Biodiversity enhancement on arable land:
The effects of local management and landscape context

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Abstract

Rising global human populations will increase competition for land, water, and energy. It seems likely that agricultural systems will suffer further degradation which will increase losses of biodiversity and disrupt key ecosystem services. Globally a number of mitigation and adaptation strategies are being implemented to preserve or enhance biodiversity in agricultural landscapes. Removal of land from agricultural production to create wildlife habitats has proved to be an effective and practical means of providing conservation benefits. Recent work has focused on how landscape context interacts with farming to determine conservation services and other benefits. Results show that both, habitat quality, food resources, and the abundance, diversity and population dynamics of key farmland taxa are significantly enhanced by both targeted local management and enhancements at the landscape scale.

Keywords: Ecosystem services, agriculture, local habitat type, landscape heterogeneity, conservation, agri-environment schemes, land use, invertebrates

Introduction

With the human population predicted to double to 9.4 billion by 2050 (Population Reference Bureau 2009) there will be increased demands on land, water, and energy (Godfray et al., 2010). About 38% of the earth's land surface has already been converted to agriculture (Wade et al., 2008) and unabated this figure will rise to 56% by the middle of this century (Tilman et al., 2001). More than a third of the production of terrestrial systems and approximately half of the available freshwater is already utilized by humans. The increasing competition for food and land resources means that both agricultural systems, and the remaining natural systems, will suffer further degradation, increasing biodiversity loss (Tilman et al., 2001) and disrupting ecosystem function (Hector and Bagchi, 2007). Fundamentally this will alter these systems' ability to deliver regulating, provisioning, cultural and basic supporting types of ecosystem services such as biological control, food production, gas regulation, nutrient cycling, pollination and water supply (Millenium Ecosystem Assessment, 2005;Wade et al., 2008). Climate change and other environmental stresses are likely to further exacerbate these effects.

The environmental effects of agriculture are inextricably linked with impacts on biodiversity. Typically complex natural ecosystems become simplified managed ones. Throughout Europe, where agriculture is the major land use, a significant proportion of biodiversity is associated with this habitat and agricultural intensification has been a major driver of species loss(Kleijn and

Sutherland, 2003).

The impacts of intensification on biodiversity can be considered at different spatial scales (Tscharntke et al., 2005). At the landscape scale, increases in field size and reductions in mixed farming have resulted in simplified landscapes with little non-crop area. At the local scale, intensification of resource use and increasing inputs have led to the simplification of remaining semi-natural habitats with knock-on effects for many taxa (Robinson and Sutherland, 2002). Understanding how different taxa are influenced by landscape context and local habitat quality has considerable implications for their conservation and management of the ecosystem services they provide (Steffan-Dewenter et al., 2002;Kremen et al., 2007;Ricketts et al., 2008;Keitt, 2009).

Intensified agriculture also has large external costs. Cost-benefit estimates suggest that while the worldwide ecosystem benefits from agriculture are £53 $ha^{-1}yr^{-1}$, the external costs (effects on soil, water, biodiversity and human health) in countries like the UK are £208 $ha^{-1}yr^{-1}$ (Wade et al., 2008). Traditionally agriculture and biodiversity conservation have been considered as incompatible but it is clear that ecological restoration of farmland is necessary to reduce these unacceptably high external costs that are borne by society. The need for agroecosystems to play a major role in the conservation of biodiversity and ecosystem services is becoming increasingly recognized (Norris, 2008).

Two strategies try to reconcile biodiversity conservation with increased agricultural production, namely 'Land sparing' and 'Wildlife-friendly farming' (Green et al., 2005). Land sparing requires large, contiguous areas to be protected for wildlife conservation whilst the intervening land is farmed intensively for maximum production. This strategy is considered more applicable to the conservation of species associated with pristine natural habitats. In contrast, wildlife-friendly farming entails the close integration of conservation and more extensive farming practices within the same landscape.

Despite a lack of supporting evidence there has been a strong policy drive for this latter strategy in Europe, largely through the agri-environmental measures incorporated into the Common Agricultural Policy (CAP). These measures pay farmers to manage their land for the benefit of particular habitats and species and are co-funded by EU member states (mean annual expenditure (2007-2013) = €3.33 billion). However, the effectiveness of these agri-environment schemes (AES) has been poorly monitored (Kleijn and Sutherland, 2003). Where assessments have been carried out the results appear mixed, suggesting few benefits for rare and declining species (Kleijn et al., 2006). Indeed, it has been suggested that without further CAP reform to make the schemes more effective the EU is likely to fail to meet many of its own and international obligations in relation to biodiversity conservation (WWF, 2009).

