Organic Farming and Biodiversity: A review of the literature

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Executive summary

Organic Farming and Biodiversity: A review of the literature

1) There is overwhelming evidence that organic farming provides more biodiversity than conventional farming. In almost all studies overall biodiversity has been found to be much greater and often significantly so, than on conventional farms (Table 1). This evidence is consistent whether the studies are based on plots, fields or whole farms. The evidence in favour of organic farming compared to conventional farming at the level of specific biodiversity components is also compelling. Studies of birds, bats, butterflies, small mammals, insects, invertebrates, soil organisms and fauna generally show enhanced levels and diversity on organic farms. There is also evidence of a greater level of rare or threatened species.

2) Analysis of the published studies of the effects of organic farming on plants, invertebrates, soil microbes, birds, landscape and ecosystem services confirms a wide range and large number of positive effects (62 out of 82 studies) with very few negative effects (6 out of 82 studies). These positive responses are most consistent for plants, with 16 out of 19 studies reporting beneficial effects of organic systems.

3) The rationale for these results varies according to the focus the study but there is a clear body of generally accepted reasons:

- The avoidance of “agro-chemical” inputs; both pesticides and soluble fertilisers
- The practice of crop rotation including grass/clover leys, mixed cropping, green manures etc.
- That most organic farms are mixed farms
- The maintenance and introduction of permanent pastures, long term grass leys, hedgerows, beetle banks etc.
- Restricted use of slurry and manure applications
- Mixed livestock enterprises
- In general, management regimes which tend towards diversity and away from intensification.

4) It is likely that the interactions between landscape, non-cropped and cropped habitat and farming practices are critically important and may explain some of the variability in biodiversity found between studies. A number of studies in recent years have explored some of these interactions and in particular the effects of landscape complexity and scale.

5) There is evidence that organic farms can extend their biodiversity benefits beyond the farm boundary into surrounding landscapes and farms. Conversely, for taxa such as plants, organic farms form “self-sufficient ecosystems” that do not rely on immigration from surrounding habitats to maintain species pools.

6) Very few studies address the impact of organic farming in grassland or upland systems. The biodiversity impacts of organic conversion in the hills and uplands were investigated in a recent Defra-funded project. The results contrast with those comparing organic and non-organic lowland arable farms. However, the project focussed only on vascular plants, and it has been demonstrated that the response of e.g. invertebrates, birds and bats to organic farming may differ. Other studies have shown that upland plant communities have been affected by anthropogenic factors including increased grazing pressure and eutrophication, with subsequent impacts on associated invertebrates. Practices inherent to organic upland systems, including lower stocking rates, mixed grazing and the use of traditional breeds, may counteract these effects. Further work is required to quantify the impact of organic conversion in the uplands.

7) However, ecological interactions are complex and the studies reveal inconsistencies and a dynamic which needs further investigation. The report discusses the limitations of the methodologies used in the published work and the limitations of the studies.

8) There is an urgent need to improve the range and amount of biodiversity in agriculture, particularly in relation to its importance for ecosystems and ecosystem services. This is of increasing importance in the context of emerging generalisations in ecology that biodiversity is positively correlated with both productivity and stability, and that biodiversity supports many other ecosystem services such as pest and disease control and pollination.

9) To date there have been few examples translating the biological value of on-farm biodiversity into an economic value based on the ecological services that are generated. However, one early attempt found that the ecological services from a sample of organic farms had a considerably higher value than those from a range of non-organic farms (organic fields ranged from US $1610 to US $19,420 ha-1 yr-1; conventional fields from US $460 to US $14,570 ha-1 yr-1).

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1 Introduction

This report was prepared during a period of uncertainty over the level of support that would be available for organic farming through the Glastir support scheme. Questions were asked about the delivery of biodiversity through organic farming. This report seeks to answer those questions.

The main body of the report draws on the literature to present results by taxa. A section on methods discusses issues relating to reviews and inconsistencies in results and finally a discussion reviews the evidence. The Appendix contains brief summaries of the literature.

1.1 Background

Exemplified by the Millennium Ecosystem Assessment (2005), there is universal concern over the current scale and rate of losses in biodiversity worldwide, and the effects that this is likely to have on ecosystems and ecosystem services. In these circumstances it is clear that all possible measures to, at the very least, slow down such losses, need to be considered, supported and implemented as rapidly as possible.

Because organic farming developed as a form of ecological farming, which depends upon local biological processes delivered by a wide range of organisms within and adjacent to the crop spaces, it has been the view of organic farmers that, by definition, the system would be beneficial for biodiversity. By its nature, organic farming should, overall, encourage rather than reduce biodiversity at least in its direct area of operation. However, there needs to be clear scientific evidence, first, that this is so, secondly, to show the main directions in which this is happening and why, and then, thirdly, from these observations and analyses, to indicate ways in which the processes could be improved both for the farming systems and for biodiversity more generally.

This last point is particularly important in relation to the general concerns about biodiversity. At one extreme, even within the geographical confines of the UK or Wales, there are elements of biodiversity which appear to have no obvious relationship to agricultural land-use, but which are an essential part of natural ecosystems, such as, for example, mosses on hill crags. At the other extreme are the soil microorganisms involved in symbiotic nitrogen fixation or phosphorus release for crop plants. However, it takes little analysis to show that these extremes are not totally isolated but that they form parts of a continuum, which are likely to have feedback effects in both directions, even though the numbers of intermediate steps may be large and their relationships complex.

The question for agricultural systems therefore, is whether they can provide, on the one hand, indirect support for agriculturally-remote ecosystems and, on the other, direct support for the many different forms of biodiversity that are involved, or that can be involved, in agricultural ecosystems.

Unfortunately, our current understanding of ecosystems at almost any level is still poor, despite remarkable progress in the last two decades. One consequence is that current studies on the relative impacts of organic and non-organic farming systems on biodiversity are necessarily crude. They are based on two kinds of observation, direct and indirect. The direct approach involves observations of some form of measurable biodiversity marker such as earthworms, butterflies or birds. Although the studies are largely supportive of the generality, that organic farming is good for biodiversity, they suffer from difficulties in defining suitable methods for comparison. More importantly, they suffer from a lack of understanding of the markers' contributions to the general world of biodiversity and the associated ecosystems, to the agricultural ecosystems, and to the linkages between the two. In this context, Hector & Bagchi (2007) pointed out that, because different species often influence different functions, studies focusing on individual processes in isolation will underestimate the levels of biodiversity required to maintain multifunctional ecosystems.

The indirect approach includes studies that attempt to analyse aspects of organic farming ecosystems such as nutrient flows or disease and pest restriction. Such analyses illustrate the ways in which biodiversity that is more directly a part of the farming system is encouraged and sustained. Again, however, it is unclear the extent to which this support for biodiversity has a value beyond that of the farm crop and into the more general natural world. Of course, many of these parts of systems are often present in non-organic systems and Shennan (2008) has a useful review of the wide range of mechanisms that are possible. Again, however, it is important to keep Hector and Bagchi's (2007) point in mind.

Thinking in ecology is progressing rapidly (McCann 2000; Loreau 2010) and it is now becoming generally accepted that, even if the processes are highly complex, there is a general positive relationship between diversity and stability and also between diversity and productivity. Given these indications, it again follows that there needs to be support for agricultural systems that encourage and enhance biodiversity at the widest range of levels. In this sense, it is evident that among the papers published on comparisons of organic and non-organic farming, based on a range of diversity markers, there is general consensus for the advantages of organic farming (see Table 1). With few exceptions, it seems clear that, over a wide geographical range and for different forms of organic and non-organic farming, the organic approach can provide reasonably consistent advantages for biodiversity.

