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Benefits of organic farming to biodiversity vary among taxa

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Habitat and biodiversity differences between matched pairs of organic and non-organic farms containing cereal crops in lowland England were assessed by a large-scale study of plants, invertebrates, birds and bats. Habitat extent, composition and management on organic farms was likely to favour higher levels of biodiversity and indeed organic farms tended to support higher numbers of species and overall abundance across most taxa. However, the magnitude of the response varied; plants showed larger and more consistent responses than other taxa. Variation in response across taxa may be partly a consequence of the small size and isolated context of many organic farms. Extension of organic farming could contribute to the restoration of biodiversity in agricultural landscapes.

Keywords: agri-environment schemes; biodiversity; farming systems; organic farming

1. INTRODUCTION

Agriculture is a principal cause of loss of wildlife and its habitats, both through expansion into natural habitats and intensification of agro-ecosystems (Green *et al.* 2005). Reduction of diversity and complexity of habitats at different scales is a critical process underpinning loss of biodiversity on agricultural land (Benton *et al.* 2003). Organic farms may have higher levels of habitat heterogeneity than non-organic farms, and so potentially offer one route to restoring farmland biodiversity (Krebs *et al.* 1999).

Of the numerous studies that claim to demonstrate that organic farming benefits biodiversity, many are poorly designed, limited in taxonomic scope, or local in scale (Hole *et al.* 2005). Meta-analysis of published studies differing in methodology and scale, suggests that biodiversity responses to organic farming vary across studies and organism groups. Organic farming appears to be associated with increased species richness and abundance for plants, predatory invertebrates and birds (Bengtsson *et al.* 2005). This paper uses data from an integrated study of plants, invertebrates, birds and bats conducted on a large sample of the organic farms growing cereals in England to address two aims. First, we test whether responses to organic farming in terms of species number, diversity and abundance are taxon-specific. Second, we assess whether organic farms differ from non-organic farms in habitat extent, composition and management and, therefore, whether any system differences in biodiversity are potentially linked to habitat heterogeneity and availability.

2. METHODS

The basic approach was a large-scale comparison during the period 2000–2003 of organic and non-organic farms paired on the basis of proximity, crop type and cropping season. Organic farms of at least 30 ha with contiguous organic fields containing arable land were identified from the databases of the Soil Association and Organic Farmers and Growers. Data were collected from 89 pairs of farms; 80% of pair members were within 10 km of one another (median distance = 6.4 km) but pair members were non-contiguous. Virtually all suitable organic farms in England growing relevant crop types (winter wheat and spring cereals) at the time of the study were examined for a minimum of three taxa (plants, spiders, carabid beetles). One organic and one non-organic cereal field were randomly selected (‘target fields’) in each of the 89 farm pairs. Plants and invertebrates were sampled on these 89 pairs of fields. All fields sampled in 2000 were spring cereals; all fields thereafter were winter cereals. The organic target fields covered a range of ages since conversion. Birds and bats were sampled at a larger spatial scale extending over several fields.

Habitat data were collected at farm and field levels once during the project period. Ground-based surveys of habitat extent were undertaken for a sample of the bird survey areas. Locations of crops and ‘habitat patches’ (e.g. hedges, ponds) were mapped at 1 : 2500. Hedge height and width were measured at 10 evenly spaced points around the boundary of each target field; tree/shrub composition, numbers of trees and gaps were recorded within 5 m of these points. Farmers were asked 40 questions concerning management of the target field and the whole farm.

Plants within target fields were sampled in 3 years (2000, 2002, 2003) with each field sampled in one of the years. Three plot types were used; the first two followed the procedure of Smart *et al.* (2003) with one plot per field. (i) Crop margin plots recorded species presence in plots extending 1 m from the ploughed edge and 100 m along the field edge. (ii) Field boundary plots recorded presence and abundance (% cover) of species in plots extending 1 m from the centre of the uncultivated field boundary and 10 m parallel to the boundary. (iii) Percent cover of within-crop plants was recorded in 0.5×0.5 m quadrats placed at distances of 2, 4, 8, 16 and 32 m from the ploughed margin on 12 transects per field.

For invertebrates, years of sampling and fields used were as for plants. A grid of 18 pitfall traps was set in each target field, comprising nine within the crop and nine within the uncropped boundary. Traps were set for one week before emptying. Paired target fields were always sampled at the same time. Because of seasonal variation in animal activity and trapping efficiency, separate samples were collected before and after harvest. Spiders and carabids were identified to species level.