In the UK approximately 77% of the usable land area is farmed (http://www.defra.gov.uk/evidence/statistics). During the last few decades of the 20th century farmland biodiversity in the UK declined substantially, largely attributed to agricultural intensification (Robinson and Sutherland, 2002). These declines occurred particularly among those species most closely associated with cropland including the arable weed flora (Preston et al., 2002;Robinson and Sutherland, 2002;Heard, 2003), non-pest invertebrates (Aebischer, 1991;Robinson and Sutherland, 2002) and farmland birds (Fuller et al., 1995;Siriwardena et al., 1998;Chamberlain et al., 2000;Newton, 2004).

In the UK, AES have comprised a major component of UK Government policy for almost two decades with the overall aim of reducing the loss of farmland biodiversity (Vickery et al., 2009). These past and current UK AES have relied heavily on the establishment and management of field margins as a means of integrating both agronomic and environmental objectives on farmland. Managed margins are potentially effective for enhancing biodiversity and are considered as important conservation measures. However, despite their popularity, there have been relatively few attempts to assess their relative value for farmland biodiversity either singly or in combination with each other at a landscape scale.

Pilot studies conducted prior to the introduction of the latest English AES (the two tiered "Environmental stewardship scheme", Defra 2005) suggested that uptake of the basic level (Entry Level Scheme, ELS) would be high with over 80% of farmers joining. However it was unclear how effective the scheme would be for biodiversity enhancement and a number of issues were highlighted: (i) farmers tended to favour a small proportion of the (then) 55 available (predominantly margin) options; and (ii) many farmers tended not to apply those options that would provide most environmental benefit in their particular circumstances.

In 2005 England launched the 'Environmental Stewardship' AES (Natural England, 2010). The main component of this is the 'Entry Level Scheme' (ELS), a non-competitive, high-uptake whole farm approach designed to deliver simple and effective environmental protection and enhancement over large areas (annual budget = €193 million, coverage 5 million ha (60% of the utilisable farmland, target = 70% by 2011)). It currently comprises over 60 land management prescriptions most of which have broad environmental aims and are simple and cheap to implement ('general' prescriptions). In contrast, a small proportion of prescriptions are closely tailored to the ecological requirements of target taxa ('evidence-based' prescriptions).

In this paper I briefly explore the evidence for the effects of farmland ecological restoration on key groups of invertebrate taxa. I draw from several studies linked to the development and application of UK AES and discuss how the effects on key taxa interact with landscape context.

Effects at the plot scale

A multi-site experiment was conducted on six arable farms in eastern England for 5 years (2003-07) to investigate the effectiveness of new AES options for conserving and enhancing a broad range of taxa and ecosystem functions. The six treatments varied in the degree of management intervention from: growing a cereal crop with restricted use of pesticide (treatment 1), to complete removal of land from production, either allowing natural regeneration of vegetation (treatment 2) or actively sowing seed mixtures which included seed-bearing crops (treatment 3), tussocky grasses (treatment 4), pollen-and nectar-rich forbs ('nectar flower mixture', treatment 5), and fine-leaved-grasses and forbs ('wildflower', treatment 6). All treatments were compared with a conventional cereal crop control.