Table 1 Results from the literature (+ positive, = no effect, - negative)

Author (year)	Plants	Invertebrates	Soil microbes	Birds	Mammals	Landscape	Ecosystem services	Interaction with landscape	Comments
Reviews									
Gardner & Brown (1998)	+	+ / -[1]	+	+	+ / =				[1] aphid-specific predators in greater densities in conventional fields
Shepherd et al (2003)	+	+ / =		+	+				
Bengtsson et al (2005)	+	+ / -[2]	+	+				yes	[2] non-predatory insects and pests in greater abundance in conventional systems
Hole et al (2005)	+ / =	+ / - / =	+ / =	+ / =	+				
Primary research									
Fuller et al (2005)	+	+ / -[3]		+	+				[3] lower species richness of ground beetles in organic
Clough et al (2007a)	+	+ / =[4]							[4] no difference in spiders, ground or rove beetles
Gabriel et al (2006)	+								
Gabriel et al (2010)	+	+ / -[5]		+ / -[6]				yes	[5] higher abundances of hoverfly adults in conventional [6] conventional farms support higher bird diversity but generalist species and crows in higher densities on organic farms
Roschewitz et al (2005)	+							yes	
Petersen et al (2006)	+								
ADAS (2005)	+								
Gibson et al (2007)	+ / =[7]								[7] higher diversity in organic arable fields, no significant difference in diversity in semi-natural habitats on organic and conventional farms
Gabriel & Tscharntke (2007)	+								
Boutin et al (2008)	+							yes	
Ulber et al (2009)	+								
Fraser (2010)	=[8]								[8] no difference in species diversity; higher percentage cover of Yorkshire Fog on long-term organic farms

Author (year)	Plants	Invertebrates	Soil microbes	Birds	Mammals	Landscape	Ecosystem services	Interaction with landscape	Comments
Watson et al (2006)				+					
Kragten & de Snoo (2008)				=/ +[9]					[9] skylark and lapwing in greater abundance on organic farms
Batáry et al (2010)				+				yes	
Chamberlain et al (2010)				+				yes	
Geiger et al (2010)				+				yes	
Smith et al (2010)				+				yes	
Schmidt et al (2005)		+ / =[10]						yes	[10] organic farming had no effect on species richness but enhanced abundance by 62%
Rundlof & Smith (2006)		+						yes	
Clough et al (2007b)		+						yes	
Feber et al (2007)		+							
Holzschuh et al (2007)		+						yes	
Rundlöf et al (2008)		+						yes	
Hodgson et al (2010)		+						yes	
Holzschuh et al (2010)		+						yes	
Diekötter et al (2010)		+							
Esperschütz et al (2007)			+						
Oehl et al (2004)			+						
Van Diepeningen et al (2006)			+						
Gosling et al (2010)			+						
Verbruggen et al (2010)			+						
Norton et al (2009)						+			

Author (year)	Plants	Invertebrates	Soil microbes	Birds	Mammals	Landscape	Ecosystem services	Interaction with landscape	Comments
Roschewitz et al (2005)							=[11]	yes	[11] no difference in parasitism rates of aphids
Macfadyen et al (2009a)		+/=[12]					=[12]		**[12]significantly more aphids on organic farms; no differences in parasitoid richness or parasitism rates**
Macfadyen et al (2009b)	+	+					+ / =[13]	yes	[13] herbivores attacked by more species, but no significant difference in mortality rates of herbivore bioassay
Crowder et al (2010)							+[14]		[14] effect due to greater evenness of natural enemies rather than higher species richness
Sandhu et al (2008)							+[15]		[15] greater value of ecosystem services in organic systems
Effects of organic farming									**Total**
Positive	**16**	**18**	**8**	**12**	**4**	**1**	**3**		**62**
Negative		**5**		**1**					**6**
No effect	**3**	**5**	**1**	**2**	**1**		**2**		**14**

2 Results

2.1 Individual taxa

2.1.1 Plants

The literature concerning plants is perhaps the most consistent in indicating an advantage in terms of species abundance and richness, with 16 out of 19 studies indicating a positive effect of organic compared with non-organic farming systems (Table 1). Fuller *et al* (2005) showed that organic fields can support 68-105% more plant species, and 74-153% greater abundance, compared with conventional fields. Roschewitz *et al* (2005) concluded that as organic systems are characterised by diverse seed banks, organic fields could be viewed as self-sufficient ecosystems for plants, therefore not relying on immigration from surrounding habitats to maintain species pools.

Positive effects of organic farming on plant diversity has been linked to organic management practices including prohibition of herbicide or mineral fertiliser inputs, sympathetic management of non-cropped areas, and more mixed farms (Hole *et al*. 2005). There have been very few studies considering the effect of organic management on plant biodiversity in upland systems. An Organic Centre Wales report (2004) identifies several aspects of organic management that are likely to benefit upland vegetation including lower stocking rates, mixed stocking, and the use of traditional livestock breeds. In an ADAS study (2005), there were indications of a positive, but slow, response in botanical composition, compared with the conventional system, following a significant reduction in stocking rates in the organic system.

An interesting observation by Ulber *et al* (2009) was that the increased plant diversity on organic farms arose from the complexity of the system including crop rotation, absence of herbicides and other chemicals and so on. This was emphasised by the observation that, under non-organic conditions, a change of only a single factor, in this case the introduction of crop rotation, did not affect plant diversity.

The positive response of plants to organic management can be regarded somewhat negatively by organic farmers themselves in that the plants that provide the advantage are often regarded as weeds (see Roschewitz *et al.* 2005) and that farmers are generally concerned to find improved ways to reduce weed numbers. If so, the plant biodiversity advantage may be countered to some extent by the processes of weed control *(see Ulber et al.* 2009), particularly if this involves excessive cultivations or highly competitive planting systems to force the crop itself to reduce the weed population by competition. However, other forms of weed control, for example through the use of crop rotation, may enhance the diversity of plants and other organisms.

It is perhaps less well understood, and certainly not quantified, that 'weeds' in themselves can have a wide range of beneficial effects in relation, for example, to nutrient flows, disease and pest control and support for pollinators (Gabriel and Tscharntke 2007). Several studies recorded higher abundances both of plants and the invertebrates associated with them in organic systems, particularly pollinators such as bees (Gabriel *et al.* 2010; Clough *et al.* 2007a; Holzschuh *et al.* 2007; Clough *et al.* 2007b).

These effects will depend, of course, on the species of 'weed' involved. For example, Petersen *et al* (2006) noted that, in organic systems, there was a relatively high frequency of stress-tolerant plants, which include the perennial weeds that are often difficult to control on organic farms. However, the stress tolerance is partly related to the ability of such plants to form stable and complex ecosystems within their immediate surroundings, which represent a benefit for the diversity of a range of, particularly, soil-borne organisms. Non-organic systems on the other hand, tended to contain more ruderal species which can grow directly and rapidly on the available nutrients and also benefit from applications of fungicides and insecticides. Such growth patterns add relatively little to the local biodiversity.

2.1.2 Birds

The papers reporting on bird diversity again show advantages for organic farming (12 out of 15 studies) but, in this case, the scale of advantage tends to be inconsistent, with variation likely to reflect species-specific responses. To some extent this may be due to the scale of physical weed control on organic farms (e.g. Geiger *et al.* 2010) but could also be partly due to the size and mobility of birds together with specialisation of habitats.

For example, Gabriel *et al* (2010) recorded higher overall diversity on conventional farms (particularly of farmland specialists), but generalist species and members of the crow family were found in higher densities on organic farms. In a study of field-breeding birds, Kragten and de Snoo (2008) found higher abundances of skylark on organic farms, reflecting this species preference for spring cereals which are generally perceived to be more widespread in UK organic systems. With a focus on upland farms in England and Wales, Watson *et al* (2006) found that in winter, there were significantly higher total densities of birds, and in particular insectivores and Farmland Bird Indicator species, on organic farms.

In the non-cropped environment, the longer and more varied hedges that tend to characterise organic farms do have some advantages for a range of bird species relative to non-organic farms, especially in simple landscapes (Batary *et al.* 2010). Invertebrate-feeding species particularly benefit from the greater habitat diversity found in organic systems, which enhance foraging resources (Smith *et al.* 2010). In these terms, non-crop habitats may often be more important than farming practices where, under organic farming, crop rotation may be a negative factor and, under non-organic farming, the limited range of monocultures may limit the habitat possibilities.

2.1.3 Invertebrates

As with plants and birds, the scientific evidence supports the biodiversity benefits of organic farming for invertebrates, with 18 out of 28 studies reporting a positive response (Table 1). Pollinating insects such as butterflies and bees particularly seem to benefit from organic practices (Feber *et al.* 2007; Rundlöf *et al.* 2008; Rundlöf and Smith 2006; Hodgson *et al*. 2010; Holzschuh *et al.* 2007; Gabriel *et al.* 2010; Clough *et al.* 2007a), probably reflecting the greater floral resource base available both within the cropped area and semi-natural habitats (see previous section on plants).

Predatory taxa including spiders, wasps and ground beetles also respond positively to organic farming (Schmidt *et al.* 2005; Holzschuh *et al.* 2007; Diekötter *et al.* 2010). This has been attributed to greater structural diversity within habitats, increased habitat connectivity and the availability of overwintering habitat and alternative feeding resources in semi-natural habitats. One of the complexities, and advantages, in enhancement of diversity in the soil fauna lies in their contributions to control of crop diseases (Friberg *et al.* 2005): certain animals will eat facultative saprophytic fungi whereas others consume the spores of obligate fungal pathogens.

A minority of studies recorded no significant differences, or a negative response to organic systems, reflecting taxon-specific variation. Ground and rove beetles, pests, and parasitoids have been recorded in lower densities on organic farms in some studies (Fuller *et al.* 2005; Clough *et al.* 2007a; Bengtsson *et al.* 2005). Species of ground and rove beetles vary widely in their habitat preferences (Luff 1996) and some species may prefer conditions found on conventional farms. Lower densities of pests on organic farms is obviously of benefit to organic farmers, and may reflect better biological control through enhanced natural enemy communities, while variable responses of parasitoids are likely to reflect the complex interaction between the dynamics of their hosts and the responses to local and landscape factors (Holzschuh *et al.* 2007).

