral unit
Acer campestre	one raceme
Acer pseudoplatanus	one raceme
Achillea millefolium	one flower head
Aegopodium podagraria	one secondary umbel
Aesculus hippocastanum	one panicle
Aethusa cynapium	single flower
Agrimonia eupatoria	one spike
Ajuga reptans	one spike
Alliaria petiolata	one raceme
Anacamptis pyramidalis	one spike
Anagallis arvensis	single flower
Anemone nemorosa	single flower
Anthriscus sylvestris	one secondary umbel
Arctium lappa	one capitulum
Arctium minus	one capitulum
Arctium spp.	one capitulum
Arenaria serpyllifolia	single flower
Artemisia vulgaris	one spike
Ballota nigra	one whorl
Barbarea vulgaris	one raceme
Bellis perennis	one capitulum
Brassica napus	one raceme
Brassica oleracea	one spike
Brassica oleracea acephala	one raceme
Bryonia dioica	single flower
Calluna vulgaris	one spike
Calystegia sepium	single flower
Calystegia silvatica	single flower
Campanula latifolia	single flower
Campanula rotundifolia	single flower
Capsella bursa-pastoris	single flower
Cardamine flexuosa	single flower
Cardamine pratensis	one raceme
Carduus nutans	one capitulum
Centaurea cyanus	one capitulum
Centaurea nigra	one capitulum
Centaurea scabiosa	one capitulum
Centaurium erythraea	one capitulum
Cerastium fontanum	single flower
Chaerophyllum temulum	one secondary umbel
Chamerion angustifolium	single flower
Chenopodium album	one spike
Cichorium intybus	one capitulum
Circaea lutetiana	single flower
Cirsium arvense	one capitulum
Cirsium palustre	one capitulum
Cirsium vulgare	one capitulum
Clematis vitalba	single flower
Clinopodium vulgare	one spike
Conium maculatum	single flower
Conopodium majus	one secondary umbel
Convolvulus arvensis	single flower
Conyza bonariensis	one capitulum
Cornus sanguinea	single flower
Crataegus monogyna	single flower
Crepis capillaris	one capitulum
Crepis vesicaria	one capitulum
Cruciata laevipes	one cluster
Dactylorhiza fuchsii	one spike
Daucus carota	one secondary umbel
Digitalis purpurea	single flower
Echium vulgare	single flower
Epilobium ciliatum	one raceme
Epilobium hirsutum	single flower
Erica cinerea	single flower
Erica tetralix	one spike
Euonymus europaeus	single flower
Euphorbia amygdaloides	one spike
Euphrasia sp.	single flower
Fagopyrum esculentum	one flower head
Fallopia convolvulus	single flower
Fragaria vesca	single flower
Fumaria officinalis	one raceme
Galeopsis tetrahit	one terminal spike
Galium aparine	single flower
Galium mollugo	one secondary spike
Galium odoratum	one whorl
Galium palustre	one raceme
Galium saxatile	one spike
Galium verum	one spike
Geranium dissectum	single flower
Geranium molle	single flower
Geranium pratense	single flower
Geranium pusillum	single flower
Geranium pyrenaicum	single flower
Geranium robertianum	single flower
Geranium rotundifolium	single flower

Geranium sanguineum	single flower	*Oenanthe crocata*	one umbel
Geum urbanum	single flower	*Onobrychis viciifolia*	one spike
Glebionis segetum	one capitulum	*Ophrys apifera*	single flower
Glechoma hederacea	one whorl	*Orchis mascula*	single flower
Hedera helix	one flower head	*Origanum vulgare*	one panicle
Heracleum sphondylium	one secondary umbel	*Orobanche minor*	one spike
		Papaver rhoeas	single flower
Hieracium spp.	one capitulum	*Papaver somniferum*	single flower
Hyacinthoides non-scripta	one raceme	*Persicaria maculosa*	one spike
Hypericum hirsutum	one raceme	*Phacelia tanacetifolia*	one spike
Hypericum humifusum	single flower	*Picris echioides*	one capitulum
Hypericum perforatum	one cyme		
Hypericum pulchrum	single flower	*Pimpinella saxifraga*	one secondary umbel
Hypochaeris radicata	one flower head	*Pisum sativum*	single flower
Knautia arvensis	one capitulum	*Plantago lanceolata*	one spike
Lactuca serriola	one capitulum	*Plantago major*	one flower head
Lamiastrum galeobdolon	one whorl	*Polygonum aviculare*	one raceme
Lamium album	single flower	*Potentilla anglica*	single flower
Lamium purpureum	single flower	*Potentilla anserina*	single flower
Lapsana communis	one capitulum	*Potentilla reptans*	single flower
Lathyrus nissolia	single flower	*Primula veris*	single flower
Lathyrus pratensis	single flower	*Primula vulgaris*	single flower
Leontodon autumnalis	one capitulum	*Prunella vulgaris*	single flower
Leontodon hispidus	one capitulum	*Prunus avium*	single flower
Leontodon saxatilis	one capitulum	*Prunus spinosa*	single flower
Lepidium campestre	single flower	*Pulicaria dysenterica*	one capitulum
Leucanthemum vulgare	one capitulum	*Ranunculus acris*	single flower
Ligustrum vulgare	one panicle	*Ranunculus ficaria*	single flower
Linaria vulgaris	one raceme	*Ranunculus repens*	single flower
Linum usitatissimum	single flower	*Raphanus raphanistrum*	one raceme
Listera ovata	single flower	*Raphanus sativus*	single flower
Lonicera periclymenum	single flower	*Reseda lutea*	one spike
Lotus corniculatus	single flower	*Reseda luteola*	one spike
Lysimachia nemorum	single flower	*Rhinanthus minor*	single flower
Malva moschata	single flower	*Rhododendron ponticum*	single flower
Malva neglecta	single flower	*Rorippa amphibia*	one column
Malva sylvestris	single flower	*Rorippa sylvestris*	one raceme
Matricaria discoidea	one capitulum	*Rosa arvensis*	single flower
Matricaria recutita	one capitulum	*Rosa canina*	single flower
Medicago lupulina	one flower head	*Rubus fruticosus agg.*	single flower
Medicago sativa	single flower	*Rumex acetosella*	one raceme
Melilotus officinalis	one flower head	*Salvia verbenaca*	single flower
Mentha arvensis	one whorl	*Sambucus nigra*	one primary umbel
Mercurialis perennis	one spike		
Mycelis muralis	one capitulum	*Sanguisorba minor subsp. minor*	one flower head
Myosotis arvensis	single flower		
Myosotis scorpioides	single flower	*Scrophularia nodosa*	one raceme
Myosotis sylvatica	one raceme	*Senecio jacobaea*	one capitulum
Odontites vernus	single flower	*Senecio vulgaris*	one capitulum

Sherardia arvensis	single flower	*Trifolium repens*	one flower head
Silene dioica	single flower	*Tripleurospermum inodorum*	one capitulum
Silene latifolia	single flower	*Verbascum nigrum*	one spike
Sinapis arvensis	single flower	*Veronica arvensis*	one raceme
Sison amomum	one umbel	*Veronica chamaedrys*	single flower
Sisymbrium officinale	one raceme	*Veronica hederifolia*	single flower
Solanum dulcamara	single flower	*Veronica montana*	one raceme
Sonchus arvensis	one capitulum	*Veronica officinalis*	one spike
Sonchus asper	one capitulum	*Veronica persica*	single flower
Sonchus oleraceus	one capitulum	*Veronica polita*	single flower
Stachys officinalis	one spike	*Veronica serpyllifolia*	one raceme
Stachys sylvatica	one whorl	*Viburnum lantana*	one umbel
Stellaria graminea	single flower	*Viburnum opulus*	single flower
Stellaria holostea	single flower	*Vicia cracca*	one raceme
Stellaria media	single flower	*Vicia faba*	one spike
Tamus communis	single flower	*Vicia hirsuta*	one raceme
Taraxacum agg.	one capitulum	*Vicia orobus*	one raceme
Teucrium scorodonia	one spike	*Vicia parviflora*	single flower
Tilia cordata	one panicle	*Vicia sativa*	single flower
Torilis japonica	one secondary umbel	*Vicia sepium*	single flower
Tragopogon pratensis	one capitulum	*Vicia tetrasperma*	one raceme
Trifolium campestre	one flower head	*Viola arvensis*	single flower
Trifolium dubium	one flower head	*Viola riviniana*	single flower
Trifolium pratense	one flower head	*Zea mays*	one panicle

Appendix 7: General linear mixed effects model on habitat diversity as a function of scheme type and radius interaction (Gaussian errors)

Marginal R^2: 0.461, Conditional R^2:0.513

Random effects:

Random effects:					
Groups	Name		Variance	Std.Dev.	
Point:(Farm:(Region:Year))	(Intercept)		0.012755	0.11294	
Farm:(Region:Year)	(Intercept)		0.004187	0.06471	
Region:Year	(Intercept)		0.015679	0.12522	
Year	(Intercept)		0	0	
Residual			0.089028	0.29838	
Fixed effects:					
	Estimate	Std. Error	df	t value	Pr(>|t|)
(Intercept)	0.69696	0.04923	29.7	14.157	<0.001
TypeCG	0.17714	0.04726	80	3.748	<0.001
TypeOrg	0.119	0.04726	80	2.518	0.0138
Radius0.25	0.53935	0.03664	1209.9	14.722	<0.001
Radius1	0.95719	0.03659	1196.3	26.16	<0.001
Radius3	0.95189	0.03659	1196.3	26.016	<0.001
TypeCG:Radius0.25	0.05736	0.05178	1203.1	1.108	0.2681
TypeOrg:Radius0.25	0.12562	0.05178	1203.1	2.426	0.0154
TypeCG:Radius1	-0.08609	0.05175	1196.3	-1.664	0.0964
TypeOrg:Radius1	-0.03444	0.05175	1196.3	-0.666	0.5058
TypeCG:Radius3	-0.22112	0.05175	1196.3	-4.273	<0.001
TypeOrg:Radius3	-0.0442	0.05175	1196.3	-0.854	0.3931

Appendix 8: Lists of species recorded in this study

List of bird species recorded in winter 2013, ELS = Entry Level Stewardship, HLS = Higher Level Stewardship

Scheme:	Conservation Grade (+ELS)
Landscape:	Chilterns South
Black-headed Gull	*Chroicocephalus ridibundus*
Blackbird	*Turdus merula*
Blue Tit	*Cyanistes caeruleus*
Buzzard	*Buteo buteo*
Chaffinch	*Fringilla coelebs*
Coal Tit	*Periparus ater*
Collared Dove	*Streptopelia decaocto*
Carrion Crow	*Corvus corone*
Dunnock	*Prunella modularis*
Fieldfare	*Turdus pilaris*
Goldfinch	*Carduelis carduelis*
Great Spotted Woodpecker	*Dendrocopos major*
Great Tit	*Parus major*
Green Woodpecker	*Picus viridis*
Jay	*Garrulus glandarius*
Long-tailed Tit	*Aegithalos caudatus*
Magpie	*Pica pica*
Meadow Pipit	*Anthus pratensis*
Mistle Thrush	*Turdus viscivorus*
Nuthatch	*Sitta europaea*
Pheasant	*Phasianus colchicus*
Pied Wagtail	*Motacilla alba*
Red Kite	*Milvus milvus*
Robin	*Erithacus rubecula*
Rook	*Corvus frugilegus*
Skylark	*Alauda arvensis*
Song Thrush	*Turdus philomelos*
Woodpigeon	*Columba palumbus*
Wren	*Troglodytes troglodytes*
Yellowhammer	*Emberiza citrinella*

Scheme:	Conservation Grade (+ELS+HLS)
Landscape:	Hampshire Downs
Blackbird	*Turdus merula*
Blue Tit	*Cyanistes caeruleus*
Brambling	*Fringilla montifringilla*
Bullfinch	*Pyrrhula pyrrhula*
Buzzard	*Buteo buteo*
Chaffinch	*Fringilla coelebs*
Carrion Crow	*Corvus corone*
Dunnock	*Prunella modularis*
Fieldfare	*Turdus pilaris*
Goldfinch	*Carduelis carduelis*
Great Spotted Woodpecker	*Dendrocopos major*
Great Tit	*Parus major*
Jay	*Garrulus glandarius*
Lapwing	*Vanellus vanellus*
Linnet	*Carduelis cannabina*
Mistle Thrush	*Turdus viscivorus*
Nuthatch	*Sitta europaea*
Pheasant	*Phasianus colchicus*
Raven	*Corvus corax*
Red Kite	*Milvus milvus*
Red-legged Partridge	*Alectoris rufa*
Robin	*Erithacus rubecula*
Rook	*Corvus frugilegus*
Skylark	*Alauda arvensis*
Song Thrush	*Turdus philomelos*
Woodpigeon	*Columba palumbus*
Wren	*Troglodytes troglodytes*
Linnet	*Carduelis cannabina*
Kestrel	*Falco tinnunculus*
Yellowhammer	*Emberiza citrinella*

Scheme:	Conservation
Landscape:	Low Weald
Blackbird	*Turdus merula*
Blue Tit	*Cyanistes caeruleus*
Buzzard	*Buteo buteo*
(Greater) Canada Goose	*Branta canadensis*
Chaffinch	*Fringilla coelebs*
Chiffchaff	*Phylloscopus collybita*
Cormorant	*Phalacrocorax carbo*
Carrion Crow	*Corvus corone*
Dunnock	*Prunella modularis*
Fieldfare	*Turdus pilaris*
Goldcrest	*Regulus regulus*
Golden Plover	*Pluvialis apricaria*
Goldfinch	*Carduelis carduelis*
Great Spotted Woodpecker	*Dendrocopos major*
Great Tit	*Parus major*
Grey Heron	*Ardea cinerea*
House Sparrow	*Passer domesticus*
Jay	*Garrulus glandarius*
Lapwing	*Vanellus vanellus*
Long-tailed Tit	*Aegithalos caudatus*
Magpie	*Pica pica*
Mallard	*Anas platyrhynchos*
Meadow Pipit	*Anthus pratensis*
Mistle Thrush	*Turdus viscivorus*
Moorhen	*Gallinula chloropus*
Pheasant	*Phasianus colchicus*
Robin	*Erithacus rubecula*
Rook	*Corvus frugilegus*
Skylark	*Alauda arvensis*
Song Thrush	*Turdus philomelos*
Starling	*Sturnus vulgaris*
Treecreeper	*Certhia familiaris*
Woodpigeon	*Columba palumbus*
Wren	*Troglodytes troglodytes*
Kestrel	*Falco tinnunculus*
Yellowhammer	*Emberiza citrinella*

Scheme:	ELS
Landscape:	Chilterns South
Black-headed Gull	*Chroicocephalus ridibundus*
Blackbird	*Turdus merula*
Blue Tit	*Cyanistes caeruleus*
Brambling	*Fringilla montifringilla*
Chaffinch	*Fringilla coelebs*
Carrion Crow	*Corvus corone*
Dunnock	*Prunella modularis*
Fieldfare	*Turdus pilaris*
Goldfinch	*Carduelis carduelis*
Great Spotted Woodpecker	*Dendrocopos major*
Great Tit	*Parus major*
Grey Wagtail	*Motacilla cinerea*
Grey Heron	*Ardea cinerea*
House Sparrow	*Passer domesticus*
Lapwing	*Vanellus vanellus*
Long-tailed Tit	*Aegithalos caudatus*
Magpie	*Pica pica*
Meadow Pipit	*Anthus pratensis*
Pheasant	*Phasianus colchicus*
Red Kite	*Milvus milvus*
Red-legged Partridge	*Alectoris rufa*
Mealy Redpoll	*Carduelis flammea*
Reed Bunting	*Emberiza schoeniclus*
Robin	*Erithacus rubecula*
Rook	*Corvus frugilegus*
Skylark	*Alauda arvensis*