There were clear and consistent responses of soil, flora and fauna to a range of agri-environment scheme options (Figure 1). The inclusion of the conventionally managed crop as a control confirmed the detrimental effects of intensive agricultural management on biodiversity and many ecosystem functions. Significant positive treatment effects were detected in 37% of the ANOVA tests carried out on 1186 variables averaged across all years. Field margins sown with the wildflower seed mixture had the highest proportion (14.9%) of significant tests compared with the other treatments (Fig. 2a), followed by pollen & nectar (7.0%), tussocky grass (6.6%) and natural regeneration (6.2%) margins. The conservation headland (1.9%) and crop (1.0%) treatments had a considerably lower proportion of significant tests than expected by chance alone (5%). Vegetation variables accounted for a high proportion of significant tests in the wildflower and natural regeneration treatments. Soil invertebrate variables accounted for a high proportion of significant tests in the tussocky grass and wildflower treatments. Soil surface active invertebrates accounted for a high proportion of significant tests in the conservation headland, natural regeneration and wildflower treatments. Pollinators accounted for a high proportion of the significant tests in the pollen and nectar, and wildflower treatments. Finally, canopy active invertebrates accounted for a high proportion of the significant tests in the wildflower, tussocky and pollen and nectar treatments. Wildflower margins had the highest proportion (24.7%) of top ranked variables regardless of significance (Figure 1), followed by natural regeneration (20.6%), pollen and nectar (18.6%), tussocky grass (15.8%) and conservation headland (14.1%). Once again the crop treatment had the lowest proportion of top ranked variables (6.3%). The proportion of top ranked variables accounted for by different taxa and functional groupings for each treatment was broadly the same as for the significant tests.

Creation of species-rich field margin vegetation resulted in significant beneficial effects for the widest range of taxa and functions both above- and below-ground but no single margin type was best for all taxa investigated. Management prescriptions specifically targeted to the requirements of declining taxa were generally more effective than those designed to deliver a broader range of environmental benefits. However, the benefits delivered by two of these ‘targeted’ prescriptions (pollen and nectar and wild bird seed mixtures) were short-lived and did not persist in after year 3.