2.1.4 Microbes

Fitter *et al* (2005) investigated the biodiversity in UK soils. In one example of what was described as an unremarkable agricultural soil, they found more than 100 species of bacteria; 350 species of protozoa; 140 species of nematode and 24 types of arbuscular mycorrhizae. The detailed roles and interactions of this wide range of organisms are largely unknown. However, a number of studies confirm that soil microbes are often more abundant and diverse under organic than under non-organic farming systems (8 out of 9 studies; Table 1).

Observations from the long-term field plot DOK trials in Switzerland indicated an increase in a range of soil-borne organisms, including mycorrhizae, under organic compared with non-organic conditions (Mader *et al.* 2002; Oehl *et al.* 2004; Esperschütz *et al.* 2007). This contrast is of particular interest because the different farming systems are represented by relatively small field plots that are sited close to each other.

Other studies have found significantly higher numbers of arbuscular mycorrhizal spores, and greater root colonisation in organic soils (Gosling *et al.* 2010; Verbruggen *et al.* 2010). Mycorrhizae are usually considered advantageous in relation to nutrient flows, particularly with soluble phosphorus. However, Gernns *et al* (2001) found that one arbuscular mycorrhiza increased the infection of barley by powdery mildew. Despite this increase, the plants were less affected by the disease than plants carrying less infection and no mycorrhiza. Possibly some improvement in plant nutrition increased the amount of disease but also the ability of the plant to cope with it.

Some important soil-borne cereal pathogens occur at considerably lower frequencies in organic compared with non-organic systems partly due to lower cereal frequencies in the crop rotations. However, another factor is the difference in frequency of fungal and bacterial competitors of the pathogen. For example, Hiddink *et al.* (2005) showed that organically managed soils were better at supporting the bacterial antagonist, *Pseudomonas fluorescens* of the take-all pathogen *Gauemannomyces graminis. P. fluorescens* is a well-known example of a PGPR (plant growth-promoting rhizobacteria) which, together with other soil-borne organisms, are able to induce resistance against pathogens of both the roots and upper parts of crop plants and also plant pathogenic nematodes (see also, Shennan (2008) and many other reviews). These organisms are often encouraged by crop rotation and the use of composts which are techniques applied more commonly in organic than in other agricultural systems.

2.2 Landscape

It is clear that interactions between a farm's landscape characteristics including non-crop habitat and farming practices have a critically important influence on biodiversity on organic farms but the nature of these interactions and impact is less obvious. For example, Norton *et al* (2009) studying farms in England that had some arable crops found that the organic farms were located in more diverse landscape types, had smaller field sizes, higher, wider and less gappy hedgerows subjected to less frequent management, use rotations that include grass, and are more likely to be mixed. Even within diverse landscapes, organic systems had greater field and farm complexity than non-organic systems.

Several studies covering the range of taxa found that the biodiversity benefits of organic systems are of particular value in simple agricultural landscapes where organic farms are both spatially and temporally more diverse than their conventional counterparts (e.g. Batary *et al.* 2010; Boutin *et al.* 2008; Clough *et al.* 2007b). Some studies have shown that that organic farms can influence biodiversity in the surrounding landscapes with higher diversity recorded on conventional farms in organic 'hotspots' (e.g. Gabriel *et al.* 2010; Hodgson *et al*. 2010; Rundlöf *et al.* 2008).

2.3 Ecosystem services

Biodiversity studies have primarily used descriptors such as species richness, abundance and diversity indices to assess the impact of organic farming on wildlife. However, these descriptors tell us little about ecosystem functioning and the provision and support of ecosystem services such as pollination and pest control. With an increasing interest in the ecosystem services that a biodiverse agroecosystem supports, several studies have aimed to quantify the link between organic farming, biodiversity and ecosystem services, with a focus primarily on pest control.

A common feature of organic systems is the creation of favourable conditions for natural biocontrol of pests through increase of predators and parasitoids. Macfadyen *et al* (2009b) found that herbivores in organic fields are attacked by more parasitoid species, while Crowder *et al* (2010) found that pest control was due to greater evenness of natural enemy populations, independent of species richness. Success is, however, variable because of environmental interactions with hosts and other factors (Macfadyen *et al.* 2009b; Roschewitz *et al.* 2005; Macfadyen *et al.* 2009a). Indeed, parasitoid effects on insect pests control often seem somewhat equivocal, perhaps because of unrecognised interactions in multitrophic feeding systems.

3 Methodological limitations

Earlier reviews identified a number of key methodological issues that may have biased results and accounted for inconsistencies in results (e.g. Hole *et al.* 2005). These include:

- Variation in the definition of organic farming standards between countries and certification bodies;
- Selection of appropriate controls taking into account landscape characteristics;
- Variation in spatial scales of study with a trade-off between studies at the field-scale to identify key management effects and farm-scale studies to identify system-level effects;
- Limited temporal replication of studies;
- Variation in measures of biodiversity across different taxa (abundance, species richness, density, breeding success etc.);
- Organic farms tend to be paired with similar sized conventional farms. As there are few large organic farms, the largest most intensive conventional farms are avoided;
- By pairing to minimise variation between sites, many studies risk excluding differences that are inherent to the organic system;
- Variation in length of time since conversion from conventional to organic management;
- Organic farms are likely to be isolated in a 'sea' of conventional farmland so that effects on mobile taxa like birds are limited.

While subsequent research has aimed to address many of these limitations, there remain a number of limitations to current approaches. Most studies are carried out at the field scale, but these may be inappropriate if there are emergent properties at the whole-farm scale. Organic management uses a holistic approach that operates at the whole-farm scale, but few studies are carried out at the whole-farm scale (but see Gibson *et al.* 2007). Indeed, most of the field studies focus on a single crop – usually winter wheat – so as to match crop types between systems. This fails to take into account that organic farms grow a wider range of crops, and the potential influence of temporal and spatial diversity of crop rotations on biodiversity. Additionally, the majority of the studies have focused on arable systems, or on arable fields within mixed systems, with very few studies having been carried out in grassland and upland systems.

Researchers try to be rigorous in their selection of comparisons and controls so as to minimise extraneous variation. This often results in minimising differences in landscape and farm size in pairs of conventional and organic farms, and so factoring out characteristics that are inherent to organic systems. By matching on farm size, with organic farms dictating the size of conventional farms selected, the largest, usually more intensive, conventional farms are not included in these studies.

4 Discussion

There is overwhelming evidence that organic farming provides more biodiversity than conventional farming. In almost all studies overall biodiversity has been found to be much greater and often significantly so, than on conventional farms (Table 1). This evidence is consistent whether the studies are based on plots, fields or whole farms. The evidence in favour of organic farming compared to conventional farming at the level of specific biodiversity components is also compelling. Studies of birds, bats, butterflies, small mammals, insects, invertebrates, soil organisms and fauna generally show enhanced levels and diversity on organic farms. There is also evidence of a greater level of rare or threatened species.

Researchers offer differing explanations for these results depending on the focus of their study and their experience but there are a number of generally accepted reasons;

- The avoidance of “agro-chemical” inputs; both pesticides and soluble fertilisers
- The practice of crop rotation including grass/clover leys, mixed cropping, green manures etc.
- That most organic farms are mixed farms
- The maintenance and introduction of permanent pastures, long term grass leys, hedgerows, beetle banks etc.
- Restricted use of slurry and manure applications
- Mixed livestock enterprises
- In general, management regimes which tend towards diversity and away from intensification.

However, ecological interactions are complex and the studies reveal inconsistencies and a dynamic which needs further investigation; e.g. Gabriel *et al* (2010) found that the larvae of hoverflies were more common on organic fields but adult hoverflies were found in greater numbers on conventional fields; some studies found differing levels of particular bird species depending on farm landscape (e.g. Smith *et al.* 2010); others (e.g. Geiger *et al.* 2010) found that some practices on some farms, such as mechanical weed control, affects the numbers of some bird species but not others.

Some of the recent contributions in the literature have been concerned with the spatial distribution of organic farms. Several authors point out that the most obvious positive effects of organic farming arise where organic farms are sparsely distributed among non-organic farms in simple landscapes. In such circumstances, it is possible for the biodiversity benefits to be evident beyond the boundaries of the organic holding. On the other hand, it is also likely that areas with high frequencies of organic farms may allow for the development of species that are relatively rare or that require large-scale habitats for their survival.