Starling	*Sturnus vulgaris*
Woodpigeon	*Columba palumbus*
Wren	*Troglodytes troglodytes*
Kestrel	*Falco tinnunculus*
Yellowhammer	*Emberiza citrinella*
Dunnock	*Prunella modularis*
Fieldfare	*Turdus pilaris*
Great Spotted Woodpecker	*Dendrocopos major*
Great Tit	*Parus major*
Jay	*Garrulus glandarius*
Lapwing	*Vanellus vanellus*
Linnet	*Carduelis cannabina*
Magpie	*Pica pica*
Marsh Tit	*Poecile palustris*
Nuthatch	*Sitta europaea*
Pheasant	*Phasianus colchicus*
Pied Wagtail	*Motacilla alba*
Raven	*Corvus corax*
Red Kite	*Milvus milvus*
Red-legged Partridge	*Alectoris rufa*
Robin	*Erithacus rubecula*
Rook	*Corvus frugilegus*
Skylark	*Alauda arvensis*
Song Thrush	*Turdus philomelos*
Starling	*Sturnus vulgaris*
Treecreeper	*Certhia familiaris*
Woodpigeon	*Columba palumbus*
Wren	*Troglodytes troglodytes*
Yellowhammer	*Emberiza citrinella*

Scheme: ELS
Landscape: Low Weald

Blackbird	*Turdus merula*
Blue Tit	*Cyanistes caeruleus*
Buzzard	*Buteo buteo*
Chaffinch	*Fringilla coelebs*
Coal Tit	*Periparus ater*
Carrion Crow	*Corvus corone*
Dunnock	*Prunella modularis*
Fieldfare	*Turdus pilaris*
Great Spotted Woodpecker	*Dendrocopos major*
Great Tit	*Parus major*
Green Woodpecker	*Picus viridis*
Jay	*Garrulus glandarius*
Long-tailed Tit	*Aegithalos caudatus*
Magpie	*Pica pica*
Mallard	*Anas platyrhynchos*
Nuthatch	*Sitta europaea*
Pheasant	*Phasianus colchicus*
Red-legged Partridge	*Alectoris rufa*
Mealy Redpoll	*Carduelis flammea*
Robin	*Erithacus rubecula*
Rook	*Corvus frugilegus*
Skylark	*Alauda arvensis*
Song Thrush	*Turdus philomelos*
Starling	*Sturnus vulgaris*
Woodpigeon	*Columba palumbus*
Wren	*Troglodytes troglodytes*
Yellowhammer	*Emberiza citrinella*
Jackdaw	*Corvus monedula*

Scheme: Organic ELS (+HLS)
Landscape: Chilterns South

Barn Owl	*Tyto alba*
Blackbird	*Turdus merula*
Blue Tit	*Cyanistes caeruleus*
Buzzard	*Buteo buteo*
Chaffinch	*Fringilla coelebs*
Dunnock	*Prunella modularis*
Fieldfare	*Turdus pilaris*
Great Spotted Woodpecker	*Dendrocopos major*
Great Tit	*Parus major*
Jay	*Garrulus glandarius*
Magpie	*Pica pica*
Mistle Thrush	*Turdus viscivorus*
Nuthatch	*Sitta europaea*
Red Kite	*Milvus milvus*
Red-legged Partridge	*Alectoris rufa*
Robin	*Erithacus rubecula*
Rook	*Corvus frugilegus*
Skylark	*Alauda arvensis*
Song Thrush	*Turdus philomelos*
Sparrowhawk	*Accipiter nisus*
Starling	*Sturnus vulgaris*
Woodpigeon	*Columba palumbus*
Wren	*Troglodytes troglodytes*
Yellowhammer	*Emberiza citrinella*

Scheme: Organic ELS (+HLS)
Landscape: Hampshire Downs

Blackbird	*Turdus merula*
Blue Tit	*Cyanistes caeruleus*
Buzzard	*Buteo buteo*
Chaffinch	*Fringilla coelebs*
Carrion Crow	*Corvus corone*
Dunnock	*Prunella modularis*
Fieldfare	*Turdus pilaris*
Great Spotted Woodpecker	*Dendrocopos major*
Great Tit	*Parus major*
Jay	*Garrulus glandarius*
Long-tailed Tit	*Aegithalos caudatus*
Magpie	*Pica pica*
Mistle Thrush	*Turdus viscivorus*
Pheasant	*Phasianus colchicus*
Pied Wagtail	*Motacilla alba*
Red Kite	*Milvus milvus*
Red-legged Partridge	*Alectoris rufa*
Redwing	*Turdus iliacus*
Robin	*Erithacus rubecula*
Rook	*Corvus frugilegus*
Skylark	*Alauda arvensis*
Song Thrush	*Turdus philomelos*
Woodpigeon	*Columba palumbus*
Wren	*Troglodytes troglodytes*
Kestrel	*Falco tinnunculus*
Yellowhammer	*Emberiza citrinella*

Scheme: Organic ELS (+HLS)
Landscape: Low Weald

Blackbird	*Turdus merula*
Blue Tit	*Cyanistes caeruleus*
Buzzard	*Buteo buteo*
Chaffinch	*Fringilla coelebs*
Carrion Crow	*Corvus corone*
Dunnock	*Prunella modularis*
Fieldfare	*Turdus pilaris*
Great Spotted Woodpecker	*Dendrocopos major*
Great Tit	*Parus major*
Green Woodpecker	*Picus viridis*
Grey Wagtail	*Motacilla cinerea*
Grey Heron	*Ardea cinerea*
Long-tailed Tit	*Aegithalos caudatus*
Magpie	*Pica pica*
Meadow Pipit	*Anthus pratensis*
Mistle Thrush	*Turdus viscivorus*
Pheasant	*Phasianus colchicus*
Pied Wagtail	*Motacilla alba*
Raven	*Corvus corax*
Red-legged Partridge	*Alectoris rufa*
Robin	*Erithacus rubecula*

Rook	*Corvus frugilegus*	Treecreeper	*Certhia familiaris*
Skylark	*Alauda arvensis*	Woodpigeon	*Columba palumbus*
Snipe	*Gallinago gallinago*	Wren	*Troglodytes troglodytes*
Song Thrush	*Turdus philomelos*	Grey Wagtail	*Motacilla cinerea*
Starling	*Sturnus vulgaris*		

List of bird species recorded in summer 2013 and 2014, ELS = Entry Level Stewardship, HLS = Higher Level Stewardship

Scheme:	Conservation Grade (+ELS+HLS)
Landscape:	Chilterns North
Swallow	*Hirundo rustica*
Magpie	*Pica pica*
Blackcap	*Sylvia atricapilla*
Black-headed Gull	*Chroicocephalus ridibundus*
Blue Tit	*Cyanistes caeruleus*
Carrion Crow	*Corvus corone*
Chaffinch	*Fringilla coelebs*
Coal Tit	*Periparus ater*
Blackbird	*Turdus merula*
Buzzard	*Buteo buteo*
Chiffchaff	*Phylloscopus collybita*
Linnet	*Carduelis cannabina*
Moorhen	*Gallinula chloropus*
Pheasant	*Phasianus colchicus*
Starling	*Sturnus vulgaris*
Swift	*Apus apus*
Whitethroat	*Sylvia communis*
Woodpigeon	*Columba palumbus*
Collared Dove	*Streptopelia decaocto*
Jackdaw	*Corvus monedula*
Jay	*Garrulus glandarius*
Sparrowhawk	*Accipiter nisus*
Goldfinch	*Carduelis carduelis*
Greenfinch	*Chloris chloris*
Robin	*Erithacus rubecula*
Garden Warbler	*Sylvia borin*
Great Spotted Woodpecker	*Dendrocopos major*
Great Tit	*Parus major*
Green Woodpecker	*Picus viridis*
Dunnock	*Prunella modularis*
Herring Gull	*Larus argentatus*
House Martin	*Delichon urbicum*
House Sparrow	*Passer domesticus*
Lesser Redpoll	*Carduelis cabaret*
Lesser Spotted Woodpecker	*Dendrocopos minor*
Lesser Whitethroat	*Sylvia curruca*
Long-tailed Tit	*Aegithalos caudatus*
Wheatear	*Oenanthe oenanthe*
Red Kite	*Milvus milvus*
Red-legged Partridge	*Alectoris rufa*
Rock Dove / Feral Pigeon	*Columba livia*
Rook	*Corvus frugilegus*
Skylark	*Alauda arvensis*
Song Thrush	*Turdus philomelos*
Tawny Owl	*Strix aluco*
Wren	*Troglodytes troglodytes*
Yellowhammer	*Emberiza citrinella*

Scheme:	Conservation Grade (+ELS)
Landscape:	Chilterns South
Swallow	*Hirundo rustica*
Magpie	*Pica pica*
Blackcap	*Sylvia atricapilla*
Blue Tit	*Cyanistes caeruleus*
Carrion Crow	*Corvus corone*
Chaffinch	*Fringilla coelebs*
Coal Tit	*Periparus ater*
Blackbird	*Turdus merula*
Bullfinch	*Pyrrhula pyrrhula*
Buzzard	*Buteo buteo*
Chiffchaff	*Phylloscopus collybita*
Kestrel	*Falco tinnunculus*
Linnet	*Carduelis cannabina*
Pheasant	*Phasianus colchicus*
Starling	*Sturnus vulgaris*
Whitethroat	*Sylvia communis*
Woodpigeon	*Columba palumbus*
Egyptian Goose	*Alopochen aegyptiaca*
Jackdaw	*Corvus monedula*
Jay	*Garrulus glandarius*
Goldfinch	*Carduelis carduelis*
Greenfinch	*Chloris chloris*
Robin	*Erithacus rubecula*
Great Spotted Woodpecker	*Dendrocopos major*
Great Tit	*Parus major*
Green Woodpecker	*Picus viridis*
Dunnock	*Prunella modularis*
House Martin	*Delichon urbicum*
Long-tailed Tit	*Aegithalos caudatus*
Mallard	*Anas platyrhynchos*
Marsh Tit	*Poecile palustris*
Meadow Pipit	*Anthus pratensis*
Mistle Thrush	*Turdus viscivorus*
Red Kite	*Milvus milvus*
Red-legged Partridge	*Alectoris rufa*
Rock Dove / Feral Pigeon	*Columba livia*
Rook	*Corvus frugilegus*
Skylark	*Alauda arvensis*
Song Thrush	*Turdus philomelos*
Stock Dove	*Columba oenas*
Willow Warbler	*Phylloscopus trochilus*
Wren	*Troglodytes troglodytes*
Nuthatch	*Sitta europaea*
Yellowhammer	*Emberiza citrinella*

Scheme:	Conservation Grade (+ELS+HLS)
Landscape:	Hampshire Downs
Swallow	*Hirundo rustica*
Magpie	*Pica pica*
Blackcap	*Sylvia atricapilla*
Blue Tit	*Cyanistes caeruleus*
Carrion Crow	*Corvus corone*
Chaffinch	*Fringilla coelebs*
Coal Tit	*Periparus ater*
Blackbird	*Turdus merula*
Bullfinch	*Pyrrhula pyrrhula*
Buzzard	*Buteo buteo*
Chiffchaff	*Phylloscopus collybita*
Kestrel	*Falco tinnunculus*
Linnet	*Carduelis cannabina*
Pheasant	*Phasianus colchicus*
Raven	*Corvus corax*
Whitethroat	*Sylvia communis*
Woodpigeon	*Columba palumbus*
Collared Dove	*Streptopelia decaocto*
Jackdaw	*Corvus monedula*
Jay	*Garrulus glandarius*
Treecreeper	*Certhia familiaris*
Goldfinch	*Carduelis carduelis*
Greenfinch	*Chloris chloris*
Robin	*Erithacus rubecula*
Cormorant	*Phalacrocorax carbo*
Great Spotted Woodpecker	*Dendrocopos major*
Great Tit	*Parus major*
Green Woodpecker	*Picus viridis*
Dunnock	*Prunella modularis*
Lesser Black-backed Gull	*Larus fuscus*
Long-tailed Tit	*Aegithalos caudatus*
Marsh Tit	*Poecile palustris*
Meadow Pipit	*Anthus pratensis*
Mistle Thrush	*Turdus viscivorus*
Lapwing	*Vanellus vanellus*
Wheatear	*Oenanthe oenanthe*
Red Kite	*Milvus milvus*

Red-legged Partridge	*Alectoris rufa*
Rook	*Corvus frugilegus*
Skylark	*Alauda arvensis*
Song Thrush	*Turdus philomelos*
Spotted Flycatcher	*Muscicapa striata*
Stock Dove	*Columba oenas*
Stone-curlew	*Burhinus oedicnemus*
Tree Pipit	*Anthus trivialis*
Willow Tit	*Poecile montana*
Wren	*Troglodytes troglodytes*
Woodlark	*Lullula arborea*
Nuthatch	*Sitta europaea*
Yellowhammer	*Emberiza citrinella*

Scheme:	Conservation Grade (+ELS+HLS)
Landscape:	Low Weald
Swallow	*Hirundo rustica*
Magpie	*Pica pica*
Blackcap	*Sylvia atricapilla*
Blue Tit	*Cyanistes caeruleus*
Carrion Crow	*Corvus corone*
Chaffinch	*Fringilla coelebs*
Coal Tit	*Periparus ater*
Blackbird	*Turdus merula*
Bullfinch	*Pyrrhula pyrrhula*
Buzzard	*Buteo buteo*
Chiffchaff	*Phylloscopus collybita*
Cuckoo	*Cuculus canorus*
Linnet	*Carduelis cannabina*
Moorhen	*Gallinula chloropus*
Nightingale	*Luscinia megarhynchos*
Pheasant	*Phasianus colchicus*
Starling	*Sturnus vulgaris*
Whitethroat	*Sylvia communis*
Woodpigeon	*Columba palumbus*
Collared Dove	*Streptopelia decaocto*
Hobby	*Falco subbuteo*
Jackdaw	*Corvus monedula*
Jay	*Garrulus glandarius*
Sparrowhawk	*Accipiter nisus*
Treecreeper	*Certhia familiaris*
Goldfinch	*Carduelis carduelis*
Greenfinch	*Chloris chloris*
Robin	*Erithacus rubecula*
Garden Warbler	*Sylvia borin*
Goldcrest	*Regulus regulus*
Great Spotted Woodpecker	*Dendrocopos major*
Great Tit	*Parus major*
Canada Goose	*Branta canadensis*
Green Woodpecker	*Picus viridis*
Dunnock	*Prunella modularis*
Herring Gull	*Larus argentatus*
House Sparrow	*Passer domesticus*
Lesser Whitethroat	*Sylvia curruca*
Long-tailed Tit	*Aegithalos caudatus*
Mallard	*Anas platyrhynchos*
Marsh Tit	*Poecile palustris*
Lapwing	*Vanellus vanellus*
Reed Bunting	*Emberiza schoeniclus*
Rock Dove / Feral Pigeon	*Columba livia*
Rook	*Corvus frugilegus*
Skylark	*Alauda arvensis*
Song Thrush	*Turdus philomelos*
Tawny Owl	*Strix aluco*
Willow Tit	*Poecile montana*
Willow Warbler	*Phylloscopus trochilus*
Wren	*Troglodytes troglodytes*
Woodlark	*Lullula arborea*
Nuthatch	*Sitta europaea*
Yellowhammer	*Emberiza citrinella*

Scheme:	ELS
Landscape:	Chilterns North
Swallow	*Hirundo rustica*
Magpie	*Pica pica*
Blackcap	*Sylvia atricapilla*
Blue Tit	*Cyanistes caeruleus*
Carrion Crow	*Corvus corone*
Chaffinch	*Fringilla coelebs*
Blackbird	*Turdus merula*
Buzzard	*Buteo buteo*
Chiffchaff	*Phylloscopus collybita*
Linnet	*Carduelis cannabina*
Pheasant	*Phasianus colchicus*
Starling	*Sturnus vulgaris*
Swift	*Apus apus*
Whitethroat	*Sylvia communis*
Woodpigeon	*Columba palumbus*
Collared Dove	*Streptopelia decaocto*
Jackdaw	*Corvus monedula*
Jay	*Garrulus glandarius*
Goldfinch	*Carduelis carduelis*
Greenfinch	*Chloris chloris*
Robin	*Erithacus rubecula*
Goldcrest	*Regulus regulus*
Great Spotted Woodpecker	*Dendrocopos major*
Great Tit	*Parus major*
Canada Goose	*Branta canadensis*
Green Woodpecker	*Picus viridis*
Grey Heron	*Ardea cinerea*
Grey Partridge	*Perdix perdix*
Dunnock	*Prunella modularis*
House Martin	*Delichon urbicum*
House Sparrow	*Passer domesticus*
Long-tailed Tit	*Aegithalos caudatus*
Mallard	*Anas platyrhynchos*
Mistle Thrush	*Turdus viscivorus*
Lapwing	*Vanellus vanellus*
Red Kite	*Milvus milvus*
Red-legged Partridge	*Alectoris rufa*
Reed Bunting	*Emberiza schoeniclus*
Rock Dove / Feral Pigeon	*Columba livia*
Rook	*Corvus frugilegus*
Skylark	*Alauda arvensis*
Song Thrush	*Turdus philomelos*
Stock Dove	*Columba oenas*
Willow Warbler	*Phylloscopus trochilus*
Wren	*Troglodytes troglodytes*
Nuthatch	*Sitta europaea*
Yellowhammer	*Emberiza citrinella*