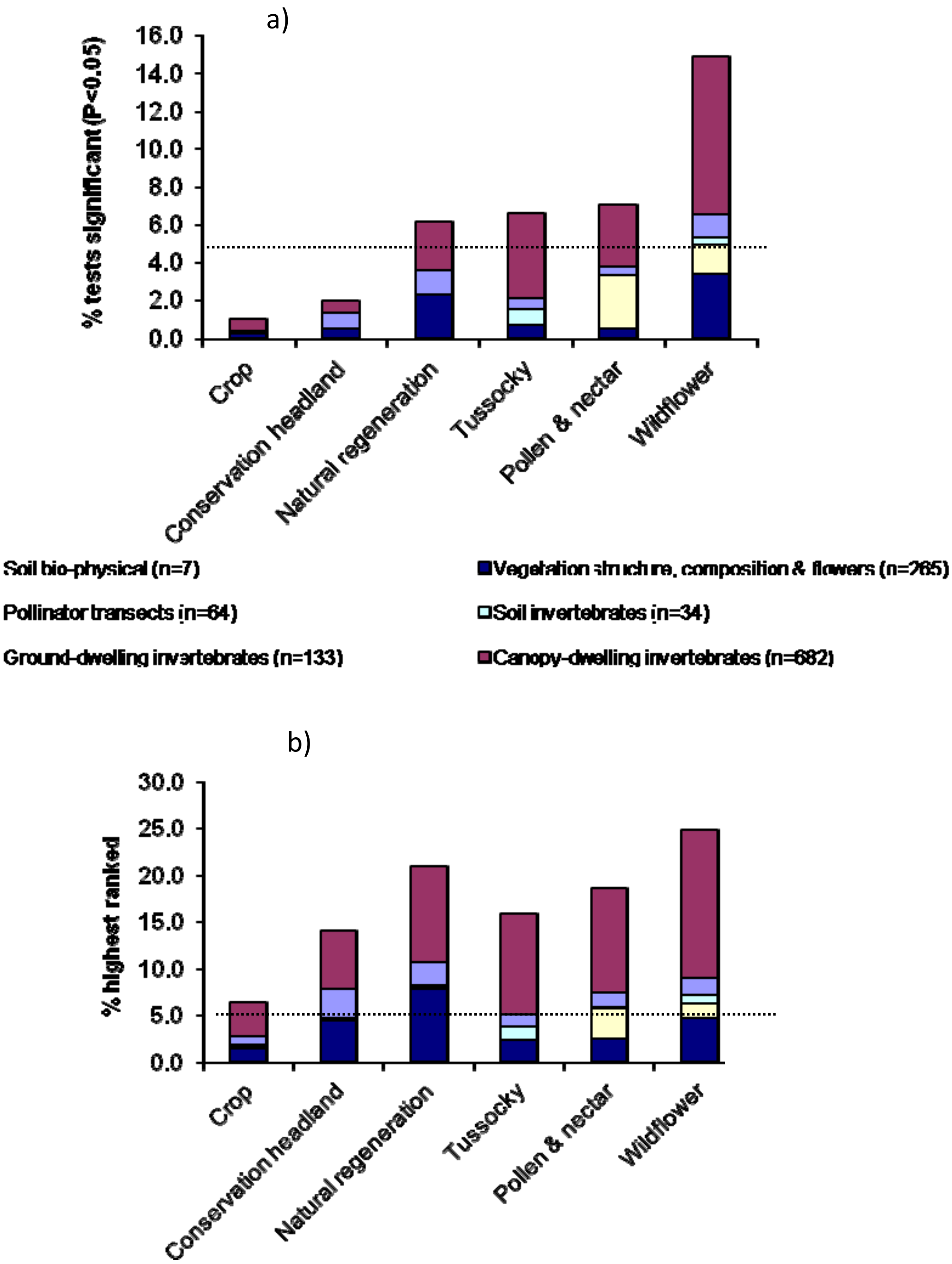

Figure 1. Summary of all 1186 ANOVA tests showing: a) percentage of significant tests (P<0.05) for each field margin treatment (dotted line represents 5% of significant tests expected by chance alone), and b) percentage of treatments with highest ranked value for each variable.

Effects at the landscape scale

i) Pollinators

The global decline of insect pollinators, especially bees, is cause for both ecological and economic concern and there is an urgent need for cost-effective conservation measures in agricultural landscapes. While landscape context and habitat quality are known to influence species richness and abundance of bees, there is a lack of evidence from manipulative field experiments on bees' responses to adaptive management across differently structured landscapes. In this study, we used a targeted AES for pollinators (the ELS "nectar flower mixture" option), implemented experimentally a across broad range of agricultural land use types, to address two main objectives: 1) to determine the response of foraging bumble bees and their colonies to sown forage patches over time; and 2) to investigate the influence of landscape context and habitat quality on the response of different bumble bee species to this targeted AES option.

Twenty four sown patches (0.25-1ha) of 'nectar flower mixture' (20% legumes, 80% fine grasses) were sown across eight sites in central and eastern England, UK, and their effects on density of bumble bee workers compared with non-crop control plots measured over four years. We also used microsatellite DNA analyses to estimate colony numbers from census data, and created a scaled measure of population change across years that took account of simultaneous changes in patch quality. In addition we conducted an intensive survey of fine-scale floral resources and landscape composition around each patch, both of which have been shown to be critical in developing models from which to design strategic adaptive management plans for pollinators (Lonsdorf et al., 2009). To our knowledge no other study has taken such a large-scale experimental approach to addressing the effects of an agri-environment scheme on any invertebrate taxon.

Species richness and worker densities (especially of the longer-tongued *Bombus* species for which the mixture was targeted) were significantly higher on sown forage patches than existing non-crop control habitats throughout the three-year study, but the strength of this response depended on both the proportions of arable land and abundance of herbaceous for b species in the surrounding landscape. The size of sown patches also affected worker density, with smaller patches (0.25ha) attracting higher densities of some species than larger patches (1.0ha). Using microsatellite DNA analyses to estimate colony numbers from census data, we created a scaled measure of population change for two species across years that took account of simultaneous changes in patch quality. This showed significant, positive effect of patches on population growth rates in more intensive landscapes (>71% arable) for both *B. lapidarius* and *B. pascuorum*.

Our models show that a targeted AES can deliver greater net benefits in more intensively farmed areas, in terms of the number of workers, population growth and species richness of bumble bees supported, than in heterogeneous landscapes where other foraging habitats exist. These findings serve to strengthen the evidence base for extending agri-environment schemes to boost declining pollinator populations to a larger number of agricultural landscapes across the globe.