It is often observed that there is a wide variation in different qualities of both organic and non-organic farms and there is no doubt that one of those qualities is biodiversity, both in the direct measures involved (compare, for example, a non-organic farm in a Tir Gofal/HLS scheme with an organic farm with no stewardship) and in indirect measures (organic arable farm compared with non-organic mixed), even without the question of variation in quality of farm management.

The studies show that organic farms tend to have more favourable habitats such as hedgerows, grass margins, grassy ditches, small fields etc than conventional farms. This has prompted considerable discussion about what is the farming system and what is habitat that is independent of the farming system. Some researchers (e.g. Chamberlain *et al.* 2010) argue that the benefits of organic farming – in this case for farmland bird populations - come “primarily through greater habitat heterogeneity” and not from organic farming practice. However, it is not a matter of chance or coincidence that that greater habitat heterogeneity is found again and again on organic farms. Habitats within and along the farm boundaries are created or protected, maintained and managed by the organic farmer and are part of the overall farming system.

Nonetheless the interactions between landscape, non-cropped and cropped habitat and farming practices are critically important and may explain some of the variability in biodiversity found between studies. More understanding of these interactions will also help to enhance further the biodiversity on organic farms and serve to inform initiatives to increase biodiversity on conventional farms.

A number of studies in recent years have explored some of these interactions and in particular the effects of landscape complexity and scale. There is much more work needed but several interesting points are emerging;

There is evidence that organic farms can extend their biodiversity benefits beyond the farm boundary into surrounding landscapes and farms (e.g. Gabriel *et al.* 2010; Hodgson *et al*. 2010; Rundlöf *et al.* 2008).

Conversely, for taxa such as plants, organic farms form "self-sufficient ecosystems" that do not rely on immigration from surrounding habitats to maintain species pools (e.g. Boutin *et al.* 2008; Roschewitz *et al.* 2005).

Organic farms increase biodiversity to a greater extent in simple landscapes than in complex landscapes and therefore offer a robust vehicle for policies to increase biodiversity in commercial agricultural regions.

Few papers discuss the policy implications of converting land to organic farming in order to increase biodiversity. However, the balance between perceived yield on organic farms and the increased biodiversity benefits has been raised. Hodgson *et al* (2010) have sought to establish a formula by which a yield/biodiversity ratio can be established. It is an interesting idea but most of the studies to date have looked at only a few crops – primarily winter wheat – and have shown variable yield throughout Europe; plus very few studies have looked at the total output of farms including ecosystem services (total productivity); much more work needs to be done before its value can be assessed. In the meantime one should treat any conclusions with caution.

There is, however, an increasing recognition that all forms of agriculture need to improve in their approach to biodiversity. Two major areas for current organic agriculture lie in weed management and nutrient cycling, both of which need to make positive use of functional biodiversity. For the longer term, there is a major opportunity through the wider introduction and application of eco-agroforestry, mainly in the form of alley-cropping. This approach introduces major elements of perennial cropping in terms of both the trees and their understorey (see Culman *et al.* 2010). There is no doubt that this approach can have a major positive effect on a wide range of biodiversity bringing a close integration of natural and agricultural landscapes to the mutual benefit of both.

A further approach to encouraging development and utilisation of biodiversity in agriculture is the interest in translating the biological value of on-farm biodiversity into an economic value based on the ecological services that are generated. In one early attempt, Sandhu *et al.* (2008) found that, from their assessment of a range of important parameters, the ecological services from a sample of organic farms had a considerably higher value than those from a range of non-organic farms (organic fields ranged from US $1610 to US $19,420 ha-1 yr-1; conventional fields from US $460 to US $14,570 ha-1 yr-1).

As noted previously, very few studies address the impact of organic farming in grassland or upland systems. Based on studies from lowland agriculture, which have shown greatest benefits of organic systems in simple landscapes, it may be questioned whether biodiversity gains can be expected from organic management in the more complex, "high nature value landscapes" of the uplands. However, studies have shown that upland plant communities have been affected by anthropogenic factors including increased grazing pressure and eutrophication (e.g. see Britton *et al.* 2009), with subsequent impacts on associated invertebrates (Littlewood *et al.* 2006). Practices inherent to organic upland systems, including lower stocking rates, mixed grazing and the use of traditional breeds, are likely to counteract these effects (Organic Centre Wales 2004). The prohibition of Avermectin-based wormers is also likely to be beneficial for associated dung-beetles and other invertebrates (Hutton and Giller 2003). The biodiversity impacts of organic conversion in the hills and uplands were investigated in the recent Defra-funded project (OF0380) (Fraser 2010). The results contrast with those from Fuller *et al's* (2005) detailed comparison of organic and non-organic lowland arable farms. However, the upland project measurements of biodiversity focussed only on vascular plants, and it has been demonstrated that the response of e.g. invertebrates, birds and bats to organic farming may differ. Further work building on this initial study is now required to quantify the impact of organic conversion in the uplands on other taxa.

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6 Appendix

6.1 Summary of previous reviews

6.1.1 Reports

Gardner, S. M. and R. W. Brown (1998). Review of the comparative effects of organic farming on biodiversity. MAFF Contract OF0149

Gardner and Brown (OF0149; 1998) carried out a comparative study of five farming regimes, comparing organic farming with conventional arable, conventional mixed farming and two integrated production regimes (LEAF (Linking Environment and Farming) and IFS-Experimental). The effect of farming regimes on biodiversity (number, abundance and activity of species) of five broad groups (soil organisms, higher plants, invertebrates, birds and mammals) was evaluated from literature according to cultivation, crop production, crop protection and post-cropping practices adopted within each system. The authors concluded that organic regimes had an overall benefit for biodiversity at the farm level, in contrast to conventional arable systems, due to a combination of the agricultural practices adopted and the occurrence and management of uncropped areas. Key practices in organic systems that benefit biodiversity were identified as the absence of chemical inputs (artificial fertilisers and pesticides), crop production practices including the use of farmyard manure, green manures and intercropping, and practices such as rotation with leys and permanent pasture. However, other practices common in organic systems have negative effects, such as intensive cultivation and weed control.

Shepherd, M., B. Pearce, et al. (2003). An assessment of the environmental impacts of organic farming. A review for Defra-funded project OF0405

Biodiversity impacts were also reviewed by Shepherd *et al* (OF0405; 2003) as part of a wider review on environmental impacts of organic farming. They found that greater floral species diversity occurs within the crop, crop margins and non-farmed areas on organic farms, with up to six times more species within the crop on organic farms compared to conventional farms. They also recorded greater occurrence of rare arable species on organic farms, attributed to management factors such as prohibition of herbicides and avoidance of soluble fertilisers. Non-cropped habitats such as field margins and hedgerows on organic farms were also shown to support greater abundance and diversity of vegetation than on conventional farms. Spiders, ground-beetles, ants, woodlice and millipedes in organic systems were found to have generally higher or at least similar species numbers as in conventional systems. Higher densities of birds were also recorded on organic farms than on conventional farms; it was concluded that these differences could not be accounted for by non-cropped habitat or cropping patterns alone, but reflected more abundant food resources (both plants and invertebrates). Increased total bat activity on organic farms was thought to be driven also by greater prey availability as well as habitat features such as taller hedgerows and better water quality.

Organic Centre Wales (2004). Environmental and biodiversity impacts of organic farming in the hills and uplands of Wales.

This review discussed the biodiversity impacts associated with organic management of the Welsh hills and uplands. Lower stocking densities in organic livestock systems are likely to promote sward diversity, and reduce the incidence of nest trampling and disturbance of ground-breeding birds, and mammals. Mixed sheep and cattle grazing systems recommended on organic farms are likely to result in greater structural diversity in the vegetation; sheep-only enterprises have led to increases in unpalatable vegetation and a reduction in the heather *Calluna*. Using native or traditional livestock breeds that are better adapted to graze semi-natural vegetation is viewed as a form of conservation grazing that can maintain areas of conservation interest to the benefit of flora and fauna. The prohibition of Avermectin-based wormers in organic systems benefits dung-beetles and other soil fauna that are negatively affected by these insecticides for weeks after treatment.

Peer-reviewed published reviews

Bengtsson, J., J. Ahnstrom, et al. (2005). The effects of organic agriculture on biodiversity and abundance: a meta-analysis. *Journal of Applied Ecology*

A quantitative analysis of research literature published before 2003 was carried out by Bengtsson *et al* (2005) through a meta-analysis of 66 publications comparing species richness and abundance of birds, arthropods, soil organisms and plants in organic and conventional farming systems. Their analysis showed that organic systems had on average 30% higher total species richness than conventional systems, but that 16% of studies recorded a negative effect of organic farming on species richness. Analysing each taxa separately, birds, insects and plants (weeds, plants in field margins and other agricultural habitats) had greater species richness in organic systems with the effect significant at all scales (plot, field and farm) but largest at the plot scale. A positive effect of organic farming on abundance was found in 96 out of 117 studies, being on average 50% higher in organic systems, but with heterogeneity among studies. Birds, predatory insects, soil organisms and plants showed positive effects, while non-predatory insects and pests responded negatively. Positive effects of organic farming on abundance was most obvious at the plot and field scales, but not at the farm scale in matched landscapes. The authors conclude that while organic farming generally has a positive effect on species richness and abundance, the response varied between different organisms and in different landscapes so that the greatest benefit of organic systems was evident in intensively managed, simple landscapes.