Scheme:	ELS
Landscape:	Chilterns South
Swallow	*Hirundo rustica*
Magpie	*Pica pica*
Blackcap	*Sylvia atricapilla*
Black-headed Gull	*Chroicocephalus ridibundus*
Blue Tit	*Cyanistes caeruleus*
Carrion Crow	*Corvus corone*
Chaffinch	*Fringilla coelebs*
Coal Tit	*Periparus ater*
Blackbird	*Turdus merula*
Buzzard	*Buteo buteo*
Chiffchaff	*Phylloscopus collybita*
Coot	*Fulica atra*
Cuckoo	*Cuculus canorus*
Kestrel	*Falco tinnunculus*
Linnet	*Carduelis cannabina*
Moorhen	*Gallinula chloropus*
Pheasant	*Phasianus colchicus*
Starling	*Sturnus vulgaris*

Swift	*Apus apus*
Whitethroat	*Sylvia communis*
Woodpigeon	*Columba palumbus*
Egyptian Goose	*Alopochen aegyptiaca*
Collared Dove	*Streptopelia decaocto*
Jackdaw	*Corvus monedula*
Jay	*Garrulus glandarius*
Reed Warbler	*Acrocephalus scirpaceus*
Siskin	*Carduelis spinus*
Sparrowhawk	*Accipiter nisus*
Treecreeper	*Certhia familiaris*
Goldfinch	*Carduelis carduelis*
Greenfinch	*Chloris chloris*
Robin	*Erithacus rubecula*
Garden Warbler	*Sylvia borin*
Goldcrest	*Regulus regulus*
Golden Pheasant	*Chrysolophus pictus*
Cormorant	*Phalacrocorax carbo*
Great Spotted Woodpecker	*Dendrocopos major*
Great Tit	*Parus major*
Canada Goose	*Branta canadensis*
Green Woodpecker	*Picus viridis*
Grey Heron	*Ardea cinerea*
Greylag Goose	*Anser anser*
Dunnock	*Prunella modularis*
House Martin	*Delichon urbicum*
House Sparrow	*Passer domesticus*
Long-tailed Tit	*Aegithalos caudatus*
Mallard	*Anas platyrhynchos*
Marsh Tit	*Poecile palustris*
Meadow Pipit	*Anthus pratensis*
Mistle Thrush	*Turdus viscivorus*
Mute Swan	*Cygnus olor*
Lapwing	*Vanellus vanellus*
Pink-footed Goose	*Anser brachyrhynchus*
Red Kite	*Milvus milvus*
Red-legged Partridge	*Alectoris rufa*
Reed Bunting	*Emberiza schoeniclus*
Rock Dove / Feral Pigeon	*Columba livia*
Rook	*Corvus frugilegus*
Ring-necked Parakeet	*Psittacula krameri*
Sedge Warbler	*Acrocephalus schoenobaenus*
Skylark	*Alauda arvensis*
Song Thrush	*Turdus philomelos*
Stock Dove	*Columba oenas*
Willow Warbler	*Phylloscopus trochilus*
Wren	*Troglodytes troglodytes*
Nuthatch	*Sitta europaea*
Yellow Wagtail	*Motacilla flava*
Yellowhammer	*Emberiza citrinella*

Scheme:	ELS
Landscape:	Hampshire Downs
Swallow	*Hirundo rustica*
Magpie	*Pica pica*
Blackcap	*Sylvia atricapilla*
Blue Tit	*Cyanistes caeruleus*
Carrion Crow	*Corvus corone*
Chaffinch	*Fringilla coelebs*
Coal Tit	*Periparus ater*
Blackbird	*Turdus merula*
Bullfinch	*Pyrrhula pyrrhula*
Buzzard	*Buteo buteo*
Chiffchaff	*Phylloscopus collybita*
Cuckoo	*Cuculus canorus*
Kestrel	*Falco tinnunculus*
Linnet	*Carduelis cannabina*
Pheasant	*Phasianus colchicus*
Raven	*Corvus corax*
Whitethroat	*Sylvia communis*
Woodpigeon	*Columba palumbus*
Hobby	*Falco subbuteo*
Jackdaw	*Corvus monedula*
Jay	*Garrulus glandarius*
Treecreeper	*Certhia familiaris*
Goldfinch	*Carduelis carduelis*
Greenfinch	*Chloris chloris*
Robin	*Erithacus rubecula*
Garden Warbler	*Sylvia borin*
Goldcrest	*Regulus regulus*
Great Spotted Woodpecker	*Dendrocopos major*
Great Tit	*Parus major*
Green Woodpecker	*Picus viridis*
Dunnock	*Prunella modularis*
House Sparrow	*Passer domesticus*
Lesser Black-backed Gull	*Larus fuscus*
Long-tailed Tit	*Aegithalos caudatus*
Marsh Tit	*Poecile palustris*
Meadow Pipit	*Anthus pratensis*
Mistle Thrush	*Turdus viscivorus*
Lapwing	*Vanellus vanellus*
Red Kite	*Milvus milvus*
Red-legged Partridge	*Alectoris rufa*
Rook	*Corvus frugilegus*
Skylark	*Alauda arvensis*
Song Thrush	*Turdus philomelos*
Spotted Flycatcher	*Muscicapa striata*
Stock Dove	*Columba oenas*
Tawny Owl	*Strix aluco*
Tree Pipit	*Anthus trivialis*
Willow Warbler	*Phylloscopus trochilus*
Wren	*Troglodytes troglodytes*
Nuthatch	*Sitta europaea*
Yellowhammer	*Emberiza citrinella*

Scheme:	ELS
Landscape:	Low Weald
Swallow	*Hirundo rustica*
Magpie	*Pica pica*
Blackcap	*Sylvia atricapilla*
Blue Tit	*Cyanistes caeruleus*
Carrion Crow	*Corvus corone*
Chaffinch	*Fringilla coelebs*
Coal Tit	*Periparus ater*
Blackbird	*Turdus merula*
Bullfinch	*Pyrrhula pyrrhula*
Buzzard	*Buteo buteo*
Chiffchaff	*Phylloscopus collybita*
Cuckoo	*Cuculus canorus*
Kestrel	*Falco tinnunculus*
Linnet	*Carduelis cannabina*
Moorhen	*Gallinula chloropus*
Nightingale	*Luscinia megarhynchos*
Pheasant	*Phasianus colchicus*
Starling	*Sturnus vulgaris*
Whitethroat	*Sylvia communis*
Woodpigeon	*Columba palumbus*
Jackdaw	*Corvus monedula*
Jay	*Garrulus glandarius*
Sparrowhawk	*Accipiter nisus*
Treecreeper	*Certhia familiaris*
Goldfinch	*Carduelis carduelis*
Greenfinch	*Chloris chloris*
Robin	*Erithacus rubecula*
Garden Warbler	*Sylvia borin*
Goldcrest	*Regulus regulus*
Great Spotted Woodpecker	*Dendrocopos major*
Great Tit	*Parus major*
Canada Goose	*Branta canadensis*
Green Woodpecker	*Picus viridis*

Grey Heron	*Ardea cinerea*
Dunnock	*Prunella modularis*
Herring Gull	*Larus argentatus*
House Martin	*Delichon urbicum*
House Sparrow	*Passer domesticus*
Lesser Whitethroat	*Sylvia curruca*
Long-tailed Tit	*Aegithalos caudatus*
Mallard	*Anas platyrhynchos*
Marsh Tit	*Poecile palustris*
Mistle Thrush	*Turdus viscivorus*
Lapwing	*Vanellus vanellus*
Wheatear	*Oenanthe oenanthe*
Reed Bunting	*Emberiza schoeniclus*
Rook	*Corvus frugilegus*
Skylark	*Alauda arvensis*
Song Thrush	*Turdus philomelos*
Stonechat	*Saxicola torquatus*
Tawny Owl	*Strix aluco*
Whimbrel	*Numenius phaeopus*
Willow Tit	*Poecile montana*
Willow Warbler	*Phylloscopus trochilus*
Wren	*Troglodytes troglodytes*
Nuthatch	*Sitta europaea*
Yellowhammer	*Emberiza citrinella*

Scheme:	Organic ELS (+HLS started in
Landscape:	Chilterns North
Swallow	*Hirundo rustica*
Magpie	*Pica pica*
Blackcap	*Sylvia atricapilla*
Blue Tit	*Cyanistes caeruleus*
Carrion Crow	*Corvus corone*
Chaffinch	*Fringilla coelebs*
Coal Tit	*Periparus ater*
Blackbird	*Turdus merula*
Buzzard	*Buteo buteo*
Chiffchaff	*Phylloscopus collybita*
Kestrel	*Falco tinnunculus*
Linnet	*Carduelis cannabina*
Pheasant	*Phasianus colchicus*
Quail	*Coturnix coturnix*
Redshank	*Tringa totanus*
Starling	*Sturnus vulgaris*
Swift	*Apus apus*
Whitethroat	*Sylvia communis*
Woodpigeon	*Columba palumbus*
Corn Bunting	*Emberiza calandra*
Collared Dove	*Streptopelia decaocto*
Jackdaw	*Corvus monedula*
Jay	*Garrulus glandarius*
Siskin	*Carduelis spinus*
Sparrowhawk	*Accipiter nisus*
Goldfinch	*Carduelis carduelis*
Greenfinch	*Chloris chloris*
Robin	*Erithacus rubecula*
Garden Warbler	*Sylvia borin*
Great Spotted Woodpecker	*Dendrocopos major*
Great Tit	*Parus major*
Green Woodpecker	*Picus viridis*
Dunnock	*Prunella modularis*
House Martin	*Delichon urbicum*
House Sparrow	*Passer domesticus*
Lesser Black-backed Gull	*Larus fuscus*
Long-tailed Tit	*Aegithalos caudatus*
Mistle Thrush	*Turdus viscivorus*
Red Kite	*Milvus milvus*
Red-legged Partridge	*Alectoris rufa*
Reed Bunting	*Emberiza schoeniclus*
Rook	*Corvus frugilegus*
Skylark	*Alauda arvensis*
Song Thrush	*Turdus philomelos*
Stock Dove	*Columba oenas*
Willow Tit	*Poecile montana*
Wren	*Troglodytes troglodytes*
Nuthatch	*Sitta europaea*
Yellow Wagtail	*Motacilla flava*
Yellowhammer	*Emberiza citrinella*

Scheme:	Organic ELS (+HLS)
Landscape:	Chilterns South
Swallow	*Hirundo rustica*
Magpie	*Pica pica*
Blackcap	*Sylvia atricapilla*
Blue Tit	*Cyanistes caeruleus*
Carrion Crow	*Corvus corone*
Chaffinch	*Fringilla coelebs*
Coal Tit	*Periparus ater*
Blackbird	*Turdus merula*
Buzzard	*Buteo buteo*
Chiffchaff	*Phylloscopus collybita*
Linnet	*Carduelis cannabina*
Pheasant	*Phasianus colchicus*
Woodpigeon	*Columba palumbus*
Jackdaw	*Corvus monedula*
Jay	*Garrulus glandarius*
Sparrowhawk	*Accipiter nisus*
Goldfinch	*Carduelis carduelis*
Robin	*Erithacus rubecula*
Fieldfare	*Turdus pilaris*
Great Spotted Woodpecker	*Dendrocopos major*
Great Tit	*Parus major*
Green Woodpecker	*Picus viridis*
Dunnock	*Prunella modularis*
Long-tailed Tit	*Aegithalos caudatus*
Mallard	*Anas platyrhynchos*
Meadow Pipit	*Anthus pratensis*
Common Gull	*Larus canus*
Mistle Thrush	*Turdus viscivorus*
Red Kite	*Milvus milvus*
Red-legged Partridge	*Alectoris rufa*
Redwing	*Turdus iliacus*
Rook	*Corvus frugilegus*
Skylark	*Alauda arvensis*
Song Thrush	*Turdus philomelos*
Spotted Flycatcher	*Muscicapa striata*
Stock Dove	*Columba oenas*
Willow Warbler	*Phylloscopus trochilus*
Wren	*Troglodytes troglodytes*
Nuthatch	*Sitta europaea*
Yellowhammer	*Emberiza citrinella*

Scheme:	Organic ELS (+HLS)
Landscape:	Hampshire Downs
Swallow	*Hirundo rustica*
Magpie	*Pica pica*
Blackcap	*Sylvia atricapilla*
Blue Tit	*Cyanistes caeruleus*
Brambling	*Fringilla montifringilla*
Carrion Crow	*Corvus corone*
Chaffinch	*Fringilla coelebs*
Coal Tit	*Periparus ater*
Blackbird	*Turdus merula*
Bullfinch	*Pyrrhula pyrrhula*
Buzzard	*Buteo buteo*
Chiffchaff	*Phylloscopus collybita*
Kestrel	*Falco tinnunculus*
Linnet	*Carduelis cannabina*
Pheasant	*Phasianus colchicus*
Quail	*Coturnix coturnix*
Raven	*Corvus corax*

Starling	*Sturnus vulgaris*
Whitethroat	*Sylvia communis*
Woodpigeon	*Columba palumbus*
Jackdaw	*Corvus monedula*
Jay	*Garrulus glandarius*
Sparrowhawk	*Accipiter nisus*
Goldfinch	*Carduelis carduelis*
Greenfinch	*Chloris chloris*
Robin	*Erithacus rubecula*
Goldcrest	*Regulus regulus*
Golden Pheasant	*Chrysolophus pictus*
Great Spotted Woodpecker	*Dendrocopos major*
Great Tit	*Parus major*
Green Woodpecker	*Picus viridis*
Dunnock	*Prunella modularis*
House Martin	*Delichon urbicum*
House Sparrow	*Passer domesticus*
Long-tailed Tit	*Aegithalos caudatus*
Red Kite	*Milvus milvus*
Red-legged Partridge	*Alectoris rufa*
Rook	*Corvus frugilegus*
Skylark	*Alauda arvensis*
Song Thrush	*Turdus philomelos*
Stock Dove	*Columba oenas*
Wren	*Troglodytes troglodytes*
Nuthatch	*Sitta europaea*
Yellowhammer	*Emberiza citrinella*

Scheme:	Organic ELS (+HLS)
Landscape:	Low Weald
Swallow	*Hirundo rustica*
Magpie	*Pica pica*
Blackcap	*Sylvia atricapilla*
Black-headed Gull	*Chroicocephalus ridibundus*
Blue Tit	*Cyanistes caeruleus*
Carrion Crow	*Corvus corone*
Cetti's Warbler	*Cettia cetti*
Chaffinch	*Fringilla coelebs*
Coal Tit	*Periparus ater*
Blackbird	*Turdus merula*
Buzzard	*Buteo buteo*
Chiffchaff	*Phylloscopus collybita*
Kestrel	*Falco tinnunculus*
Linnet	*Carduelis cannabina*
Moorhen	*Gallinula chloropus*
Nightingale	*Luscinia megarhynchos*
Pheasant	*Phasianus colchicus*
Raven	*Corvus corax*
Redstart	*Phoenicurus phoenicurus*
Starling	*Sturnus vulgaris*
Swift	*Apus apus*
Whitethroat	*Sylvia communis*
Woodpigeon	*Columba palumbus*
Hobby	*Falco subbuteo*
Jackdaw	*Corvus monedula*
Jay	*Garrulus glandarius*
Reed Warbler	*Acrocephalus scirpaceus*
Sparrowhawk	*Accipiter nisus*
Treecreeper	*Certhia familiaris*
Goldfinch	*Carduelis carduelis*
Greenfinch	*Chloris chloris*
Robin	*Erithacus rubecula*
Garden Warbler	*Sylvia borin*
Great Spotted Woodpecker	*Dendrocopos major*
Great Tit	*Parus major*
Canada Goose	*Branta canadensis*
Green Sandpiper	*Tringa ochropus*
Green Woodpecker	*Picus viridis*
Grey Heron	*Ardea cinerea*
Dunnock	*Prunella modularis*
House Martin	*Delichon urbicum*
House Sparrow	*Passer domesticus*
Little Grebe	*Tachybaptus ruficollis*
Long-tailed Tit	*Aegithalos caudatus*
Mallard	*Anas platyrhynchos*
Meadow Pipit	*Anthus pratensis*
Mistle Thrush	*Turdus viscivorus*
Lapwing	*Vanellus vanellus*
Red-legged Partridge	*Alectoris rufa*
Reed Bunting	*Emberiza schoeniclus*
Rook	*Corvus frugilegus*
Sedge Warbler	*Acrocephalus schoenobaenus*
Skylark	*Alauda arvensis*
Song Thrush	*Turdus philomelos*
Spotted Flycatcher	*Muscicapa striata*
Stock Dove	*Columba oenas*
Tree Pipit	*Anthus trivialis*
Willow Warbler	*Phylloscopus trochilus*
Wren	*Troglodytes troglodytes*
Woodlark	*Lullula arborea*
Nuthatch	*Sitta europaea*
Yellow Wagtail	*Motacilla flava*
Yellowhammer	*Emberiza citrinella*