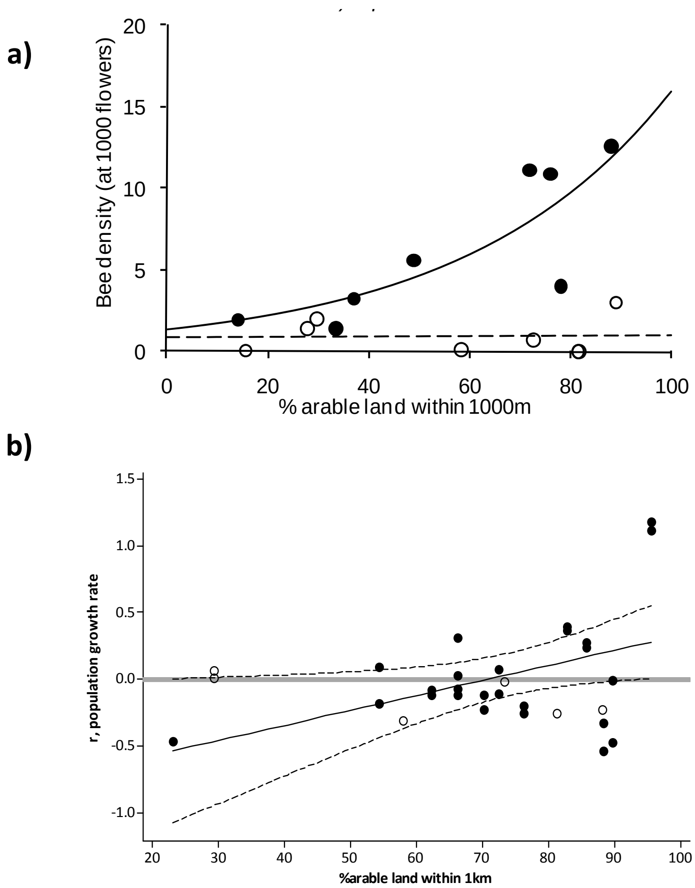

Figure 2. Effects of landscape context and sown AES forage patches on a) relationships between predicted bumblebee worker densities of *B. pascuorum* and landscape variables for control patches (dashed line: open circles) and sown forage patches (solid line: filled circles) R^2=0.644, P=0.017 (sown) and R^2=0.001 P=0.933 (control); b) population growth rate, *r* in *B. lapidarius* and *B. pascuorum* on sown (filled circles) and control (open circles) patches. The effect of sown patches shows a significant positive effect where surrounding landscape is >71% (r = -0.8+0.011×%arable, P=0.032, r^2=0.19). There was no significant effect in control patches. Dotted line =95% CI, grey line =equilibrium. (Carvell et al., 2010 in press,(Heard et al., 2010).

ii) Invertebrate predators

In 2005 we established a farm-scale randomized block experiment to compare the effects on biodiversity of conventional intensive arable farming under cross compliance with: (i) typical UK AES ELS option uptake; and (ii) enhanced and targeted ELS option uptake. The experimental design applies combinations of margin options to parcels of land and seeks to gain a more holistic view of the impacts on wildlife at this landscape scale than the traditional small plot experimental approach. This has the added benefit of allowing monitoring of more mobile species e.g. bumblebees, mammals and birds that utilize larger areas and are amongst the most threatened and declining taxa associated with farmed landscapes.

The farm was divided into five replicated experimental blocks of between 150-180 ha. Each block was separated into three areas of c. 60 ha and each of these was randomly allocated one of three treatments: 1) Cross Compliance (CC): which simulates a 'business as usual' scenario of farming according to CAP compliance and acts as the control treatment; 2) Entry-Level Scheme (ELS): 1% of land removed from production to mimic AES option preference based on the average ELS uptake (hedges cut every two years, one winter bird food patch and some grass margins); 3) Entry-Level Scheme Extra (ELSX): 5% of land removed from production with a more diverse range of nine AES options (including biennial hedge cutting, three sorts of bird food patch and a range of different grass and flower rich margins and patches).

As part of the study we investigated how local habitat type (crop type and margin area and diversity) and landscape structure affects the biomass, species richness and functional diversity of ground beetles. Landscape structure was defined using remote sensed data from Specim AISA Eagle (400–970 nm) and Hawk (970–2450 nm) hyperspectral sensors. Ground beetles were divided into predatory and phytophagous trophic levels. Local habitat type only affected phytophagous ground beetle biomass, which was lowest within crops ($F_{6,27} = 3.42$, $P<0.05$). Total biomass of predatory beetles was negatively correlated, and species richness positively correlated, with landscape habitat diversity (Figure 3). Only the functional diversity of predatory ground beetles responded to landscape structure, showing positive correlations with the proportion of tussock grass field margins ($F_{1,28} = 4.40$, $P<0.05$). Predatory ground beetles show a greater dependence on landscape structure than phytophagous species, a response that is attributed to their high mobility needed for movement between dynamically variable food resources.