Hole, D. G., A. J. Perkins, et al. (2005). Does organic farming benefit biodiversity? *Biological Conservation*

Hole *et al* (2005) carried out a qualitative review of 76 studies from 1981 to 2005 comparing organic and conventional systems to identify the effects on biodiversity and identify key management practices associated with these effects. Their review showed that in general, organic management supported higher abundances and/or species richness of a wide range of taxa including arable weeds, bacteria and fungi, insects, earthworms, birds and mammals. Several studies also recorded more frequent occurrence of rare or declining species in fields under organic management. A minority of studies recorded little or no differences between organic and conventional systems, or that some species are found in higher abundances on conventional sites. This was attributed to variation in factors such as location, climate, crop-type and species, as well as some more intensive organic management practices like excessive tillage that may negatively impact soil fauna. Key management practices intrinsic to organic systems that were identified as being beneficial to biodiversity were the lack of chemical pesticides and fertilisers, sympathetic management of non-cropped areas and preservation of mixed farming.

6.2 Primary research literature since 2005

6.2.1 Multi-taxa studies

Fuller, R. J., L. R. Norton, et al. (2005). Benefits of organic farming to biodiversity vary among taxa. *Biology Letters*

Fuller et al (2005) carried out a large-scale study of plant, invertebrate, bird and bat biodiversity and habitat differences between 89 pairs of conventional and organic farms with arable land in lowland England. They paired farms based on proximity, crop type and cropping season, with plants and invertebrates sampled in one target field in each farm, and birds and bats sampled over several fields. Habitat differences included higher densities of all boundaries and hedgerows, higher and wider hedges, higher proportion of grassland, and smaller field sizes on organic than on conventional farms. Farming practices also differed significantly, with organic crops sown later, and organic rotations always including a ley and no continuous cropping compared to a fifth of conventional farms that did. Organic farms were also more likely to have livestock, with more grazing on arable land than conventional systems. A higher proportion of organic farms had agri-environment agreements. However, there were no significant differences between farming systems in farm size, woodland area, number of ponds and the extent and management of permanent pasture. There was significantly higher species density (number of species), higher diversity (i.e. lower dominance) or higher abundance on organic farms, except for ground beetles in boundaries post-harvest with fewer species recorded on organic farms. Plants showed the most consistent response, with organic fields estimated as containing between 68-105% more plant species and 74-153% greater abundance (as percentage cover) than conventional fields. The estimated effects on other taxa were relatively small, with wide confidence intervals suggesting variable responses. The authors suggest that the variation in magnitude of responses among taxa may reflect colonisation traits of organisms, with plants able to recolonise immediately from the seed bank, while recolonisation rates of other taxa are influenced by the proximity of source populations. As many organic farms in lowland England are isolated within a matrix of non-organic farmland with low habitat diversity, recolonisation potential is low; and this is coupled with the possibility that existing organic farms offer insufficient resources to support species with large spatial scales such as birds. The authors recommend strategies to increase the extent of organic farming as well as the size and contiguity of individual farms.

Clough, Y., A. Holzschuh, et al. (2007a). Alpha and beta diversity of arthropods and plants in organically and conventionally managed wheat fields. *Journal of Applied Ecology*

Gabriel, D., I. Roschewitz, et al. (2006). Beta diversity at different spatial scales: plant communities in organic and conventional agriculture. *Ecological Application*

Clough et al (2007a) and Gabriel et al (2006) used a biodiversity-partitioning approach to compare species richness of plants, bees, ground beetles, rove beetles and spiders in 42 paired organic and conventional wheat fields in 3 regions of Germany. The aim was to identify the contribution of farm system to different levels of biodiversity: α (plot scale diversity), β (species turnover between plots) and γ (total diversity across all plots) and so gain an understanding of whether organic farming results in overall increased species diversity through an increase in local diversity and/or high species turnover between sites. They found that β diversity accounted for a large part of total species richness for all taxa in this agricultural landscape which was surprising given the homogeneity of the wheat fields, and they suggest that this is influenced by the surrounding landscape composition. α diversity was significantly higher in organic systems for plants and bees, but there were no significant differences for spiders, ground beetles or rove beetles. Species turnover between sites (β diversity) was also significantly higher for plants and bees in organic systems, but the reverse was true for spiders. The lack of a positive effect of organic management on epigaeic arthropods was suggested to be due to a limited use of insecticides in the conventional fields or the use of comb-harrowing in organic fields. This study highlights the contribution of landscape heterogeneity to both within-field diversity and species turnover between fields, with the extent of the influence dependent on both management type and species characteristics such as dispersal ability.

Gabriel, D., S. M. Sait, et al. (2010). Scale matters: the impact of organic farming on biodiversity at different spatial scales. *Ecology Letters*

Gabriel et al (2010) assessed the effect of land use at multiple spatial scales, from fine-scale to regional, on a range of taxa including birds, butterflies, insect pollinators, epigeal arthropods, earthworms and plants. Assessments were carried out in fields of cereals (predominantly winter wheat) and grass on matched organic and conventional farms. These were located in 16 paired landscapes containing either high (‘hotspot’: average 17.2%) or low (‘coldspot’: average 1.4%) proportions of organic land within two regions of lowland England. Farmland biodiversity was found to respond to management at the farm and landscape scale, with highest biodiversity recorded on organic farms in landscapes with a high proportion of organic land in the area. Biodiversity levels on conventional farms in organic hotspots were similar to levels on organic farms in a cold spot. There were complex interactions in the response of different taxa to factors at different spatial scales. Plant species density was considerably higher in organic than conventional fields, and epigeal arthropods, butterflies and bumblebees were also found in higher abundance in organic farms and hotspots. However, despite their larvae being more common in organic fields, adult hoverflies were found in higher abundances on conventional farms, especially in hotspots. Conventional farms also supported higher bird diversity (especially of farmland bird specialists), although this response did not apply to generalist species or members of the crow family, which were found in higher densities on organic farms in hotspots. The authors conclude that organic farming has a positive effect on biodiversity at both farm and landscape scales, but there is variation between taxa in their responses.

6.2.2 Plants

Roschewitz, I., D. Gabriel, et al. (2005). The effects of landscape complexity on arable weed species diversity in organic and conventional farming. *Journal of Applied Ecology*

In a study comparing the relative importance of farm management (organic vs. conventional) and landscape complexity for arable weed species diversity, Roschewitz et al (2005a) measured species diversity and abundance of vegetation, seed rain and seed bank in 24 winter wheat fields in 12 landscapes in north Germany. Weed species diversities (α, β and γ) of the vegetation were higher in organic than in conventional fields, and higher in complex than in simple landscapes. The two farming systems had similar diversities in complex landscapes, with a steep decline in diversity in conventional fields as the percentage of arable land in the surrounding landscape increased. Seed rain diversity at all levels was higher in organic than in conventional fields, and there was no correlation with percentage arable land, while in the seed bank, α (mean number of species per plot) and γ (total number of species per field) diversity at the field scale were also significantly higher in organic than in conventional fields. These patterns were primarily determined by broad-leaved species rather than the grasses. Overall diversity was strongly influenced by heterogeneity between the fields, with beta diversity contributing 65% indicating considerable between-field diversity. As with other studies, the authors conclude that while total diversity of weeds was higher in organic fields, this was particularly obvious in fields in simple landscapes with a high percentage of arable land. The authors suggest that as total diversity (γ) of organic fields was only weakly related to landscape complexity, organic fields could be viewed as self-sufficient ecosystems, therefore not relying on immigration from surrounding habitats to maintain species pools.

ADAS Consulting Ltd. (2005) Organic production in the hills and uplands. Final Report Defra Project OF0319

As part of a study investigating the long-term potential of organic livestock production in the hills and uplands (ADAS 2005), botanical composition was more affected by stocking levels (previous and current) than by organic or conventional management on an upland beef and sheep farm. However, following a significant reduction in stocking rates to accommodate an organic system, there were indications of a positive, but slow, response in botanical composition, compared with the conventional system.