Plants recorded in 2012 for Chapter 3

Scheme: Conservation Grade
Landscape: Chilterns North

Acer campestre
Achillea millefolium
Agrostis capillaris
Alopecurus myosuroides
Angelica sylvestris
Arrhenatherum elatius
Avena sativa
Bromus sterilis
Capsella bursa-pastoris
Cerastium fontanum
Cirsium arvense
Convolvulus arvensis
Crepis capillaris
Dactylis glomerata
Daucus carota
Festuca pratensis
Festuca rubra
Galium aparine
Geranium dissectum
Glechoma hederacea
Hedera helix
Heracleum sphondylium
Holcus lanatus
Hordeum vulgare
Lactuca serriola
Lamium purpureum
Lapsana communis
Lathyris pratensis
Lolium multiflorum
Lolium perenne
Lotus corniculatus
Medicago lupulina
Onobrychis viciifolia
Papaver rhoeas
Persicaria maculosa
Phleum pratense
Pimpinella saxifraga
Pisum sativum
Plantago lanceolata
Poa annua
Poa trivialis
Ranunculus acris
Rosa canina
Rumex acetosa
Salix caprea
Senecio vulgaris
Setaria verticillata
Sherardia arvensis
Sinapis arvensis
Sisymbrium officinale
Sonchus asper
Taraxacum agg.
Trifolium campestre
Trifolium pratense
Triticum aestivum
Tripleurospermum inodorum
Veronica chamaedrys
Veronica persica
Vicia faba
Viola arvensis
Urtica dioica

Scheme: ELS
Landscape: Chilterns North

Alopecurus myosuroides
Arrhenatherum elatius
Avena sativa
Brassica napus
Bromopsis ramosa
Cirsium vulgare
Dactylis glomerata
Elymus caninus
Epilobium ciliatum
Epilobium hirsutum
Festuca rubra
Galium aparine
Geranium dissectum
Geranium molle
Hordeum vulgare
Lolium perenne
Medicago lupulina
Phleum pratense
Poa annua
Rumex obtusifolius
Senecio jacobaea
Sonchus asper
Stellaria media
Taraxacum agg.
Triticum aestivum
Veronica chamaedrys
Viola arvensis
Urtica dioica

Scheme: Organic ELS
Landscape: Chilterns North

Agrostis stolonifera
Alopecurus myosuroides
Angelica sylvestris
Arrhenatherum elatius
Avena sativa
Cirsium arvense
Cirsium vulgare
Convolvulus arvensis
Crepis capillaris
Dactylis glomerata
Daucus carota
Elymus caninus
Elytriga repens
Festuca rubra
Fumaria officinalis
Galium aparine
Geranium columbinum
Geranium dissectum
Glechoma hederacea
Heracleum sphondylium
Hieracium sp.
Holcus lanatus
Lactuca serriola
Lapsana communis
Lolium perenne
Medicago lupulina
Myostotis arvensis
Papaver rhoeas
Phleum pratense
Poa annua
Polygonum aviculare
Rumex crispus
Rumex obtusifolius
Secale cereale
Senecio jacobaea
Setaria verticillata
Sherardia arvensis
Sinapis arvensis
Sisymbrium officinale

Sonchus oleraceus
Sonchus asper
Stellaria media
Trifolium pratense
Trifolium repens
Triticum aestivum
Tripleurospermum inodorum
Veronica persica
Vicia faba
Vicia sativa
Viola arvensis
Urtica dioica

Scheme: Conservation Grade
Landscape: Chilterns South
Anisantha sterilis
Arrhenatherum elatius
Avena sativa
Brassica napus
Bromus hordaceus
Cerastium fontanum
Chamerion angustifolium
Cirsium arvense
Cirsium vulgare
Crepis capillaris
Dactylis glomerata
Daucus carota
Elymus caninus
Festuca rubra
Fraxinus excelsior
Fumaria officinalis
Galium aparine
Geranium dissectum
Glechoma hederacea
Hedera helix
Holcus lanatus
Hordeum vulgare
Hypochaeris radicata
Leucanthemum vulgare
Linum usitatissimum
Lolium perenne
Medicago lupulina
Medicago sativa sativa
Mercurialis perennis
Myostotis arvensis
Papaver rhoeas
Phleum pratense
Plantago major
Poa annua
Poa sp.
Poa trivialis
Prunella vulgaris
Pteridium aquilinum
Quercus sp. (seedling)
Rhamnus cathartica
Rumex obtusifolius
Senecio jacobaea
Silene dioica
Silene latifolia
Taraxacum agg.
Trifolium dubium
Trifolium pratense
Trifolium repens
Triticum aestivum
Tussilago farfara
Veronica chamaedrys
Veronica persica
Vicia tetrasperma
Viola arvensis

Scheme: ELS
Landscape: Chilterns South
Allium vineale
Alopecus pratensis
Anagallis arvensis
Arrhenatherum elatius
Brassica napus
Cirsium vulgare
Elymus caninus
Festuca pratensis
Festuca rubra
Galium aparine
Geranium dissectum
Lolium perenne
Papaver rhoeas
Papaver somniferum
Pastinaca sativa
Phleum pratense
Poa annua
Prunella vulgaris
Ranunculus repens
Rumex obtusifolius
Senecio vulgaris
Sonchus asper
Stellaria media
Taraxacum agg.
Triticum aestivum
Veronica persica
Urtica dioica
Zea mays

Scheme: Organic ELS (+HLS)
Landscape: Chilterns South
Acer campestre
Achillea millefolium
Agrostis capillaris
Alopecus pratensis
Anagallis arvensis
Anthoxanthum odoratum
Avena sativa
Bromus hordaceus
Centaurea nigra
Cerastium fontanum
Cirsium arvense
Cirsium vulgare
Conopodium majus
Convolvulus arvensis
Crepis biennis
Crepis capillaris
Cretageous monogyna
Cynosurus cristatus
Dactylis glomerata
Daucus carota
Festuca rubra
Galium aparine
Geranium dissectum
Geum urbanum
Glechoma hederacea
Holcus lanatus
Hordeum vulgare
Hypochaeris radicata
Ilex aquifolium
Leucanthemum vulgare
Lolium perenne
Lotus corniculatus
Mercurialis perennis
Papaver rhoeas
Phleum pratense
Plantago lanceolata
Poa annua

Poa trivialis
Prunella vulgaris
Ranunculus repens
Rubus fruticosa
Rumex acetosa
Rumex crispus
Rumex obtusifolius
Sambucus nigra
Sinapis arvensis
Sonchus asper
Stachys silvatica
Taraxacum agg.
Tragopogon pratensis
Trifolium dubium
Trifolium pratense
Trifolium repens
Triticum aestivum
Veronica persica
Vicia sativa
Vicia tetrasperma
Viola arvensis
Urtica dioica

Scheme: Conservation Grade
Landscape: Hampshire Downs
Allium ursinum
Avena sativa
Brassica napus
Brassica oleracea acephala
Cerastium fontanum
Cirsium arvense
Cirsium vulgare
Crepis capillaris
Crepis vesicaria
Cretageous monogyna
Cynosurus cristatus
Dactylis glomerata
Daucus carota
Festuca rubra
Galium aparine
Galium verum
Geranium dissectum
Glechoma hederacea
Holcus lanatus
Hordeum vulgare
Hypochaeris radicata
Lolium perenne
Lotus corniculatus
Mercurialis perennis
Phacelia tanacetifolia
Phleum pratense
Plantago lanceolata
Poa annua
Prunella vulgaris
Rubus fruticosa
Rumex obtusifolius
Sambucus nigra
Senecio jacobaea
Sherardia arvensis
Sinapis arvensis
Sonchus asper
Taraxacum agg.
Trifolium campestre
Trifolium dubium
Trifolium repens
Triticum aestivum
Veronica persica
Urtica dioica
Scheme: ELS
Landscape: Hampshire Downs
Achillea millefolium
Anisantha sterilis
Arrhenatherum elatius
Brassica juncea
Cerastium fontanum
Chaerophyllum temulum
Chicorium intybus
Cirsium arvense
Convolvulus arvensis
Crepis vesicaria
Cynosurus cristatus
Dactylis glomerata
Daucus carota
Festuca rubra
Galeopsis tetrahit
Galium aparine
Geranium dissectum
Glechoma hederacea
Hedera helix
Heracleum sphondylium
Holcus lanatus
Knautia arvensis
Lathyris pratensis
Leontodon hispidus
Leucanthemum vulgare
Linum catharticum
Lolium perenne
Lotus corniculatus
Odontites vernus
Pastinaca sativa
Phleum pratense
Pimpinella saxifraga
Plantago lanceolata
Poa annua
Poa trivialis
Prunella vulgaris
Ranunculus repens
Rubus fruticosa
Rumex acetosa
Rumex obtusifolius
Senecio jacobaea
Sonchus asper
Stachys officinalis
Stellaria media
Stellaria pallida
Taraxacum agg.
Trifolium dubium
Trifolium pratense
Trifolium repens
Triticum aestivum
Veronica chamaedrys
Veronica persica
Viola arvensis
Urtica dioica

Scheme: Organic ELS (+HLS)
Landscape: Hampshire Downs
Anagallis arvensis
Arrhenatherum elatius
Avena sativa
Bellis perrenis
Cerastium fontanum
Chaerophyllum temulum
Convolvulus arvensis
Cynosurus cristatus
Dactylis glomerata
Galium aparine
Geranium dissectum
Glechoma hederacea
Holcus lanatus

Hordeum vulgare
Lamium purpureum
Lolium perenne
Lotus corniculatus
Myostotis arvensis
Papaver rhoeas
Phleum pratense
Plantago lanceolata
Poa annua
Poa trivialis
Ranunculus repens
Rosa canina
Rumex obtusifolius
Senecio jacobaea
Sherardia arvensis
Sinapis arvensis
Sonchus asper
Stellaria media
Taraxacum agg.
Trifolium pratense
Trifolium repens
Triticum aestivum
Triticum spelta
Tripleurospermum inodorum
Veronica persica
Vicia sp.
Viola arvensis
Urtica dioica

Scheme: Conservation Grade
Landscape: Low Weald
Alopecus pratensis
Avena sativa
Brassica napus
Bromus hordaceus
Circaea lutetiana
Cirsium vulgare
Dactylis glomerata
Galium aparine
Geranium columbinum
Geranium dissectum
Geum urbanum
Glechoma hederacea
Holcus lanatus
Hyacinthoides non-scripta
Lapsana communis
Lolium perenne
Medicago lupulina
Mercurialis perennis
Phleum pratense
Plantago major
Poa annua
Poa trivialis
Prunella vulgaris
Pulicaria dysenterica
Ranunculus repens
Rubus fruticosa
Rumex crispus
Rumex obtusifolius
Sison amomum
Taraxacum agg.
Trifolium dubium
Trifolium repens
Triticum aestivum
Tripleurospermum inodorum
Veronica chamaedrys
Veronica persica
Vicia sativa

Scheme: ELS
Landscape: Low Weald
Alopecus pratensis
Anagallis arvensis
Avena sativa
Centaurium erythraea
Cerastium fontanum
Cirsium arvense
Cretageous monogyna
Cynosurus cristatus
Dactylis glomerata
Epilobium ciliatum
Equisetum sp.
Fagus sylvatica
Festuca rubra
Fraxinus excelsior
Galium aparine
Geranium dissectum
Geum urbanum
Glechoma hederacea
Holcus lanatus
Hyacinthoides non-scripta
Hypericum perforatum
Lapsana communis
Lolium perenne
Mercurialis perennis
Myostotis arvensis
Phleum pratense
Poa annua
Poa trivialis
Quercus sp. (seedling)
Ranunculus repens
Rosa canina
Rubus fruticosa
Rumex crispus
Rumex obtusifolius
Senecio vulgaris
Sonchus asper
Stellaria pallida
Taraxacum agg.
Trifolium pratense
Trifolium repens
Triticum aestivum
Vicia sativa
Vicia tetrasperma
Viola riviniana
Urtica dioica

Scheme: Organic ELS (+HLS)
Landscape: Low Weald
Achillea millefolium
Agrostis stolonifera
Anagallis arvensis
Anthoxanthum odoratum
Argentina anserina
Arrhenatherum elatius
Bellis perrenis
Bromopsis ramosa
Bromus hordaceus
Calluna vulgaris
Cerastium fontanum
Chenopodium ficifolium
Cirsium arvense
Convolvulus arvensis
Crepis capillaris
Cruciata laevipes
Cynosurus cristatus
Dactylis glomerata
Deschampsia flexuosa
Elytriga repens

Erica cinerea
Festuca rubra
Fraxinus excelsior
Galium aparine
Galium saxatile
Geranium dissectum
Glechoma hederacea
Holcus lanatus
Hordeum brachyantherum
Hordeum vulgare
Hypochaeris radicata
Lolium perenne
Lonicera periclymenum
Lotus corniculatus
Mentha arvensis
Phleum pratense
Pinus sylvestris
Pisum sativum
Plantago lanceolata
Plantago major
Poa annua
Poa trivialis
Polygonum aviculare
Prunella vulgaris
Pteridium aquilinum
Quercus sp. (seedling)
Ranunculus repens
Rubus fruticosa
Rumex acetosa
Rumex acetosella
Rumex crispus
Senecio jacobaea
Sinapis arvensis
Sonchus asper
Stellaria holostea
Senecio sylvaticus
Taraxacum agg.
Teucrium scorodonia
Trifolium pratense
Trifolium repens
Trisetum flavescens
Tripleurospermum inodorum
Veronica chamaedrys
Veronica persica
Ulex europaeus

Butterfly species recorded in 2012, 2013 and 2014

Scheme:	Conservation Grade (+ELS+HLS)
Landscape:	Chilterns North
Peacock	*Aglais io*
Small Tortoiseshell	*Aglais urticae*
Orange-tip	*Anthocharis cardamines*
Ringlet	*Aphantopus hyperantus*
Meadow Brown	*Maniola jurtina*
Marbled White	*Melanargia galathea*
Large Skipper	*Ochlodes sylvanus*
Speckled Wood	*Pararge aegeria*
Large White	*Pieris brassicae*
Green-veined White	*Pieris napi*
Small White	*Pieris rapae*
Common Blue	*Polyommatus icarus*
Gatekeeper	*Pyronia tithonus*
Small Skipper	*Thymelicus sylvestris*

Scheme:	Conservation Grade (+ELS)
Landscape:	Chilterns South
Peacock	*Aglais io*
Small Tortoiseshell	*Aglais urticae*
Orange-tip	*Anthocharis cardamines*
Ringlet	*Aphantopus hyperantus*
Small Heath	*Coenonympha pamphilus*
Small Copper	*Lycaena phlaeas*
Meadow Brown	*Maniola jurtina*
Marbled White	*Melanargia galathea*
Large Skipper	*Ochlodes sylvanus*
Speckled Wood	*Pararge aegeria*
Large White	*Pieris brassicae*
Green-veined White	*Pieris napi*
Small White	*Pieris rapae*
Comma	*Polygonia c-album*
Gatekeeper	*Pyronia tithonus*
Small Skipper	*Thymelicus sylvestris*
Red Admiral	*Vanessa atalanta*