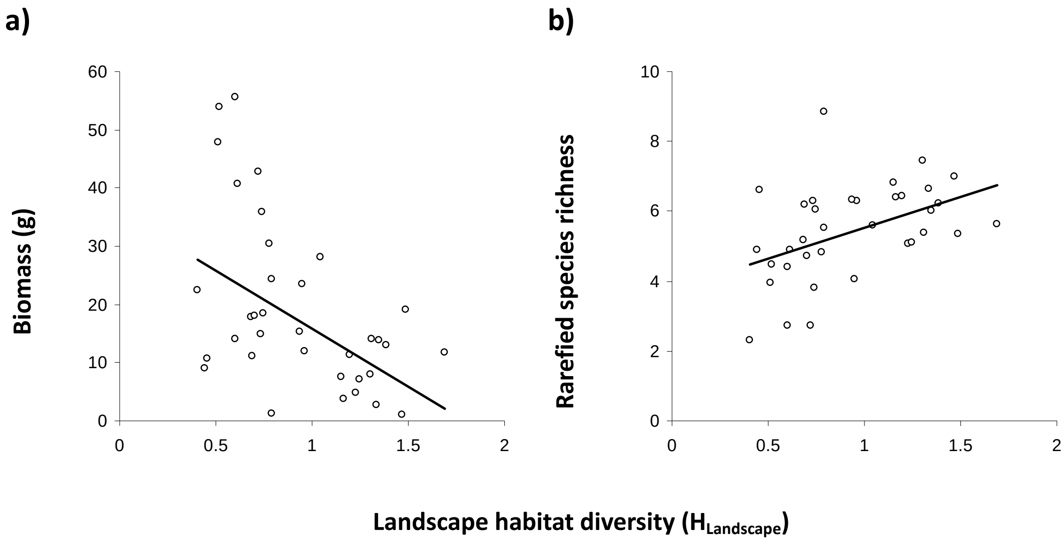

Figure. 3. The response of predatory carabids to landscape habitat diversity ($H_{Landscape}$) recorded with a 500 m radii around each sampling area. (A) total predatory Carabidae biomass (g) HLandscape: $F_{1,28} = 5.70$ $P<0.05$ and (B) rarefied species richness HLandscape: $F_{1,28} = 8.42$, $P<0.01$. (Woodcock et al., 2010).

Effects at the national scale

We undertook national monitoring to compare the effectiveness of ‘general’ with ‘evidence-based’ ELS habitat restoration methods in conserving and promoting diversity and abundance of plants and bees. For arable plants we compared ’conservation headlands’ (a ‘general’ option) with uncropped, annually cultivated field margins (‘evidence-based’ option) and an intensively managed cereal crop (control). ‘Conservation headlands’ are aimed at improving the survival of broad leaved weeds and beneficial insects within cereal crops by restricting herbicide and pesticide inputs. An example of each measure was selected at random from thirty nine 20 × 20 km squares across lowland England. Arable plant diversity and abundance was recorded from thirty 0.5 × 0.5 m quadrats within a 100 × 6 m wide sampling zone on each site (Walker et al., 2007). For bumblebees we contrasted a widespread ‘general’ option that provides nesting habitat and limited resources of pollen and nectar (an uncropped field margin sown with a simple grass mixture, with an ‘evidence-based’ approach (margin sown with a pollen- and nectar-rich plants) and a cereal crop (control). An example of each measure was selected from thirty two 10 × 10 km squares. On each option bumblebee species were counted along a randomly located 100 × 6 m transect in July and August (Pywell et al., 2005). Species were classified as rare or common based on a range of rarity criteria including the UK Biodiversity Action Plan (UKBAP).

Species richness of both common and rare taxa was consistently higher on the ‘evidence-based’ options compared to the ‘general’ options and control for both taxa. For the plants, richness and abundance of common and rare species was significantly higher on uncropped, annually cultivated margins (‘evidence-based’) than either the conservation headland (general) or the cereal crop control (Figure 4). Similarly, species richness of common and rare bumblebees was significantly higher in the ‘evidence-based’ pollen and nectar-rich field margins than both the generalist simple grass strip and cereal control. In addition, abundance of bumblebees was significantly higher in the ‘evidence-based’ option compared with either the ‘general’ option or the cereal crop (Figure 3). Finally, regression showed there were significant positive relationships between the number of rare plant and bee species recorded on the evidence-based habitats and the richness of species pools at the landscape (10 km) scale.