Petersen, S., J. A. Axelsen, et al. (2006). Effects of organic farming on field boundary vegetation in Denmark. *Agriculture, Ecosystems and Environment*

Petersen et al (2006) investigated the effects of organic and conventional dairy farming on vegetation diversity of grassy strip and hedgerows field boundaries in Denmark. They recorded higher abundance, species richness (number of species) and species diversity (Shannon-Weiner diversity index) in both short-term (3-4 years since conversion) and long-term (7-8 years since conversion) organic field boundaries compared to the conventional farms. There was higher relative abundance of ruderal species and those with an association with nutrient-rich conditions on conventional farms, with a dominance of stress-tolerant species characterising organic boundaries. The authors suggest that this may reflect the higher levels of disturbance, including use of herbicides and fertilisation in conventional borders.

Gibson, R. H., S. Pearce, et al. (2007). Plant diversity and land use under organic and conventional agriculture: a whole-farm approach. *Journal of Applied Ecology*

Gibson et al (2007) used a whole-farm approach to compare plant abundance, richness and diversity within cropped and semi-natural areas on 10 organic and 10 conventional farms in a complex landscape in south-west England. They found that organic farms had greater total areas of semi-natural habitats (woodland, field margins and hedgerows combined) than conventional farms, with more continuous blocks of woodland with simpler perimeters than patches of a similar size on conventional farms. These semi-natural habitats showed no differences in plant diversity, abundance or richness between organic and conventional farms, with an increase in these measures of biodiversity found only in organic arable fields compared with conventional arable fields. The authors conclude that landscape differences between organic and conventional farms exist even in complex landscapes but with the exception of arable fields, habitat quality did not differ. They suggest that conventional farmers may be able to increase plant diversity by adopting some organic management practices at the field scale.

Gabriel, D. and T. Tscharntke (2007). Insect pollinated plants benefit from organic farming. *Agriculture, Ecosystems and Environment*

Gabriel and Tscharntke (2007) investigated the influence of organic farming on arable weed community structure to test the hypothesis that organic crop fields supported a higher proportion of insect pollinated species. In a study of arable weed communities in the edges and centres of 20 organic and 20 conventional fields in Germany, they found higher species numbers of both insect-pollinated and non-insect pollinated weeds in organic than in conventional fields, with a higher proportion of insect-pollinated species in organic fields. The authors relate this to higher pollinator densities in organic fields and conclude that the effect of agricultural intensification on plant-pollinator interactions can result in important shifts in plant community structure.

Boutin, C., A. Baril, et al. (2008). Plant diversity in crop fields and woody hedgerows of organic and conventional farms in contrasting landscapes. *Agriculture, Ecosystems and Environment*

As part of a study identifying the effects of farming practice, habitat structure and landscape characteristics on plant assemblages, Boutin et al (2008) recorded species richness and composition in hedgerows and crop fields on organic and conventional farms in Ontario. Organic sites had higher species richness of both native and exotic plants in hedgerows and fields than conventional sites, with many species found only in organic hedgerows, including several long-lived herbaceous forest species of conservation interest. Species composition of hedgerows was also influenced by the presence of old-field habitats (areas with sparse shrubs and trees re-colonising cleared land) and the overall number of habitats in the surrounding areas. The authors also found that, despite careful site selection to avoid bias in landscape structure, organic hedgerows were located in areas with more non-crop habitats including old-field and forest patches, which may have provided a larger species pool in organic sites. However, analyses confirmed that both landscape variables and farm system had significantly influenced species richness and composition.

Ulber, L., H.-H. Steinmann, et al. (2009). An on-farm approach to investigate the impact of diversified crop rotations on weed species richness and composition in winter wheat. *Weed Research*

The role of crop rotations and weed management in influencing arable weed species diversity was investigated by Ulber et al (2009). They compared species richness and cover in 24 winter wheat fields from three crop rotation intensities: organic crop rotations with three to five crop species including legumes; conventional farms with a simple crop rotation including three or less autumn-sown crop species; and conventional farms with a diverse crop rotation with three to five crops including a spring sown crop. Within the three crop rotation intensities, the effect of weed control was studied by comparing plots with and without standard weed control practices (mechanical weed control in organic fields and herbicides in conventional fields). Species richness was significantly higher in organic crop rotations, with no differences detected between the simple and diverse conventional crop rotations. Weed control was effective in reducing species richness and weed cover within the conventional fields but there were no significant differences in species richness and weed cover of organic plots with and without weed control. This study indicated that increasing the diversity of the conventional crop rotation did not lead to higher weed species richness and cover and that herbicide use is the main factor limiting species diversity in conventional systems. This effect was also identified for species of biodiversity value for supporting farmland birds and invertebrates, thus impacting on resource provision for these taxa.

FRASER, M. D. (2010). Biodiversity and other beneficial environmental impacts of organic conversion in hills and uplands. OF0380. Final report to Defra.

This study was the first to explore in detail the extent to which conversion to organic farming influences habitat diversity in the uplands. Botanical surveys were undertaken on a total of 45 upland farms; 13 recently converted organic farms, 16 long-term organic farms and 16 conventional farms; across England and Wales. The total area of land assessed within the survey was 4083 ha. The high numbers of farms in all categories signed up to agri-environment schemes reflect the reliance upland farmers have on the economic support such schemes provide. Research is now required to differentiate the impact of conversion to organic from the effects of participation in other schemes.

Results from the study found little difference in the plant species encountered on the three different farm types, although there was greater distinction between the farm types when percentage cover of the different species was taken into account. The cover of perennial ryegrass was lower in Improved Grassland on Long-term organic farms, whereas the cover of Yorkshire fog was higher. This change is likely to have implications for productivity, since Yorkshire fog has a lower nutritional value and is less acceptable to stock than ryegrass. The general similarity across farm types in Improved Grassland composition can be linked in part to key sward management decisions being influenced by the particular challenges faced by farmers in such regions. For example, many take only one cut of winter forage, and choice of timing for is largely dictated by the later start to the growing season in upland areas.

Purple Moor-grass and Rush Pastures is one of the semi-natural grassland habitats most commonly encountered on upland farms. While previous studies have demonstrated changes in grazing pressure can alter floristic diversity within purple moor-grass-dominated grassland, there is little evidence of organic conversion affecting the plant species encountered within this community. Likewise, there was little evidence of organic conversion influencing average plant species number per holding.

6.2.3 Birds

Watson, C. et al (2006). Can organic farming deliver natural heritage goals in the UK uplands? *Aspects of Applied Biology*

In this study, Watson et al (2006) analysed a subset of biodiversity data from England and Wales to identify the effect of organic farming on bird diversity in the uplands. They found that in winter, there were significantly higher total densities of birds, and in particular insectivores and Farmland Bird Indicator species, on organic farms. During the summer breeding season, insectivores were again found in higher densities on organic farms.

Kragten, S. and G. R. de Snoo (2008). Field-breeding birds on organic and conventional arable farms in the Netherlands. *Agriculture, Ecosystems and Environment*

Kragten and de Snoo (2008) compared territory densities of field-breeding farmland birds in paired organic and conventional arable farms in the Netherlands over two years to identify the effect of three factors: differences in non-crop habitats, differences in crop type and differences in within-crop factors. They found no significant differences in total territory densities between organic and conventional farms, and at the species level only skylark and lapwing were recorded in greater abundance on organic farms. There were no differences in the area of non-cropped habitats on organic and conventional farms, and the authors suggest that crop-type influenced the territory densities of skylark and lapwing, with skylarks showing a preference for spring cereals which are more widespread on organic farms. They found no significant differences in territory densities between organic and conventional fields with the same crop type, and so conclude that organic farming primarily benefits these species of farmland birds through its diverse cropping regime.

Batáry, P., T. Matthiesen, et al. (2010). Landscape-moderated importance of hedges in conserving farmland bird diversity of organic vs. conventional croplands and grasslands. *Biological Conservation*

In a study investigating the interaction of organic management, hedgerow length and landscape scale variables, Batáry et al (2010) recorded bird species richness, abundance and community composition in wheat fields and meadows and adjacent hedges in paired conventional and organic winter wheat fields in 10 landscapes in Germany. They recorded higher bird richness and abundance in organic than in conventional fields, independent of land-use (wheat fields and meadows), but found that hedge length had a greater effect on richness than organic management. The benefit of hedge length was dependent on landscape complexity so that hedge length increased bird richness only in simple landscapes.

Chamberlain, D. E., A. C. Joys, et al. (2010). Does organic farming benefit farmland birds in winter? *Biology Letters*

Chamberlain et al (2010) collected bird and habitat data from 48 paired organic and conventional farms in the UK over two winters to identify the effect of habitat differences and management on farmland bird abundance. Abundance was significantly higher on organic farms for six species (stock dove, starling, jackdaw, linnet, woodpigeon and greenfinch) as was total abundance of all species combined. No species were significantly more abundant on conventional farms. However, using an information-theoretic approach, the authors found that both habitat extent and farm management were important determinants of starling and greenfinch abundances only, but for other species, there was no additional effect of organic farming independent of habitat variables. This indicated that organic farming benefits farmland bird populations primarily through greater habitat heterogeneity, and that variation in landscape-scale variables is a better predictor of bird abundance and richness than farming practice. Chamberlain et al suggest that as organic farms tend to have less stubble than conventional farms over winter, they may not provide adequate resources for seed-feeding species over winter.