Scheme:	Conservation Grade (+ELS+HLS)
Landscape:	Hampshire Downs
Peacock	*Aglais io*
Small Tortoiseshell	*Aglais urticae*
Orange-tip	*Anthocharis cardamines*
Ringlet	*Aphantopus hyperantus*
Silver-washed Fritillary	*Argynnis paphia*
Brimstone	*Gonepteryx rhamni*
Meadow Brown	*Maniola jurtina*
Marbled White	*Melanargia galathea*
Large White	*Pieris brassicae*
Green-veined White	*Pieris napi*
Small White	*Pieris rapae*
Common Blue	*Polyommatus icarus*
Gatekeeper	*Pyronia tithonus*
Small Skipper	*Thymelicus sylvestris*

Scheme:	Conservation Grade (+ELS+HLS)
Landscape:	Low Weald
Peacock	*Aglais io*
Small Tortoiseshell	*Aglais urticae*
Orange-tip	*Anthocharis cardamines*
Purple Emperor	*Apatura iris*
Ringlet	*Aphantopus hyperantus*
Silver-washed Fritillary	*Argynnis paphia*
Small Heath	*Coenonympha pamphilus*
Brimstone	*Gonepteryx rhamni*
Small Copper	*Lycaena phlaeas*
Meadow Brown	*Maniola jurtina*
Marbled White	*Melanargia galathea*
Large Skipper	*Ochlodes sylvanus*
Speckled Wood	*Pararge aegeria*
Large White	*Pieris brassicae*
Green-veined White	*Pieris napi*
Small White	*Pieris rapae*
Comma	*Polygonia c-album*
Common Blue	*Polyommatus icarus*
Gatekeeper	*Pyronia tithonus*
Small Skipper	*Thymelicus sylvestris*
Red Admiral	*Vanessa atalanta*

Scheme:	ELS
Landscape:	Chilterns North
Peacock	*Aglais io*
Small Tortoiseshell	*Aglais urticae*
Orange-tip	*Anthocharis cardamines*
Ringlet	*Aphantopus hyperantus*
Meadow Brown	*Maniola jurtina*
Large White	*Pieris brassicae*
Green-veined White	*Pieris napi*
Small White	*Pieris rapae*
Common Blue	*Polyommatus icarus*
Small Skipper	*Thymelicus sylvestris*
Red Admiral	*Vanessa atalanta*

Scheme:	ELS
Landscape:	Chilterns South
Peacock	*Aglais io*
Small Tortoiseshell	*Aglais urticae*
Orange-tip	*Anthocharis cardamines*
Ringlet	*Aphantopus hyperantus*
Wall	*Lasiommata megera*
Meadow Brown	*Maniola jurtina*
Large Skipper	*Ochlodes sylvanus*
Large White	*Pieris brassicae*
Green-veined White	*Pieris napi*
Small White	*Pieris rapae*
Comma	*Polygonia c-album*
Common Blue	*Polyommatus icarus*
Gatekeeper	*Pyronia tithonus*
Small Skipper	*Thymelicus sylvestris*
Red Admiral	*Vanessa atalanta*

Scheme:	ELS
Landscape:	Hampshire Downs
Peacock	*Aglais io*
Small Tortoiseshell	*Aglais urticae*
Orange-tip	*Anthocharis cardamines*
Ringlet	*Aphantopus hyperantus*
Small Heath	*Coenonympha pamphilus*
Small Copper	*Lycaena phlaeas*
Meadow Brown	*Maniola jurtina*
Marbled White	*Melanargia galathea*
Large White	*Pieris brassicae*
Green-veined White	*Pieris napi*
Small White	*Pieris rapae*
Common Blue	*Polyommatus icarus*
Gatekeeper	*Pyronia tithonus*
Small Skipper	*Thymelicus sylvestris*
Red Admiral	*Vanessa atalanta*

Scheme:	ELS
Landscape:	Low Weald
Small Tortoiseshell	*Aglais urticae*
Orange-tip	*Anthocharis cardamines*
Ringlet	*Aphantopus hyperantus*
Small Heath	*Coenonympha pamphilus*
Clouded Yellow	*Colias croceus*
Meadow Brown	*Maniola jurtina*
Large Skipper	*Ochlodes sylvanus*

Speckled Wood	*Pararge aegeria*
Large White	*Pieris brassicae*
Green-veined White	*Pieris napi*
Small White	*Pieris rapae*
Common Blue	*Polyommatus icarus*
Gatekeeper	*Pyronia tithonus*
Small Skipper	*Thymelicus sylvestris*

Scheme:	Organic ELS (+HLS in 2013)
Landscape:	Chilterns North
Peacock	*Aglais io*
Small Tortoiseshell	*Aglais urticae*
Orange-tip	*Anthocharis cardamines*
Ringlet	*Aphantopus hyperantus*
Meadow Brown	*Maniola jurtina*
Marbled White	*Melanargia galathea*
Large Skipper	*Ochlodes sylvanus*
Speckled Wood	*Pararge aegeria*
Large White	*Pieris brassicae*
Green-veined White	*Pieris napi*
Small White	*Pieris rapae*
Common Blue	*Polyommatus icarus*
Gatekeeper	*Pyronia tithonus*
Small Skipper	*Thymelicus sylvestris*

Scheme:	Organic ELS (+HLS)
Landscape:	Chilterns South
Peacock	*Aglais io*
Small Tortoiseshell	*Aglais urticae*
Ringlet	*Aphantopus hyperantus*
Brimstone	*Gonepteryx rhamni*
Small Copper	*Lycaena phlaeas*
Meadow Brown	*Maniola jurtina*
Marbled White	*Melanargia galathea*
Speckled Wood	*Pararge aegeria*
Large White	*Pieris brassicae*
Green-veined White	*Pieris napi*
Small White	*Pieris rapae*
Common Blue	*Polyommatus icarus*
Gatekeeper	*Pyronia tithonus*
Small Skipper	*Thymelicus sylvestris*
Red Admiral	*Vanessa atalanta*

Scheme:	Organic ELS (+HLS)
Landscape:	Hampshire Downs
Peacock	*Aglais io*
Small Tortoiseshell	*Aglais urticae*
Orange-tip	*Anthocharis cardamines*
Ringlet	*Aphantopus hyperantus*
Clouded Yellow	*Colias croceus*
Brimstone	*Gonepteryx rhamni*
Small Copper	*Lycaena phlaeas*
Meadow Brown	*Maniola jurtina*
Speckled Wood	*Pararge aegeria*
Large White	*Pieris brassicae*
Green-veined White	*Pieris napi*
Small White	*Pieris rapae*
Gatekeeper	*Pyronia tithonus*
Small Skipper	*Thymelicus sylvestris*

Scheme:	Organic ELS (+HLS)
Landscape:	Low Weald
Peacock	*Aglais io*
Small Tortoiseshell	*Aglais urticae*
Orange-tip	*Anthocharis cardamines*
Ringlet	*Aphantopus hyperantus*
Holly Blue	*Celastrina argiolus*
Clouded Yellow	*Colias croceus*
Brimstone	*Gonepteryx rhamni*
Small Copper	*Lycaena phlaeas*
Meadow Brown	*Maniola jurtina*
Speckled Wood	*Pararge aegeria*
Large White	*Pieris brassicae*
Green-veined White	*Pieris napi*
Small White	*Pieris rapae*
Comma	*Polygonia c-album*
Common Blue	*Polyommatus icarus*
Gatekeeper	*Pyronia tithonus*
Small Skipper	*Thymelicus sylvestris*

Bumblebee species recorded in 2012, 2013 and 2014 on transects

Scheme: Conservation Grade (+ELS)
Landscape: Chilterns North
Bombus hypnorum
Bombus lapidarius
Bombus lucorum agg.
Bombus pascuorum
Bombus pratorum
Bombus terrestris

Scheme: Conservation Grade (+ELS)
Landscape: Chilterns South
Bombus hortorum
Bombus hypnorum
Bombus lapidarius
Bombus lucorum agg.
Bombus pascuorum
Bombus pratorum
Bombus terrestris
Bombus vestalis

Scheme: Conservation Grade (+ELS)
Landscape: Hampshire Downs
Bombus hortorum
Bombus hypnorum
Bombus lapidarius
Bombus lucorum agg.
Bombus pascuorum
Bombus pratorum
Bombus terrestris
Bombus vestalis
Bombus rupestris

Scheme: Conservation Grade (+ELS)
Landscape: Low Weald
Bombus lapidarius
Bombus lucorum agg.
Bombus pascuorum
Bombus pratorum
Bombus terrestris
Bombus hypnorum

Scheme: ELS
Landscape: Chilterns North
Bombus campestris
Bombus hypnorum
Bombus lapidarius
Bombus lucorum agg.
Bombus pascuorum
Bombus sylvestris
Bombus terrestris
Bombus vestalis

Scheme: ELS
Landscape: Chilterns South
Bombus lapidarius
Bombus lucorum agg.
Bombus pascuorum
Bombus pratorum
Bombus terrestris
Bombus hypnorum
Bombus hortorum

Scheme: ELS
Landscape: Hampshire Downs
Bombus lapidarius
Bombus lucorum agg.
Bombus pascuorum
Bombus terrestris
Bombus rupestris

Scheme: ELS
Landscape: Low Weald
Bombus hortorum
Bombus lapidarius
Bombus lucorum agg.
Bombus pascuorum
Bombus pratorum
Bombus terrestris
Bombus hypnorum

Scheme: Organic ELS (+HLS in 2013)
Landscape: Chilterns North
Bombus campestris
Bombus lapidarius
Bombus lucorum agg.
Bombus pascuorum
Bombus pratorum
Bombus ruderarius
Bombus terrestris

Scheme: Organic ELS (+HLS)
Landscape: Chilterns South
Bombus campestris
Bombus hortorum
Bombus hypnorum
Bombus lapidarius
Bombus pascuorum
Bombus pratorum
Bombus terrestris
Bombus lucorum agg.

Scheme: Organic ELS (+HLS)
Landscape: Hampshire Downs
Bombus hortorum
Bombus lapidarius
Bombus lucorum agg.
Bombus pascuorum
Bombus rupestris
Bombus terrestris
Bombus hypnorum
Bombus pratorum
Bombus vestalis

Scheme: Organic ELS (+HLS)
Landscape: Low Weald
Bombus campestris
Bombus lapidarius
Bombus lucorum agg.
Bombus pascuorum
Bombus terrestris
Bombus hypnorum
Bombus pratorum

Solitary bee species recorded in pan traps in 2012, 2013 and 2014

Scheme: Conservation Grade (+ELS+HLS)
Landscape: Chilterns North

Andrena bicolor
Andrena carantonica
Andrena chrysosceles
Andrena cineraria
Andrena dorsata
Andrena flavipes
Andrena fucata
Andrena fulva
Andrena haemorrhoa
Andrena helvola
Andrena labiata
Andrena minutula
Andrena nigroaenea
Andrena nitida
Andrena proxima
Andrena semilaevis
Andrena subopaca
Halictus rubicundus
Halictus tumulorum
Hylaeus confusus
Hylaeus dilatatus
Lasioglossum albipes
Lasioglossum calceatum
Lasioglossum fulvicorne
Lasioglossum leucopus
Lasioglossum leucozonium
Lasioglossum malachurum
Lasioglossum minutissimum
Lasioglossum morio
Lasioglossum parvulum
Lasioglossum pauxillum
Lasioglossum quadrinotatum
Lasioglossum villosulum
Lasioglossum zonulum
Nomada fabriciana
Nomada flava
Nomada flava/panzeri
Nomada flavoguttata
Nomada goodeniana
Nomada lathburiana
Nomada ruficornis
Sphecodes ephippius
Sphecodes miniatus
Sphecodes monilicornis

Scheme: Conservation Grade (+ELS)
Landscape: Chilterns South

Andrena bicolor
Andrena carantonica
Andrena cineraria
Andrena dorsata
Andrena flavipes
Andrena fulva
Andrena labiata
Andrena haemorrhoa
Andrena minutula
Andrena nigroaenea
Andrena nitida
Andrena praecox
Andrena semilaevis
Andrena subopaca
Andrena synadelpha
Lasioglossum albipes
Lasioglossum calceatum
Lasioglossum leucozonium
Lasioglossum malachurum
Lasioglossum morio
Lasioglossum quadrinotatum
Lasioglossum xanthopus
Lasioglossum zonulum
Nomada fabriciana
Nomada flava
Nomada flavoguttata
Nomada goodeniana
Nomada panzeri
Osmia bicolor
Osmia bicornis

Scheme: Conservation Grade (+ELS+HLS)
Landscape: Hampshire Downs

Andrena bicolor
Andrena carantonica
Andrena chrysosceles
Andrena cineraria
Andrena dorsata
Andrena flavipes
Andrena fucata
Andrena fulva
Andrena haemorrhoa
Andrena helvola
Andrena minutula
Andrena nigroaenea
Andrena nitida
Andrena praecox
Andrena semilaevis
Andrena subopaca
Andrena synadelpha
Andrena varians
Chelostoma campanularum
Halictus rubicundus
Halictus tumulorum
Hylaeus communis
Lasioglossum albipes
Lasioglossum calceatum
Lasioglossum fulvicorne
Lasioglossum lativentre
Lasioglossum leucopus
Lasioglossum leucozonium
Lasioglossum malachurum
Lasioglossum morio
Lasioglossum parvulum
Lasioglossum pauxillum
Lasioglossum villosulum
Lasioglossum xanthopus
Lasioglossum zonulum
Melitta haemorrhoidalis
Nomada fabriciana
Nomada flava/panzeri
Nomada flavoguttata
Nomada goodeniana
Nomada lathburiana
Nomada panzeri
Osmia bicolor
Osmia bicornis
Sphecodes miniatus

Scheme: Conservation Grade (+ELS+HLS)
Landscape: Low Weald

Andrena angustior
Andrena chrysosceles
Andrena cineraria
Andrena dorsata
Andrena flavipes
Andrena haemorrhoa
Andrena helvola
Andrena labiata
Andrena minutula
Andrena nigroaenea
Andrena nitida
Andrena semilaevis
Andrena subopaca
Andrena synadelpha
Anthidium manicatum
Halictus tumulorum
Hylaeus communis
Hylaeus confusus
Hylaeus dilatatus
Lasioglossum calceatum
Lasioglossum laevigatum
Lasioglossum lativentre
Lasioglossum malachurum
Lasioglossum morio
Lasioglossum pauxillum
Lasioglossum smeathmanellum
Lasioglossum villosulum
Lasioglossum zonulum
Megachile centuncularis
Megachile versicolor

Nomada fabriciana
Nomada flava
Nomada flavoguttata
Nomada goodeniana
Nomada panzeri
Osmia bicornis
Sphecodes ephippius

Scheme: ELS
Landscape: Chilterns North
Andrena bicolor
Andrena chrysosceles
Andrena cineraria
Andrena dorsata
Andrena flavipes
Andrena fulva
Andrena haemorrhoa
Andrena minutula
Andrena nigroaenea
Andrena nitida
Andrena subopaca
Halictus rubicundus
Halictus tumulorum
Hylaeus confusus
Hylaeus dilatatus
Lasioglossum calceatum
Lasioglossum fulvicorne
Lasioglossum leucopus
Lasioglossum malachurum
Lasioglossum minutissimum
Lasioglossum pauxillum
Lasioglossum zonulum
Nomada fabriciana
Nomada flava
Nomada flavoguttata
Nomada goodeniana
Nomada marshamella
Nomada ruficornis
Osmia bicornis
Osmia spinulosa
Sphecodes ephippius
Sphecodes monilicornis

Scheme: ELS
Landscape: Chilterns South
Andrena bicolor
Andrena chrysosceles
Andrena cineraria
Andrena clarkella
Andrena dorsata
Andrena flavipes
Andrena fulva
Andrena haemorrhoa
Andrena minutula
Andrena nigroaenea
Andrena nitida
Andrena praecox
Andrena semilaevis
Andrena subopaca
Andrena synadelpha
Andrena trimmerana
Halictus tumulorum
Hylaeus dilatatus
Lasioglossum calceatum
Lasioglossum fulvicorne
Lasioglossum leucopus
Lasioglossum leucozonium
Lasioglossum malachurum
Lasioglossum minutissimum
Lasioglossum morio
Lasioglossum parvulum
Lasioglossum pauxillum
Lasioglossum smeathmanellum
Lasioglossum villosulum
Megachile willughbiella
Melitta haemorrhoidalis
Melitta leporina
Nomada fabriciana
Nomada flavoguttata
Osmia bicolor
Osmia bicornis
Osmia leaiana
Osmia spinulosa
Panurgus banksianus
Sphecodes ephippius