Sampling of birds was carried out on 61 farm pairs in winters 2000/2001 and 2002/2003 (29 in both winters and 32 in one winter). Surveys took place on the target field and up to five adjacent fields once per month at each site between October and February. During each visit, the observer walked the perimeter of each field and once across the centre of each field. Birds were mapped on large-scale maps and individual records were subsequently allocated to habitat categories. Abundance values for individual farms were based on mean counts across visits.

Bat surveys were completed pre-harvest on 65 farm pairs between June and August in 2002 and 2003. Using transects of approximately 3 km starting in the target field, activity of *Nyctalus leisleri*, *Nyctalus noctula* and *Eptesicus serotinus* was identified using heterodyne bat detectors tuned to 25 kHz. Transects were as close as possible to triangular with an apex pointing north. Bat passes and feeding calls were counted for each 125 m transect section, at the end of which the detector was retuned to 50 kHz and the number of *Pipistrellus* passes and feeding buzzes counted for 1 min.

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An abundance index for all bats was based on total passes per 3 km. Bat activity along transects was also recorded onto minidisc and sonograms were analysed using Batsound software. The data were adjusted for recording duration and used to derive indices of bat activity, species density and dominance.

Comparisons of habitat and management attributes are based on Wilcoxon matched-pair tests. Analyses in table 1 follow the format of Perry *et al.* (2003).

3. RESULTS

The density (km ha^{-1}) of all boundaries and of hedges was higher on organic than non-organic farms (means of 0.15 ± 0.02 and 0.10 ± 0.01, $n=48$, $p<0.05$; 0.12 ± 0.02 and 0.07 ± 0.01, $n=48$, $p<0.01$, respectively). The proportion of land that was grass rather than cropped land was much higher on organic than non-organic farms (respective percentage means of 37.7 ± 3.5 and 17.2 ± 2.5, $n=56$, $p<0.001$). Organic target fields were smaller than their non-organic pairs (7.3 ± 0.5 ha and 10.7 ± 0.9 ha, $n=89$, $p<0.001$). There were also marked differences in hedgerow structure around the target fields (figure 1). Height ($p<0.05$), base width ($p<0.05$) and top width ($p<0.01$) were greater on organic farms and there were more gaps in hedgerows ($p<0.05$) surrounding non-organic fields. There were no significant differences between systems in the numbers of trees or of tree and shrub species recorded in hedges.

Based on interviews with farmers, we quantified other significant ($p<0.05$) differences between systems that were likely to influence biodiversity. Organic farmers sowed crops later in all 3 years. Rotations differed, with organic systems always including a ley as part of a cereal/vegetable rotation. Approximately a fifth (22%) of non-organic farms cropped continuously (set-aside excluded), but no organic farmers did. Organic farms were more likely to include livestock (and a wider variety of types) and were more likely to graze them on arable land, e.g. on stubbles or leys. Organic farmers cut their hedges less often and were more likely to use a traditional hedge management method (laying). More organic farms (64%, $n=73$) had agri-environment agreements (in addition to the Organic Farming Scheme) than non-organic (43%, $n=87$). There were no significant differences between farm types in farm size, woodland area, number of ponds, the extent and management of permanent pasture, or whether set-aside was rotated or permanent. More non-organic farmers used natural regeneration as a set-aside option than did organic farmers.

Numbers of species, measured as species density (Gotelli & Colwell 2001), and abundance were typically higher on organic farms (24 out of 27 D values in table 1 were positive). However, the pattern was less clear for diversity as measured by the Berger–Parker dominance index (May 1975). All significant differences ($p<0.05$), with one exception, related to higher species density, higher diversity (i.e. lower dominance) or higher abundance on organic compared to non-organic (table 1). The exception was carabids in the boundary, post-harvest, which showed a weak tendency for fewer species to be recorded on organic farms. Significant differences between systems were evident in 15 out of 40 comparisons and were more frequent for species density (6/14) and overall abundance (7/13) than for dominance (2/13).

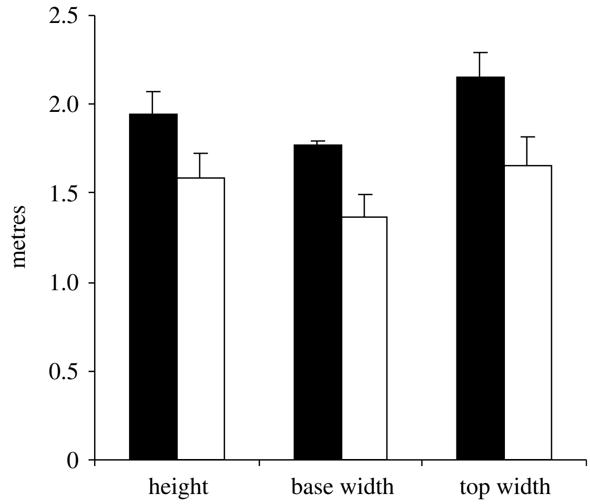

Figure 1. Hedge parameters (m) of target fields on organic and non-organic farms (mean+s.e.). Black bars are hedges next to organic fields and open bars are for non-organic.