Geiger, F., G. R. de Snoo, et al. (2010). Landscape composition influences farm management effects on farmland birds in winter: A pan-European approach. *Agriculture, Ecosystems and Environment*

In a large-scale pan-European study carried out by Geiger *et al* (2010) the effects of agricultural intensity, farming practices, landscape composition and vegetation cover on abundance and species richness of wintering farmland birds was assessed. Bird abundance and species richness was higher on organic farms, with a significant interaction between farm type and landscape complexity indicating that this positive effect was found only in simple landscapes. Bird abundance was actually lower on organic farms in complex landscapes; the authors relate this to lower abundances of yellowhammers in the organic fields which reflected marginally smaller field sizes in the conventional sites. Mechanical weed control used frequently during the previous growing season on organic farms was correlated with lower farmland bird abundances and species; this was related to the effect on reducing weed cover and invertebrate abundance with subsequent effects on food abundance during the winter months.

Smith, H. G., J. Dänhardt, et al. (2010). Consequences of organic farming and landscape heterogeneity for species richness and abundance of farmland birds. *Oecologia*

Smith et al (2010) compared bird species richness and abundance on organic and conventional farms in two contrasting landscapes (simple and complex) in southern Sweden. Their results indicated that for passerine birds (particularly invertebrate feeders), positive effects of organic farming on species richness were significant only in homogeneous landscapes. In contrast, non-passerine species richness was significantly higher in organic systems, independent of landscape complexity. Bird abundance was significantly higher in heterogeneous landscapes, but there was no relationship between bird abundance and organic farming. The authors suggest that organic farming is particularly beneficial for invertebrate-feeding species in homogeneous landscapes, as organic systems enhance foraging conditions by increasing structural complexity of the farm habitat.

6.2.4 Invertebrates

Schmidt, M. H., I. Roschewitz, et al. (2005). Differential effects of landscape and management on diversity and density of ground-dwelling farmland spiders. *Journal of Applied Ecology*

Schmidt et al (2005) investigated the relationships of ground-dwelling spiders to landscape features and organic farming in 12 pairs of organic and conventional winter wheat fields on a gradient of landscape complexity. They found that species richness increased with increasing area of non-crop habitats in the landscape, irrespective of management, while spider abundance was related to percentage of non-crop habitats only in conventional fields. Organic farming had no effect on species richness but enhanced spider abundance by 62%.

Rundlöf, M. and H. G. Smith (2006). The effect of organic farming on butterfly diversity depends on landscape context. *Journal of Applied Ecology*

Rundlöf and Smith (2006) investigated the effect of landscape complexity on the benefits of organic farming for enhancing butterfly diversity. They recorded butterfly species richness and abundance in cereal field headlands and margins on 12 matched pairs of organic and conventional farms in homogeneous and heterogeneous landscapes in Sweden. They found that both organic farming and landscape complexity significantly enhanced butterfly species richness and abundance, and a significant interaction between the two factors indicated that the beneficial effects of organic farming was only evident in homogeneous landscapes.

Clough, Y., A. Kruess, et al. (2007b). Local and landscape factors in differently managed arable fields affect the insect herbivore community of a non-crop plant species. *Journal of Applied Ecology*

Clough et al (2007b) studied farm management and landscape effects on insect herbivore communities of a non-crop species, the creeping thistle (*Cirsium arvense*) in 48 paired organic and conventional wheat fields in Germany. Measured across a gradient of landscape diversity, they found that species richness of the herbivore community was enhanced by both organic farming and landscape complexity, with higher colonisation rates of host plants in organic than in conventional fields likely to reflect slightly higher natural cover of creeping thistle in organic fields.

Feber, R. E., P. J. Johnson, et al. (2007). A comparison of butterfly populations on organically and conventionally managed farmland. *Journal of Zoology*

In a study on the effects of organic farming on butterflies, Feber et al (2007) compared butterfly abundance on organic and conventional farms in southern England over three years. They recorded higher overall abundance on organic than on conventional farms, with a greater decline in abundance between field margin and crop edge evident in conventional systems. Species richness also tended to be higher on organic farms. There were no significant differences between the two systems in terms of habitat features such as abundance of grassy margins, ditch size or presence and abundance of mature trees, although hedges were significantly larger on organic farms which may have a positive influence on butterfly populations. Similarly, grass and forb species richness was similar in the field boundaries of both systems, but a higher frequency of annuals on conventional farms may cause differences in nectar resources and host plant availability for butterflies.

Holzschuh, A., I. Steffan-Dewenter, et al. (2007). Diversity of flower-visiting bees in cereal fields: effects of farming system, landscape composition and regional context. *Journal of Applied Ecology*

Investigating the effects of farming systems and landscape on bees and floral resources, Holzschuh et al (2007) compared bee richness, flower cover and flowering plant diversity in organic and conventional wheat fields across a gradient of landscape complexity in three regions in Germany. Organic fields supported higher bee abundance and species richness, flower cover and diversity of flowering plants than conventional fields. As bee diversity was related to both flower cover and diversity, the authors suggest that the beneficial effect of organic farms on bees is mediated through the effect on floral resources. As the proportion of arable crops in the landscape increased, the differences in bee diversity between the farming systems increased.

Rundlöf, M., J. Bengtsson, et al. (2008). Local and landscape effects of organic farming on butterfly species richness and abundance. *Journal of Applied Ecology*

In a later study, Rundlöf et al (2008) recorded butterflies and their nectar and host-plant resources in organic and conventional fields and adjacent borders in eight pairs of landscapes differing in the proportion of land under organic management within the surrounding landscape. They found higher butterfly species richness and abundance on organic farms at a local scale, with a positive effect on butterfly diversity of a large proportion of organic land in the surrounding area, independent of local farming practice. These benefits could only be partly explained by variation in local availability of floral and host-plant resources. Based on these results, the authors conclude that by enhancing butterfly diversity on nearby conventional land, organic farming has a landscape-scale effect on biodiversity conservation.

Hodgson, J. A., W. E. Kunin, et al. (2010). Comparing organic farming and land sparing: optimizing yield and butterfly populations at a landscape scale. *Ecology Letters*

Hodgson et al (2010) investigated the trade-off between productivity and nature conservation through a comparative study of butterfly species richness and abundance in fields of winter wheat and pasture on organic and conventional farms and nature reserves in 16 landscapes in England. They found that organic farms supported higher densities of butterflies than conventional farms, with an interaction with the amount and pattern of organic farms in the surrounding area indicating that butterfly density increases with the proportion of organic farms in the landscape. Nature reserves supported the highest densities of butterflies. Modelling the optimum land use to meet both productivity and conservation targets based on organic: conventional yield ratios and butterfly data, the authors calculated that when organic yields fall below 87% of conventional yields a ‘land sparing’ approach, where farming is conventional and land is dedicated to nature reserves, is better for butterfly conservation. An alternative scenario where spared land is in the form of extra grass field margins indicates that organic farming (‘land sharing’) is an optimum land use if organic yields are at least 35% that of conventional.

Holzschuh, A., I. Steffan-Dewenter, et al. (2010). How do landscape composition and configuration, organic farming and fallow strips affect the diversity of bees, wasps and their parasitoids? *Journal of Animal Ecology*

In a more detailed study of landscape-mediated effects on the diversity of bees, wasps and their parasitoids on organic and conventional farms, Holzschuh et al (2010) investigated the relative importance of changed landscape composition (increased areas of cropped land), reduced habitat connectivity and reduced habitat quality on nest colonisation. Standardised nest traps were placed in field centres and neighbouring permanent fallow strips on 23 pairs of conventional and organic wheat fields varying in edge densities and % non-crop habitats. Species richness and nest colonisation by wasps was higher in organic than in conventional fields, with the mean number of wasp brood cells more than 200% higher in organic than in conventional fields. Species richness of bees was also higher in organic than in conventional sites, whereas parasitoid responses to local and landscape effects were mediated by their hosts. The positive effect of organic farming also influenced adjacent fallow strips with a decrease in bee and wasp diversity between fallow strips and field centres found only in conventional fields. Bees and wasps were also affected by landscape characteristics; bees were enhanced by high proportions of non-crop habitats (i.e. landscape composition), while wasps increased with increasing edge densities (i.e. landscape configuration). This indicates the importance for wasps of boundary features such as bank vegetation, fallow strips and hedges to increase habitat connectivity and support dispersal from source habitats to new nesting opportunities. An interaction between landscape and local factors meant that the diversity of flower-visiting bees decreased with decreasing landscape heterogeneity in conventional but not in organic fields, indicating that organic fields compensate for low availability of non-crop foraging habitats in simple landscapes.