Scheme: ELS
Landscape: Hampshire Downs
Andrena bicolor
Andrena carantonica
Andrena chrysosceles
Andrena cineraria
Andrena clarkella
Andrena dorsata
Andrena flavipes
Andrena fulva
Andrena haemorrhoa
Andrena minutula
Andrena nigroaenea
Andrena nitida
Andrena semilaevis
Anthidium manicatum
Halictus rubicundus
Halictus tumulorum
Hylaeus confusus
Lasioglossum albipes
Lasioglossum calceatum
Lasioglossum fulvicorne
Lasioglossum lativentre
Lasioglossum leucopus
Lasioglossum malachurum
Lasioglossum morio
Lasioglossum pauxillum
Lasioglossum villosulum
Lasioglossum xanthopus
Lasioglossum zonulum
Melitta haemorrhoidalis
Nomada fabriciana
Nomada flava
Nomada flavoguttata
Nomada goodeniana
Nomada ruficornis
Osmia bicolor

Scheme: ELS
Landscape: Low Weald
Andrena angustior
Andrena carantonica
Andrena dorsata
Andrena flavipes
Andrena helvola
Andrena labialis
Andrena haemorrhoa
Andrena minutula
Andrena nigroaenea
Andrena nitida
Andrena semilaevis
Andrena similis
Andrena subopaca
Andrena synadelpha
Andrena trimmerana
Andrena wilkella
Halictus tumulorum
Hylaeus confusus
Hylaeus dilatatus
Lasioglossum albipes
Lasioglossum calceatum
Lasioglossum laevigatum
Lasioglossum lativentre
Lasioglossum leucopus
Lasioglossum malachurum
Lasioglossum minutissimum
Lasioglossum morio
Lasioglossum pauxillum
Lasioglossum punctatissimum
Lasioglossum quadrinotatum
Lasioglossum villosulum
Lasioglossum zonulum
Melitta tricincta
Nomada fabriciana
Nomada flava
Nomada flavoguttata
Nomada striata
Osmia bicornis

Scheme: Organic ELS (+HLS in 2013)
Landscape: Chilterns North

Andrena bicolor
Andrena chrysosceles
Andrena cineraria
Andrena dorsata
Andrena helvola
Andrena labialis
Andrena labiata
Andrena haemorrhoa
Andrena minutula
Andrena nigroaenea
Andrena nitida
Andrena semilaevis
Andrena subopaca
Andrena synadelpha
Andrena wilkella
Halictus rubicundus
Halictus tumulorum
Hylaeus confusus
Lasioglossum calceatum
Lasioglossum fulvicorne
Lasioglossum laevigatum
Lasioglossum lativentre
Lasioglossum leucopus
Lasioglossum malachurum
Lasioglossum morio
Lasioglossum pauxillum
Megachile ligniseca
Nomada fabriciana
Nomada flava
Nomada flavoguttata
Nomada goodeniana
Nomada ruficornis

Scheme: Organic ELS (+HLS)
Landscape: Chilterns South

Andrena bicolor
Andrena chrysosceles
Andrena cineraria
Andrena dorsata
Andrena flavipes
Andrena fulvago
Andrena helvola
Andrena labiata
Andrena haemorrhoa
Andrena minutula
Andrena nigroaenea
Andrena nitida
Andrena semilaevis
Andrena subopaca
Andrena synadelpha
Andrena wilkella
Chelostoma campanularum
Halictus rubicundus
Halictus tumulorum
Hylaeus confusus
Lasioglossum albipes
Lasioglossum calceatum
Lasioglossum fulvicorne
Lasioglossum lativentre
Lasioglossum malachurum
Lasioglossum morio
Nomada fabriciana
Nomada flava/panzeri
Nomada flavoguttata
Nomada goodeniana
Nomada marshamella
Nomada panzeri
Nomada ruficornis
Osmia bicolor
Osmia bicornis
Osmia leaiana

Sphecodes ephippius

Scheme: Organic ELS (+HLS)
Landscape: Hampshire Downs

Andrena bicolor
Andrena chrysosceles
Andrena cineraria
Andrena dorsata
Andrena flavipes
Andrena fucata
Andrena haemorrhoa
Andrena minutula
Andrena nigroaenea
Andrena nitida
Andrena semilaevis
Halictus rubicundus
Halictus tumulorum
Hylaeus communis
Lasioglossum albipes
Lasioglossum calceatum
Lasioglossum leucopus
Lasioglossum malachurum
Lasioglossum parvulum
Lasioglossum villosulum
Megachile centuncularis
Melitta haemorrhoidalis
Nomada fabriciana
Nomada goodeniana
Nomada lathburiana
Nomada ruficornis
Osmia bicolor
Sphecodes ephippius
Sphecodes niger

Scheme: Organic ELS (+HLS)
Landscape: Low Weald

Andrena angustior
Andrena bicolor
Andrena carantonica
Andrena dorsata
Andrena minutula
Andrena nigroaenea
Andrena nitida
Anthophora bimaculata
Colletes daviesanus
Epeolus cruciger
Halictus rubicundus
Hylaeus brevicornis
Hylaeus confusus
Hylaeus dilatatus
Lasioglossum calceatum
Lasioglossum fulvicorne
Lasioglossum laevigatum
Lasioglossum leucozonium
Lasioglossum malachurum
Lasioglossum morio
Lasioglossum punctatissimum
Lasioglossum zonulum
Megachile ligniseca
Melitta haemorrhoidalis
Melitta tricincta
Nomada fabriciana
Nomada marshamella
Osmia bicornis
Sphecodes ephippius
Sphecodes geoffrellus
Sphecodes miniatus
Sphecodes niger

Appendix 9: Results of GLMM models testing habitat diversity as a predictor of species richness

Radius (km)	Estimate	Std Error	LRT Chi^2	p value	Marginal R^2	Conditional R^2
Plants						
0.10	**0.470**	**0.150**	**12.13**	**<0.001**	**0.500**	**0.558**
0.25	**0.418**	**0.164**	**6.291**	**0.012**	**0.440**	**0.491**
1.00	-0.003	0.355	0.048	0.826	<0.001	0.009
3.00	0.138	0.464	0.088	0.766	0.659	0.691
Butterflies						
0.10	**0.535**	**0.099**	**30.71**	**<0.001**	**0.939**	**0.940**
0.25	**0.330**	**0.121**	**7.44**	**0.006**	**0.940**	**0.940**
1.00	0.338	0.208	2.56	0.110	0.949	0.949
3.00	0.344	0.210	2.56	0.110	0.948	0.948
Bumblebees						
0.10	-0.090	0.093	0.949	0.330	0.723	0.723
0.25	-0.158	0.110	2.043	0.153	0.716	0.716
1.00	-0.117	0.190	0.376	0.540	0.703	0.703
3.00	-0.213	0.206	1.084	0.298	0.697	0.697
Solitary bees						
0.10	**0.197**	**0.078**	**6.055**	**0.014**	**0.286**	**0.334**
0.25	0.137	0.101	1.771	0.183	0.310	0.355
1.00	**-0.463**	**0.179**	**4.743**	**0.029**	**0.621**	**0.628**
3.00	-0.422	0.001	2.330	0.127	0.585	0.596
Birds (summer)						
0.10	0.003	0.043	0.004	0.948	0.999	0.999
0.25	-0.023	0.042	0.303	0.582	0.999	0.999
1.00	0.122	0.088	0.121	0.088	0.999	0.999
3.00	0.023	0.131	0.031	0.861	0.999	0.999
Birds (winter)						
0.10	**0.178**	**0.069**	**6.314**	**0.012**	0.144	0.145
0.25	0.054	0.078	0.456	0.498	0.195	0.198
1.00	-0.281	0.172	2.686	0.101	0.572	0.575
3.00	0.011	0.118	0.009	0.926	0.240	0.245

Appendix 10: Most parsimonious models after simplification of GLMM models testing effects of AES type and habitat diversity, plus their interaction on species richness

Taxonomic group	Scale	Variable	Estimate	SE	df	LRT Chi^2	P value
Plants							
	100 m						
		Scheme type			2	7.78	0.020
		CG	-0.0008	0.201			
		Org	0.0022	0.194			
		Habitat diversity	-0.0003	0.130	1	13.2	<0.001
	250 m						
		Scheme type			2	6.32	0.043
		CG	-0.015	0.202			
		Org	0.468	0.194			
		Habitat diversity	0.407	0.165	1	5.93	0.015
Butterflies							
	100 m						
		Abundance	5.889	0.526	1	96.77	<0.001
		Habitat diversity	0.530	0.098	1	29.87	<0.001
		Scheme type			2	6.25	0.044
		CG	0.186	0.122			
		Org	0.286	0.114			
		MFC 1km	0.013	0.005	1	8.21	0.004
		Year	0.540	0.105	1	27.63	<0.001
	250 m						
		Abundance	6.04	0.520	1	106.00	<0.001
		Habitat diversity	0.293	0.124	1	5.60	0.018
		Scheme type			2	5.26	0.072
		CG	0.216	0.123			
		Org	0.248	0.114			
		MFC 1km	0.012	0.005	1	6.93	0.008
		Year	0.556	0.105	1	29.39	<0.001
Bumblebees							
	100 m						
		Abundance	1.587	0.217	1	41.7	<0.001
		Habitat diversity	-0.096	0.093	1	1.07	0.300
		Scheme type			2	1.70	0.427
		CG	0.029	0.108			
		Org	-0.106	0.111			
		MFC 1km	0.007	0.004	1	2.41	0.121
		Year	1.668	0.133	1	216	<0.001
	250 m						
		Abundance	1.599	0.214	1	42.8	<0.001
		Habitat diversity	-0.157	0.114	1	1.89	0.169
		Scheme type			2	1.42	0.491
		CG	0.047	0.110			
		Org	-0.080	0.114			
		MFC 1km	0.008	0.004	1	3.08	0.08
		Year	1.679	0.133	1	217	<0.001

Taxonomic group	Scale	Variable	Estimate	SE	df	LRT Chi^2	P value
Solitary bees							
	100 m						
		Abundance	1.118	0.125	1	74.52	<0.001
		Habitat diversity	0.196	0.079	1	6.007	0.014
		Scheme type			2	1.155	0.561
		CG	-0.027	0.128			
		Org	-0.138	0.129			
		MFC 1km			1	7.393	0.007
		Year			1	35.229	<0.001
	250 m						
		Abundance	1.166	0.125	1	80.70	<0.001
		Habitat diversity	0.144	0.102	1	1.948	0.163
		Scheme type			2	1.378	0.502
		CG	-0.023	0.132			
		Org	-0.152	0.132			
		MFC 1km	0.012	0.005	1	6.415	0.011
		Year	0.456	0.076	1	33.988	<0.001
Summer birds							
	100 m						
		Abundance	0.307	0.030	1	88.07	<0.001
		Habitat diversity				0.003	0.959
		Scheme type			2	1.117	0.572
		CG	-0.029	0.049			
		Org	-0.057	0.055			
		Year	0.172	0.039	1	18.35	<0.001
	250 m						
		Abundance	0.307	0.030	1	18.297	<0.001
		Habitat diversity	-0.015	0.043	1	0.118	0.732
		Scheme type			2	0.933	0.673
		CG	-0.027	0.048			
		Org	-0.053	0.056			
		Year	0.175	0.040	1	18.297	<0.001
Winter birds							
	100 m						
		Abundance	0.102	0.005	1	382.5	<0.001
		Habitat diversity	0.192	0.068	1	7.46	0.006
		Scheme type			2	2.36	0.307
		CG	-0.024	0.064			
		Org	0.073	0.066			
	250 m						
		Abundance	0.107	0.005	1	490.2	<0.001
		Habitat diversity	0.073	0.081	1	0.80	0.372
		Scheme type			2	1.56	0.459
		CG	-0.044	0.065			
		Org	0.042	0.067			

Appendix 11: Scatter plots showing the relationships between habitat diversity and species richness for taxa where significant relationships were found

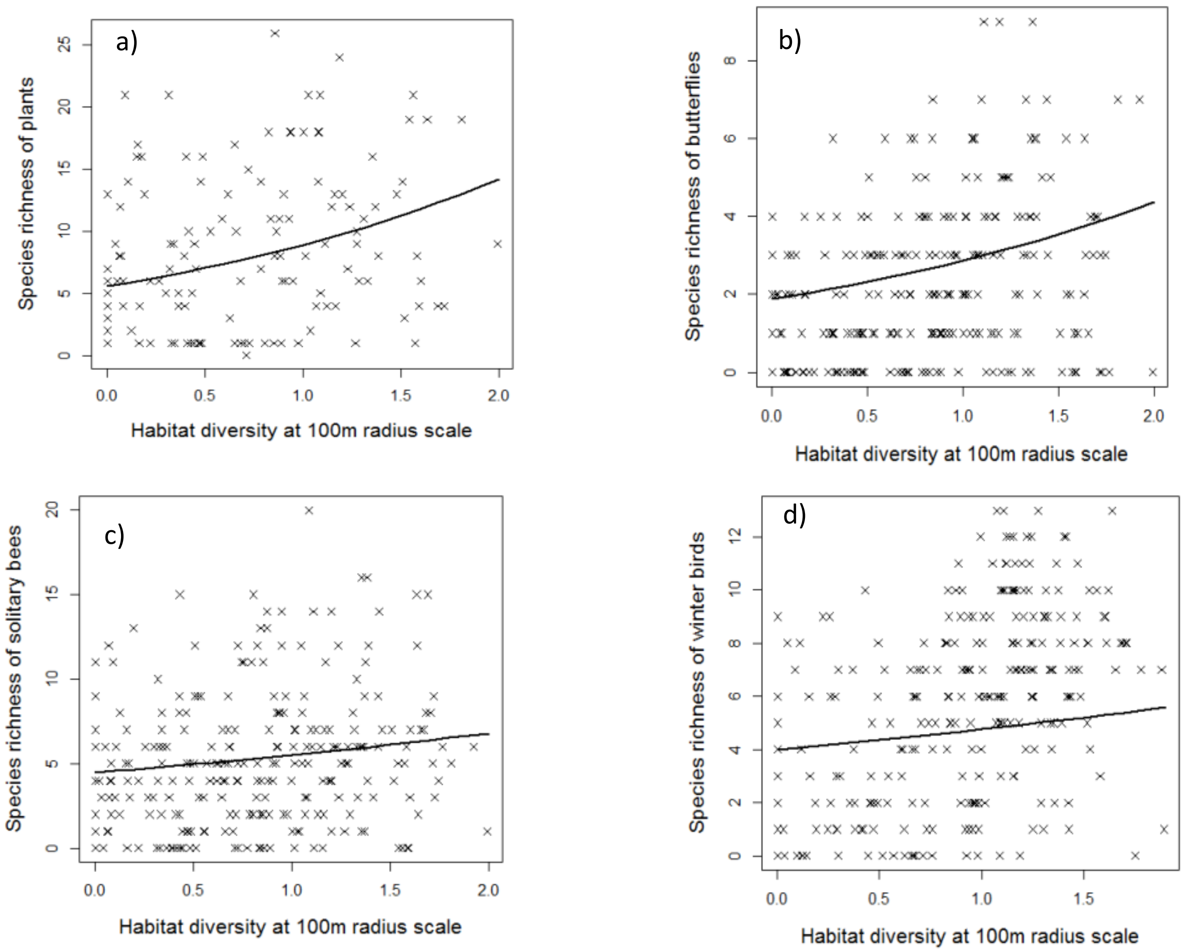


Figure A1: Scatter plots and regression lines for relationships between habitat diversity at the 100 m radius scale and species richness of a) plants, b) butterflies, c) solitary bees and d) winter birds

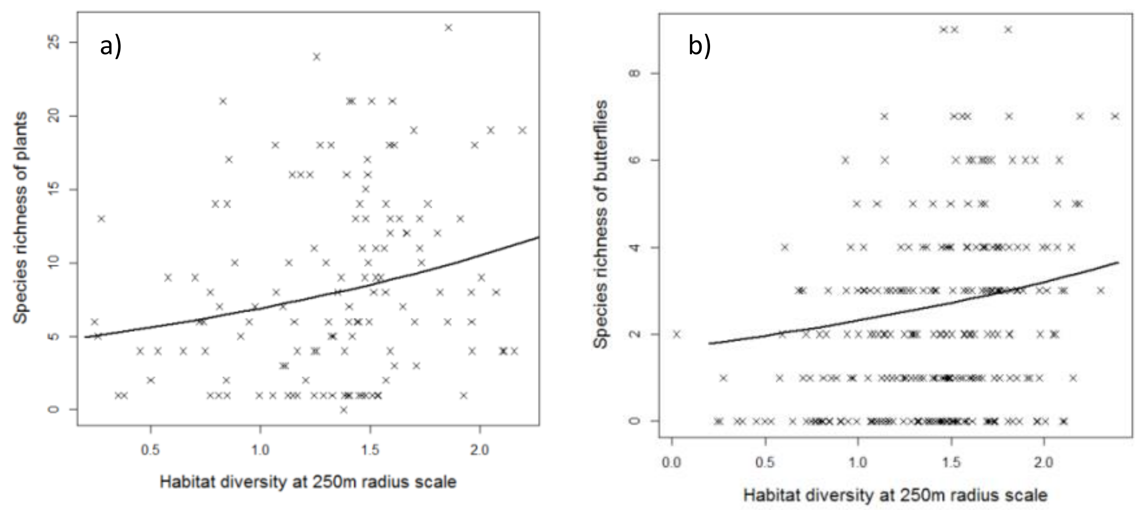


Figure A2: Scatter plots and regression lines for relationships between habitat diversity at the 250 m radius scale and species richness of a) plants and b) butterflies.