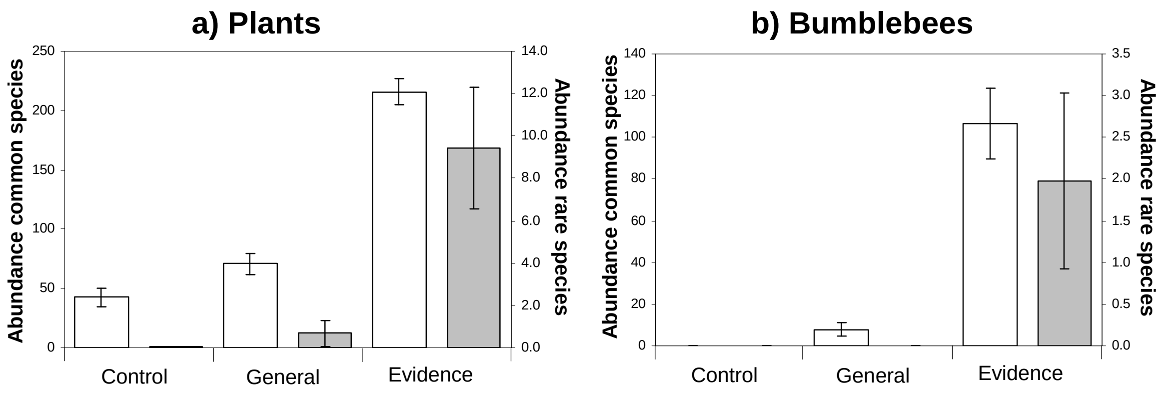

Figure 4. The abundance of rare and common a) plant (rooted frequency; common, $F_{2,76}$=97.30***; rare, $F_{2,76}$= 9.34***), b) bumblebee (counts per 100m; $F_{2,73}$=134.96***; rare species $F_{2,73}$= 5.02**) in general and evidence-based habitat compared with a cereal crop control. ***P*<0.01, ****P*<0.001. Pywell et al. (2010, *in prep.*)

Discussion

Our studies show that overall removal of land from arable production is a practical and effective means of enhancing biodiversity and ecosystem functions. Our results consistently showed that the use of the scientific evidence base to create habitats closely tailored to the ecological requirements of target species had strong beneficial effects on key farmland taxa. Ecological restoration delivered through AES options can clearly provide a space-efficient means of reconciling the need for increased food production with the conservation of biodiversity.

While the response of invertebrates to both local management and landscape structure differed across and within taxa, large-scale conservation management within agricultural systems must focus on the management of whole assemblages (Stoner and Joern, 2004). Maintaining or restoring ecological heterogeneity at multiple scales is key to sustaining biodiversity within temperate agricultural landscapes. However an understanding of the factors that can be manipulated to promote biomass, species richness and function diversity of key taxa, is valuable for both conservation and to maximize the management of ecosystem functions within agricultural systems.

Clearly the effectiveness of restoration efforts can be modified by interactions with landscape context. For bumblebees, greater net benefits of AES can be delivered in more intensively farmed areas, in terms of the number of foragers, colonies and species richness of bumble bees supported, than in heterogeneous landscapes where other foraging habitats exist and are likely to buffer populations. Carabid predator functional diversity responds positively to the provision of overwintering habitats (tussocky grass margins) at landscape scales. At the national scale, the magnitude of responses to habitat creation or both plants and bees was highly dependent on the diversity of the species pool at the landscape scale.

This understanding will help the development of policy to address the challenges of designing landscapes to more efficiently deliver biodiversity and multiple ecosystem services in the face of increasing anthropogenic pressures on habitats, and the effects of climate change on shifting species distributions. However if the conservation potential of habitat restoration is to be maximised, policy makers will need to overcome barriers to the uptake and effective implementation of AES measures. This includes limitations in funding, and improving engagement with farmers to enhance their willingness and ability to implement options successfully.

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