Diekötter, T., S. Wamser, et al. (2010). Landscape and management effects on structure and function of soil arthropod communities in winter wheat. *Agriculture, Ecosystems and Environment*

Diekötter et al (2010) carried out a multi-taxa study of landscape and management effects on soil arthropod communities and functioning in six pairs of organic and conventional winter wheat fields in Germany. Using pitfall traps, the activity densities of ground beetles, spiders, millipedes, woodlice and springtails were measured, and litter decomposition, soil biological activity and weed seed predation were investigated. Activity densities of millipedes and woodlice, and species richness of ground beetles were higher in organic fields in a landscape with a higher proportion of organic land. Seed predation on arable weeds was also higher in organic than in conventional fields.

6.2.5 Soil microbes

Esperschütz, J., A. Gattinger, et al. (2007). Res ponse of soil microbial biomass and community structures to conventional and organic farming systems under identical crop rotations. *FEMS Microbiological Ecology*

Oehl, F., E. Sieverding, et al. (2004). Impact of long-term conventional and organic farming on the diversity of arbuscular mycorrhizal fungi. *Oecologia*

The long-term DOK field experiment in Switzerland has used to study the effect of different farming systems on microbial communities (Esperschütz et al. 2007; Oehl et al. 2004). Esperschütz et al (2007) measured microbial communities in winter wheat plots under organic and conventional management and an unfertilized control. They found a significant influence of organic farming on microbial biomass and diversity, related primarily to the input of farmyard manure which stimulates microbial growth. Oehl et al (2004) recorded higher arbuscular mycorrhizal fungal spore abundance and species diversity in the organic plots under grass-clover. Organic and conventional systems were characterised by different communities, with organic plots supporting some species that are present in natural ecosystems.

van Diepeningen, A. D., O. J. de Vos, et al. (2006). Effects of organic versus conventional management on chemical and biological parameters in agricultural soils. *Applied Soil Ecology*

Van Diepeningen et al (2006) considered the effects of organic and conventional management on microbial and nematode communities on 13 pairs of farms in the Netherlands. They recorded higher numbers of bacteria of different trophic groups, and larger species richness of both bacteria and nematode communities in organic systems.

Gosling, P., A. Ozaki, et al. (2010). Organic management of tilled agricultural soils results in a rapid increase in colonisation potential and spore populations of arbuscular mycorrhizal fungi. *Agriculture, Ecosystems and Environment*

In a study of arbuscular mycorrhizal fungal communities in tilled agricultural soils, Gosling et al (2010) recorded significantly higher spore numbers in organically managed soils, although there was considerable variation in numbers between sites. Root colonisation was also higher in organic soils in cereal based arable, mixed arable/horticultural and horticultural systems. There was no relationship between spore numbers or root colonisation and the time since conversion to organic management, with both parameters responding rapidly post-conversion.

Verbruggen, E., W. F. M. Roling, et al. (2010). Positive effects of organic farming on below-ground mutualists: large-scale comparison of mycorrhizal fungal communities in agricultural soils. *New Phytologist*

In a large-scale comparison of mycorrhizal fungal communities, Verbruggen et al (2010) assessed AMF community composition in 13 pairs of organic and conventional arable fields and five semi-natural grasslands. Highest AMF richness was recorded in grasslands, and organic systems had significantly higher numbers than conventional fields. AMF richness increased significantly with time since conversion from conventional to organic management. AMF communities in organic fields were more similar to grasslands than conventional fields, and were less uniform with higher between-site diversity.

6.2.6 Landscape

Norton, L. R., P. J. Johnson, et al. (2009). Consequences of organic and non-organic farming practices for field, farm and landscape complexity. *Agriculture, Ecosystems and Environment*

In trying to unravel the interaction between farming system and landscape characteristics, Norton et al (2009) identified habitat and management differences between 89 pairs of organic and conventional fields on 161 farms containing arable crops in England. They found that organic farms were located in more diverse landscape types, had smaller field sizes, higher, wider and less gappy hedgerows subjected to less frequent management, use rotations that include grass, and are more likely to be mixed. Even within diverse landscapes, organic systems had greater field and farm complexity than non-organic systems.

Gabriel, D., S. J. Carver, et al. (2009). The spatial aggregation of organic farming in England and its underlying environmental correlates. *Journal of Applied Ecology*

Gabriel et al (2009) explored the environmental, social and cultural factors associated with the distribution of organic farms in the English agricultural landscape. They found that organic farms are spatially aggregated at the regional and neighbourhood scales. The strongest predictor of concentration of organic farms in an area is the size and type of farm, with organic farms more likely to occur where farms are small, and are mixed or dairy rather than arable. Soil conditions are also a main predictor, with organic farming associated with poorer, less productive soils. Organic farms are also more likely to occur in areas with a higher degree of ruralisation than conventional intensive farms which are concentrated around the most urbanised areas of the UK. Modelling suggested that a range of environmental factors associated with lower agricultural potential leads to an aggregation of organic farms.

6.2.7 Ecosystem Services

Roschewitz, I., M. Hücker, et al. (2005). The influence of landscape context and farming practices on parasitism of cereal aphids. *Agriculture, Ecosystems and Environment*

Roschewitz et al (2005b) investigated biological pest control of cereal aphids by parasitoids on 24 paired organic and conventional winter wheat fields in 12 landscapes along a gradient of landscape complexity. They found that aphid abundance varied considerably over the three years of the study and across the 12 different landscapes. Organic farms had a lower abundance of cereal aphids during wheat flowering, but there was no difference in parasitism rates. Landscape complexity influenced both pest and parasitoid communities, with higher aphid densities and parasitism rates in complex landscapes, presumably due to availability of alternative resources.

Macfadyen, S., R. H. Gibson, et al. (2009b). Do differences in food web structure between organic and conventional farms affect the ecosystem service of pest control? *Ecology Letters*

Macfadyen et al (2009b) investigated pest control on organic and conventional farms using a food-web approach to analyse plant, herbivore and parasitoid community structure at the whole-farm scale. On each farm, each landscape element was sampled according to the area it occupied. By constructing qualitative food webs from 10 pairs of organic and conventional farms, they showed that organic farms have significantly more species at the three trophic levels, resulting in significant structural differences between organic and conventional food webs. Herbivores were attacked by more parasitoid species on organic than on conventional farms. Using a novel herbivore (leaf miner *Phyllonorycter leucographella*) to bioassay pest control as an ecosystem service, the authors found that higher species richness of parasitoids in organic systems did not result in higher mortality of the pest species. This was attributed to differences in management strategies and landscape structure between organic and conventional systems.

Macfadyen, S., R. Gibson, et al. (2009a). Parasitoid control of aphids in organic and conventional farming systems. *Agriculture, Ecosystems and Environment*

In a study of aphid pest control by parasitoids in cereal crops on 10 organic and 10 conventional farms in southwest England, Macfadyen et al (2009a) recorded significantly higher aphid abundance on organic farms, but aphid populations in both farming systems were below the threshold of economic losses. However, they found no difference in parasitism rate, parasitoid richness and parasitoid community diversity between the farming systems.

Crowder, D. W., T. D. Northfield, et al. (2010). Organic agriculture promotes evenness and natural pest control. *Nature*

Crowder et al (2010) carried out a study of biological pest control in agricultural systems, investigating whether organic farming promotes pest control by increasing species richness and evenness of the natural enemy community in potato fields in Washington. They found no difference in species richness between organic and conventional fields. However, they recorded higher evenness in organic fields where abundance of natural enemies were relatively equally distributed, compared to conventional fields which were dominated by one enemy species that accounted for up to 80% of individuals. By experimentally manipulating natural enemy evenness in potato field enclosures, Crowder et al found that greater evenness promoted plant biomass and increased pest (potato beetle) mortality; this response was independent of species richness, and species identity, indicating this was an effect of greater community evenness rather than the impact of any specific species. The increase in natural enemy evenness in organic fields translates into pest densities 18% lower and potato plants 35% larger than in conventional fields.

Sandhu, H. S., S. D. Wratten, et al. (2008). The future of farming: The value of ecosystem services in conventional and organic arable land. An experimental approach. *Ecological Economics*

Sandhu et al (2008) quantified the economic value of ecosystem services provided by organic and conventional arable systems in New Zealand. They used a 'bottom-up' approach comprising field experiments to attribute economic values to a range of ecosystem services including biological pest control, soil formation, mineralisation of plant nutrients, pollination, aesthetics, food and raw material provision and carbon accumulation. They calculated that the total economic values of ecosystem services in organic fields were considerably higher than in conventional fields (organic fields ranged from US $1610 to US $19,420 ha-1 yr-1; conventional fields from US $460 to US $14,570 ha-1 yr-1 (Sandhu et al. 2008)).

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