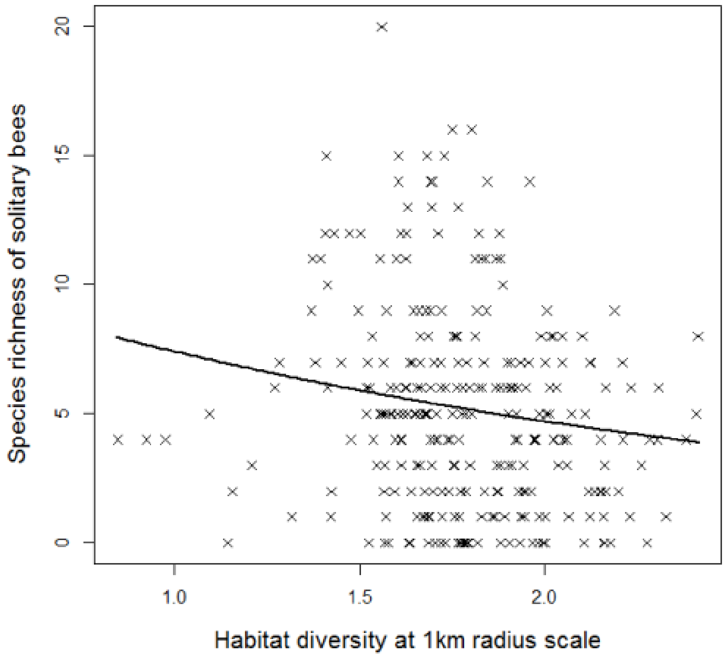
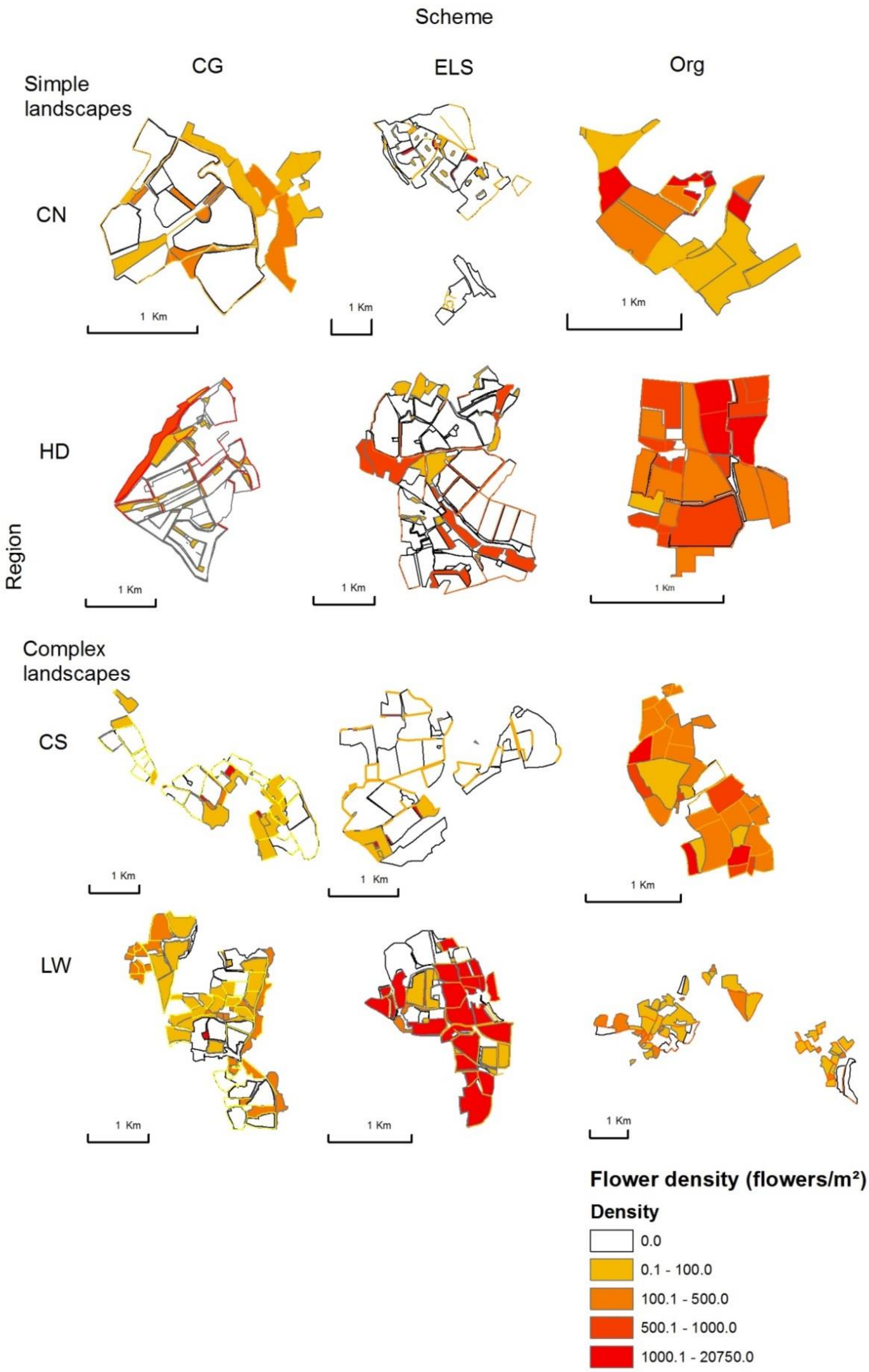


Figure A3: Scatter plots and regression lines for relationships between habitat diversity at the 1 km radius scale and species richness of solitary bees.

Appendix 12: Differences in presence of floral resources, pollinators and pollination services

There were no significant differences between farm types in the presence of bees (GLMM LRT, Chi^2 (2) = 0.348, p=0.840) or hoverflies (GLMM LRT, Chi^2 (2) = 0.341, p=0.843) at pollinator sampling points. The presence of pollinator visitation to wildflowers did not significantly differ between farm types for bees (GLMM LRT, Chi^2 (2) = 1.351, p=0.509) or hoverflies (GLMM LRT, Chi^2 (2) = 1.453, p=0.484). The presence of fruit set did not vary between farm types (GLMM LRT, Chi^2 (2) = 1.819, p=0.403), with only 5 of 105 sampling points having zero fruit set.

Appendix 13: Habitat maps (including hedgerows) coloured by flower density (flowers per m^2) in July from twelve farms in three different wildlife-friendly farming schemes across four regions. Farm triplets labelled by National Character Area: CN=Chilterns North, CS=Chilterns South, LW=Low Weald, HD=Hampshire Downs.



Appendix 14: Model results for a zero-inflated negative binomial model on floral density

Count model coefficients (negative binomial with log link):

	Estimate	Std. Error	z value	Pr(>|z|)	
(Intercept)	4.4442	0.7003	6.346	2.21E-10	***
Farmtype CG	1.1771	1.2836	0.917	0.35913	
Farmtype Org	3.223	0.8491	3.796	0.000147	***
Cropfactor: noncrop	4.1027	0.7513	5.461	4.75E-08	***
Farmtype CG:cropfactor noncrop	-1.6906	1.3328	-1.268	0.204662	
Farmtype Org:cropfactor noncrop	-3.161	0.9245	-3.419	0.000628	***
Log(theta)	-0.9501	0.1302	-7.296	2.97E-13	***

Zero-inflation model coefficients (binomial with logit link):

	Estimate	Std. Error	z value	Pr(>|z|)	
(Intercept)	1.1118	0.4655	2.388	0.0169	*
Farmtype CG	-0.2582	0.4569	-0.565	0.5721	
Farmtype Org	-1.9836	0.6873	-2.886	0.0039	**
Cropfactor noncrop	-2.4014	0.4847	-4.954	7.26E-07	***

Appendix 15: Winter wheat yields for the twelve study farms and sources of reports of winter wheat yields on organic farms in England and Wales

Scheme	Region	Mean winter wheat yield (t/ha) (±SE)
ELS	LW	6.85±0.23
ELS	CS	6.81±0.23
ELS	CN	6.92±0.58
ELS	HD	7.48±0.40
Org	LW	NA
Org	CS	2.29±0.36
Org	CN	2.99±0.19
Org	HD	3.18±0.53
CG	LW	8.56±0.49
CG	CS	7.72±0.42
CG	CN	NA
CG	HD	7.61±0.00

List of reports used to calculate 5 year average yield difference between organic and conventional winter wheat for England and Wales, available at http://www.orgprints.org/

Moakes, Simon and Lampkin, Nicolas (2010) Organic farm incomes in England and Wales 2008/09 (OF 0373). Aberystwyth University and Organic Research Centre, Aberystwyth and Newbury.

Moakes, Simon and Lampkin, Nicolas (2011) Organic farm incomes in England and Wales 2009/10 (OF 0373). Aberystwyth University and Organic Research Centre, Aberystwyth and Newbury.

Moakes, Simon; Lampkin, Nicolas and Gerrard, Catherine L (2012) Organic farm incomes in England and Wales 2010/11 (OF 0373). Aberystwyth University and Organic Research Centre, Aberystwyth and Newbury.

Moakes, Simon; Lampkin, Nicolas and Gerrard, Catherine L (2013) Organic farm incomes in England and Wales 2011/12 (OF0373). Aberystwyth University and Organic Research Centre, Aberystwyth and Newbury

Moakes, Simon; Lampkin, Nicolas and Gerrard, Catherine L (2014) Organic farm incomes in England and Wales 2012/13. Aberystwyth University and Organic Research Centre, Aberystwyth and Newbury

Appendix 16: Sampling methods for pollen and nectar content per flower (Baude et al. (unpublished)

Overview

Sampling was carried out between February and October in 2011 and 2012 in southern England. The species list of plants to survey was created by computing the mean vegetative cover from the Countryside Survey 2007 (Carey *et al.* 2008). Of the 454 species that covered 99% of the UK land area, over half were not considered rewarding to pollinators (wind-pollinated angiosperms, bryophytes, pteridophytes and gymnosperms). The remaining 220 species, plus 50 known to be locally important to pollinators were used as a list to survey.

Nectar survey methods

A total of 175 species were surveyed for nectar (sample sizes given in Appendix 13). Flowers were bagged 24 hours before sampling to allow nectaries to fill. Sampling was carried out between 9am and 4pm. Glass microcapillaries were used to sample nectar wherever possible. When not possible, flowers were rinsed with distilled water and the diluted solution was sampled. The volume collected was measured and a refractometer was used to measure the concentration of sugar. Then the volume and concentration were used to estimate an amount of sugar produced per flower per 24 hours, using equations in Corbet *et al.* (2001).

Pollen survey methods (see Dicks et al. 2015, Supplementary Information).

References

Carey, P.D., Wallis, S., Chamberlain, P.M., Cooper, A., Emmett, B.A., Maskell, L.C., McCann, T., Murphy, J., Norton, L.R., Reynolds, B., Scott, W.A., Simpson, I.C., Smart, S.M. & Ullyett, J.M. (2008) Countryside Survey: UK Results from 2007.

Corbet, S. a, Bee, J., Dasmahapatra, K., Gale, S., Gorringe, E., La Ferla, B., Moorhouse, T., Trevail, a, Van Bergen, Y. & Vorontsova, M. (2001) Native or exotic? Double or single? Evaluating plants for pollinator-friendly gardens. Annals of Botany, 87, 219–232.

Dicks, L. V., Baude, M., Roberts, S.P.M., Phillips, J., Green, M. & Carvell, C. (2015) How much flower-rich habitat is enough for wild pollinators? Answering a key policy question with incomplete knowledge. Ecological Entomology, 40, 22–35.

Appendix 17: Species where substitutions were used because pollen and nectar data were not available

Species with data missing	Missing N?	Missing P?	Substitute	Occur-rence*	Notes
Aethusa cynapium		Y	*Anthriscus sylvestris*	9	
Chaerophyllum temulum		Y	*Anthriscus sylvestris*	7	
Euonymus europaeus	Y	Y	*Oxalis acetosella*	6	
Persicaria maculosa		Y	*Polygonum aviculare agg.*	6	
Rumex acetosella		Y	*Polygonum aviculare agg.*	6	
Tamus communis	Y	Y	*Iris pseudacorus*	5	
Conopodium majus		Y	*Anthriscus sylvestris*	5	
Alliaria petiolata		Y	*Sisymbrium officinale*	4	
Centaurium erythraea	Y	Y	*Galium*	4	Genus average for Galium
Sanguisorba minor subsp. minor		Y	*Agrimonia eupatoria*	4	
Dactylorhiza fuchsii		Y	*Iris pseudacorus*	3	
Cichorium intybus		Y	*Lapsana communis*	3	
Clinopodium vulgare	Y	Y	*Prunella vulgaris*	3	
Conium maculatum		Y	*Aethusa cynapium*	3	
Malva moschata	Y	Y	*Acer pseudoplatanus*	3	
Orobanche minor	Y	Y	*Euphrasia officinalis agg.*	3	
Reseda lutea	Y		*Capsella bursa-pastoris*	3	
Sherardia arvensis		Y	*Galium*	3	Genus average for Galium
Arenaria serpyllifolia		Y	*Stellaria graminea*	2	Genus average for Stellaria
Artemisia vulgaris		Y	*Achillea millefolium*	2	
Ballota nigra		Y	*Stachys sylvatica*	2	
Bryonia dioica	Y	Y	*Corylus avellana*	2	
Cruciata laevipes		Y	*Galium*	2	Genus average for Galium
Hieracium agg.	Y	Y	*Crepis capillaris*	2	
Malva neglecta	Y	Y	*Acer pseudoplatanus*	2	
Malva sylvestris	Y	Y	*Acer pseudoplatanus*	2	
Melilotus officinalis		Y	*Medicago*	2	Genus average for Medicago
Mentha arvensis		Y	*Thymus polytrichus*	2	
Oenanthe crocata		Y	*Aethusa cynapium*	2	
Phacelia tanacetifolia	Y	Y	*Myosotis arvensis*	2	
Sison amomum	Y	Y	*Angelica sylvestris*	2	

Tragopogon pratensis	Y	Y	*Sonchus*	2	Genus average for Sonchus
Anacamptis pyramidalis	Y	Y	*Iris pseudacorus*	1	
Listera ovata	Y	Y	*Iris pseudacorus*	1	
Orchis mascula	Y	Y	*Iris pseudacorus*	1	
Aegopodium podagraria		Y	*Anthriscus sylvestris*	1	
Barbarea vulgaris	Y	Y	*Capsella bursa-pastoris*	1	
Carduus nutans		Y	*Cirsium*	1	Genus average for Cirsium
Conyza bonariensis	Y	Y	*Aster tripolium*	1	
Euphorbia amygdaloides	Y	Y	*Mercurialis perennis*	1	
Fagopyrum esculentum	Y	Y	*Polygonum aviculare agg.*	1	
Fragaria vesca	Y	Y	*Geum urbanum*	1	
Fumaria officinalis		Y	*Papaver rhoeas*	1	
Galeopsis tetrahit	Y	Y	*Lamium*	1	Genus average for Lamium
Lepidium campestre	Y	Y	*Cardamine*	1	Genus average for Cardamine
M. x verticillata	Y	Y	*Thymus polytrichus*	1	
Pimpinella saxifraga		Y	*Anthriscus sylvestris*	1	
Reseda luteola	Y		*Capsella bursa-pastoris*	1	
Rorippa amphibia	Y	Y	*Capsella bursa-pastoris*	1	
Rorippa sylvestris	Y	Y	*Capsella bursa-pastoris*	1	
Rumex acetosa	Y	Y	*Polygonum aviculare agg.*	1	
Salvia verbenaca		Y	*Thymus polytrichus*	1	
Tilia cordata	Y	Y	*Acer pseudoplatanus*	1	
Viburnum lantana		Y	*Sambucus nigra*	1	
Viburnum opulus	Y	Y	*Sambucus nigra*	1	
Zea mays[¶]	Y	Y	*Literature*	1	

*Number of sampling points at which the plant species occurred.[¶]Zea mays has 45 000 pollen grains to every ovule (Weatherwax 2013), we assumed that this means 45 000 per flower. Grain size was 58 – 99 um diameter (Sluyter 1997), so we took the mean and presuming a spherical shape, calculated the volume per flower.

References

Sluyter, A. (1997)) pollen: Normalizing the effects of microscope-slide mounting media on diameter determinations. Palynology, 21, 35–39.

Weatherwax, P. (2013) Torrey Botanical Society Morphology of the Flowers of Zea mays of Zea Mays flowers of the Morphology. , 43, 127–144.

Appendix 18: Sources of error in pollen and nectar density calculations

Source of error	Notes
PF: Pollen or nectar content per flower	Number of stamens per flower, number of pollen grains per stamen and the volume of one pollen grain are all sources of error that could be reduced by sampling more flowers, from a range of sites. In the Müller et al., (2006) dataset, 30 flowers from 30 individuals were sampled for pollen. In the Baude et al. dataset, pollen was counted in 1-4 tubes containing 1-460 stamens (depending of species specific stamen size) collected from one or three populations (median: 4 tubes of 32 stamens from 2 populations). Pollen grain was measured for 5-24 pollen grains from one or three populations (median: 10 pollen grains from 2 populations). Flower life span was not considered. For some species data were not available so substitute values were used. Intraspecific variability was not assessed (flower sex and flower age not considered; climatic and edaphic conditions not controlled).
NF: Nectar content per flower	In the Baude et al. dataset of nectar content per flower, sources of error include: the use of sucrose equivalents from refractometer measures and the potential water loss for rinsed flowers. In addition the secretion rates were not assessed. Between 5 and 30 flowers were collected from one or three populations (median: 20 flowers from 2 populations). Errors could be reduced by sampling more flowers from a range of sites. For some species data were not available so substitute values were used. This error could be reduced by expanding the number of species sampled. Intraspecific variability was not assessed (flower sex and flower age not considered; climatic and edaphic conditions not controlled).
FFU: Flowers per floral unit	Five representative floral units were dissected to count the number of open flowers, each time a new compound flower was found on a farm in each sampling round. This error could be reduced by sampling more flowers.
FUH: Floral units per m^2	We assume that the sampling area is representative of the whole habitat area. The distribution of plants is patchy which introduces error. This could be reduced by widening the survey area.

References

Müller, A., Diener, S., Schnyder, S., Stutz, K., Sedivy, C. & Dorn, S. (2006) Quantitative pollen requirements of solitary bees: Implications for bee conservation and the evolution of bee-flower relationships. Biological Conservation, 130, 604–615.

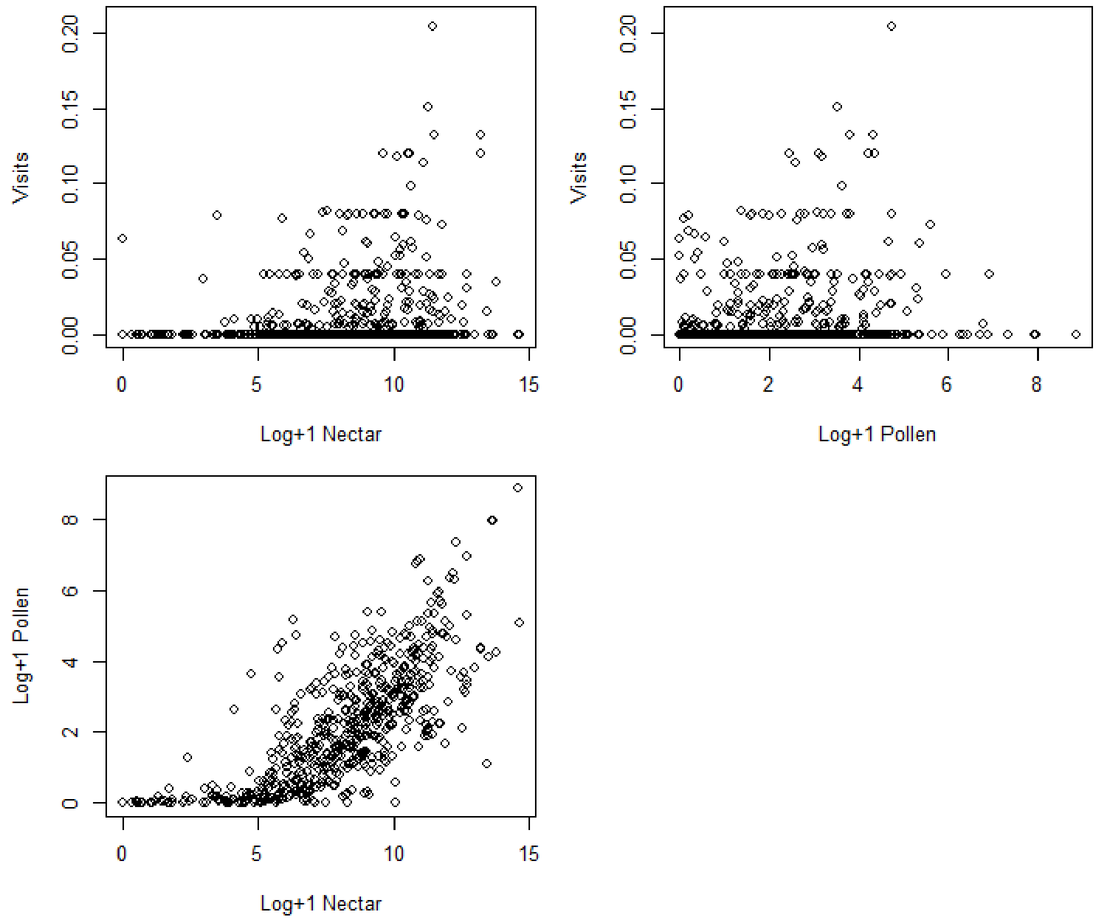
Appendix 19: Mean and standard error for variables used to calculate pollen supply

	Variable	Mean	SE	N	SE (% of mean)
	Data from literature				
PF	Pollen volume per flower (Müller et al 2006, mm^3)	0.56	0.21	16	37.5
	Pollen volume per flower (Baude et al. unpublished,	0.75	0.18	156	24.0
NF	Nectar sugar content per flower (Baude et al.	241.3	55.9	176	23.0
	Data from this study				
FUU	Open flowers per floral unit*	40.9	5.72	197	14.0
FUH	Floral units per m^2¶	8.82	1.11	3105	12.6

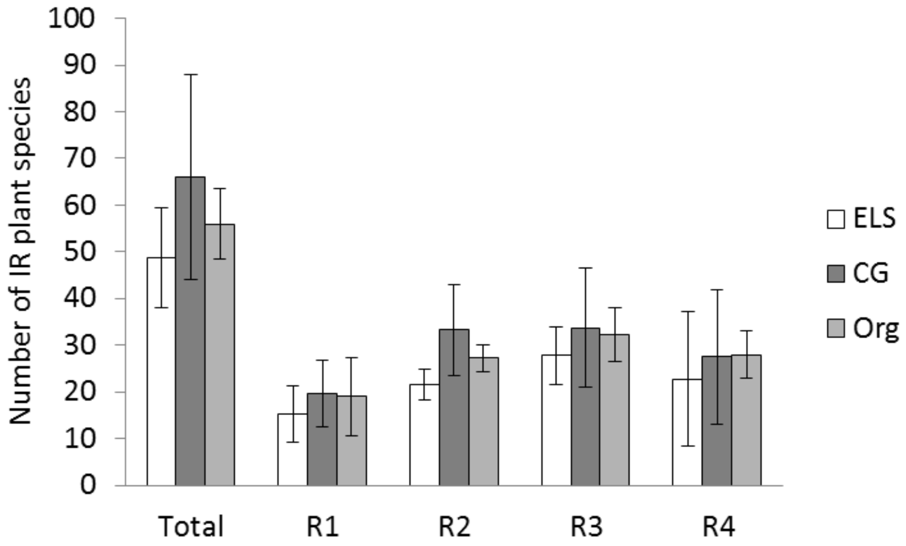
*This includes variation between species, variation within species over time and variation within species between sites. ¶This includes variation within habitats, between habitats and between sites.

Appendix 20: Correlations between local density of pollen, nectar and bee flower visits: density of nectar (µg sugar/m^2/24 hrs) and pollen (mm^3/m^2) were log+1 transformed.

Visit density was significantly positively correlated with pollen density (Estimate =0.002 ±0.0008, LRT Chi^2 (1) = 7.92, p=0.005) and nectar density (Estimate =0.001 ±0.0004, LRT Chi^2 (1) = 8.08, p= 0.004). Nectar and pollen density were significantly correlated (Estimate= 0.4226± 0.0151 LRT Chi^2 (1) = 511.1, p<0.001).



Appendix 21: Variation in the farm-level number of insect-rewarding plants through the seasonal rounds between wildlife-friendly farming scheme types. Bars show the mean and 95% confidence intervals across four farms per scheme. The total is the total number of plant species across all rounds combined. R=round, CG=Conservation Grade, Org=Organic, ELS=Entry Level Stewardship.



Appendix 22: Results of linear models testing for the effect of the interaction between scheme type and round on the density of pollen, nectar and visits at the farm scale

		F	df	P	Post-hoc test	Est	SE	P	
Pollen density	Scheme * Round	2.45	6	0.043	R4:Org > R4:CG	1.62	0.66	0.173	
					R4:Org > R4:ELS	2.07	0.66	0.035	*
					R4:CG > R4:ELS	0.45	0.66	0.997	
					R3:Org > R3:CG	0.85	0.66	0.864	
					R3:Org>R3:ELS	1.09	0.66	0.640	
					R3:CG > R3:ELS	0.24	0.66	1.000	
					R2:Org > R2:CG	0.86	0.66	0.854	
					R2:Org > R2:ELS	1.38	0.66	0.348	
					R2:CG > R2:ELS	0.51	0.66	0.992	
					R1:Org < R1:CG	-1.23	0.66	0.489	
					R1:Org < R1:ELS	-0.94	0.66	0.788	
					R1:CG > R1:ELS	0.29	0.66	1.000	
Nectar density	Scheme * Round	7.34	6	0.291					
	Round	5.13	3	0.163					
	Scheme	13.69	2	0.001	CG > ELS	0.52	0.45	0.470	
					Org > ELS	1.61	0.45	<0.001	***
					Org > CG	1.08	0.45	0.040	*
Visit density	Scheme * Round	1.27	6	0.294					
	Round	27.1	3	<0.001	R4 > R1	4.55	0.62	<0.001	***
					R4 > R2	0.32	0.62	0.994	
					R4 < R3	0.29	0.62	0.996	
					R3 > R2	0.61	0.62	0.898	
					R3 > R1	4.84	0.62	<0.001	***
					R2 > R1	4.23	0.62	<0.001	***
	Scheme	11.33	2	<0.001	CG > ELS	0.66	0.54	0.781	
					Org > ELS	2.47	0.54	<0.001	***
					Org > CG	1.81	0.54	0.013	*

Appendix 23: Results of general linear mixed effects models (GLMM) on farm scale density of pollen, nectar and visits as a function of an interaction between habitat type, wildlife-friendly farming scheme type and seasonal round, with the results of likelihood ratio tests (LRT) and post-hoc tests

Farm scale		GLMM			Post-hoc test results				
		LRT Chi^2	df	P		Est	SE	P	
Pollen density	Scheme * Round	38.01	42	0.647					
	Habitat *Round	55.15	54	0.431					
	Habitat * Scheme	77.17	48	0.005	CG AES margin > ELS AES margin	0.64	0.44	0.739	
					CG AES grass > ELS AES grass	0.15	0.50	1.000	
					CG hedgerow > ELS hedgerow	0.51	0.44	0.908	
					Org cereal > CG cereal	2.56	0.47	<0.001	***
					Org cereal > ELS cereal	2.26	0.47	<0.001	**
	Round	14.88	3	0.002	R4 < R2	0.60	0.19	0.020	*
					R4 < R1	0.66	0.19	0.008	**
					R4 < R3	0.39	0.19	0.358	
					R3 < R2	0.22	0.19	0.925	
					R2 < R1	0.05	0.19	1.000	
					R3 < R1	0.27	0.19	0.785	
Nectar density	Scheme * Round	101.7	24	<0.001	Habitat * Round * Scheme				
	Habitat *Round	56.1	18	<0.001	R1 CG Hedge > R1 ELS Hedge	1.22	0.72	0.365	
	Habitat * Scheme	46.7	14	<0.001	R4 CG AESM > R4 ELS AESM	1.19	0.72	0.390	
					R4 CG AESG > R4 ELS AESG	0.73	0.83	0.897	
					R4 Org cereal > R4 CG cereal	5.07	0.78	<0.001	***
					R4 Org cereal > R4 ELS cereal	3.79	0.78	<0.001	***
Visit density	Scheme * Round	74.74	39	<0.001	R1 CG Hedge > R1 ELS Hedge	<0.01	0.74	1.000	
	Habitat *Round	95.09	51	<0.001	R4 CG AESM > R4 ELS AESM	0.76	0.74	0.835	
	Habitat * Scheme	111.91	44	<0.001	R4 CG AESG > R4 ELS AESG	0.78	0.86	0.890	
					R4 Org cereal < R4 CG cereal	0.35	1.21	0.999	
					R4 Org cereal > R4 ELS cereal	0.43	0.96	0.994	

Appendix 24: The top five plants in terms of density of pollen, nectar and visitation, at both local (per m^2) and farm (per 100 ha) scales, with density values given in the table

		Pollen		**Nectar**		**Visitation**	
Local scale		mm^3 per m^2		mg sugar per 24 hrs per m^2		Visits per m^2 per min	
	1.	*Acer pseudoplatanus*	752.25	*Crataegus monogyna*	159.06	*Rubus fruiticosus agg.*	41.9×10^{-3}
	2.	*Crataegus monogyna*	512.25	*Tripleurospermum inodorum*	154.8	*Glechoma hederacea*	11.0×10^{-3}
	3.	*Hyacinthoides non-scripta*	183.21	*Acer pseudoplatanus*	89.57	*Taraxacum agg.*	10.6×10^{-3}
	4.	*Calluna vulgaris*	127.97	*Calluna vulgaris*	58.06	*Cirsium vulgare*	10.1×10^{-3}
	5.	*Brassica napus*	98.04	*Brassica napus*	46.63	*Trifolium pratense*	6.9×10^{-3}
Farm scale		L per 100 ha		Kg sugar per 24 hrs per 100 ha		Thousands per 100 ha per min	
	1.	*Hyacinthoides non-scripta*	46.5	*Tripleurospermum inodorum*	37.05	*Rubus fruiticosus agg.*	0.55
	2.	*Crataegus monogyna*	16.8	*Trifolium pratense*	7.46	*Cirsium vulgare*	0.16
	3.	*Fumaria officinalis*	6.24	*Trifolium repens*	7.23	*Trifolium repens*	0.14
	4.	*Ranunculus repens*	5.41	*Crataegus monogyna*	5.07	*Taraxacum agg.*	0.06
	5.	*Brassica napus*	5.31	*Taraxacum agg.*	3.65	*Trifolium pratense*	0.06

Appendix 25: Variance components analysis from mixed effects models with Poisson errors (from 2012 pan trap and transect surveys). The analysis uses a mixed effects model to determine the proportions of variance attributable to each spatial scale in the sampling design. Farm type, round, maximum temperature and number of hours traps were left out were included as main effects. Points within farms within regions were specified as a nested random effects.

Scale	Abundance of bees	Species richness of bees	Abundance of butterflies	Abundance of hoverflies
Point	81.584	75.870	75.631	46.330
Farm	12.917	0.238	24.369	10.940
Region	5.499	0.003	0.000	42.731