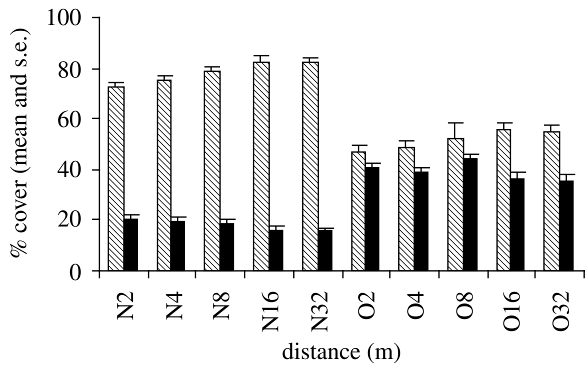

Figure 2. Crop and weed cover (mean+s.e.) along transects into the crop on non-organic farms (N) and organic farms (O). Hatched bars show cover values for cereal crop plants and black bars show values for weeds at 2, 4, 8, 16 and 32 m from the field edge.

Evidence for system differences was not evenly distributed across taxa (table 1). The largest and most consistent effects were for plants and the smallest for carabids. Based on the confidence intervals given in table 1, organic fields were estimated to hold 68–105% more plant species and 74–153% greater abundance of weeds (measured as cover) than non-organic fields. Cover of weeds was consistently higher at all distances into the crop (figure 2). Examination of the D and R values in table 1 shows that estimated effect sizes for other taxa were relatively small. For example, based on the confidence intervals for abundance, organic was estimated to support 5–48% more spiders in pre-harvest crops, 16–62% more birds in the first winter and 6–75% more bats.

4. DISCUSSION

The indications from this study, as with previous work (Hole *et al.* 2005), are that organic farming is associated with higher levels of biodiversity. The

Table 1. Effects of farming system on number of species (species density), diversity (dominance) and abundance.
(Dominance is measured as the Berger–Parker dominance index (May 1975). *Significance of system effect (shown in bold) was based on *z*-tests (birds) or GLM models taking account of year (all other taxa). **Mean difference between organic (O) and non-organic (N) log-scale attribute (positive values indicate O > N).)

	species density			dominance			abundance		
	*p**	*D***	*R* (CI)[a]	*p**	*D***	*R* (CI)[a]	*p**	*D***	*R* (CI)[a]
plants (crop margin)[b]	< **0.001**	0.42	1.51 (1.37–1.67)	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
plants (field boundary)[b]	< **0.001**	0.16	1.17 (1.07–1.27)	0.525	−0.03	0.97 (0.87–1.07)	0.249	0.04	1.04 (0.97–1.23)
plants (within-crop)[b]	< **0.001**	0.62	1.85 (1.68–2.05)	< **0.001**	−0.44	0.64 (0.56–0.74)	< **0.001**	0.74	2.09 (1.74–2.53)
spiders (boundary pre-harvest)	0.544	0.03	1.03 (0.92–1.17)	0.618	−0.01	0.99 (0.95–1.03)	0.322	0.10	1.10 (0.92–1.32)
spiders (boundary post-harvest)	0.171	0.10	1.11 (0.92–1.34)	0.465	0.03	1.03 (0.96–1.12)	**0.011**	0.20	1.22 (1.05–1.42)
spiders (crop pre-harvest)	**0.003**	0.16	1.17 (1.06–1.30)	0.099	−0.04	0.96 (0.93–1.00)	**0.013**	0.22	1.25 (1.05–1.48)
spiders (crop post-harvest)	0.175	0.12	1.17 (0.92–1.46)	0.088	−0.07	0.93 (0.86–1.01)	0.690	0.05	1.06 (0.83–1.36)
carabids (boundary pre-harvest)	0.212	−0.09	0.91 (0.79–1.06)	0.092	0.05	1.05 (0.99–1.12)	0.876	0.04	1.04 (0.78–1.37)
carabids (boundary post-harvest)	**0.046**	−0.01	0.83 (0.66–1.03)	0.782	−0.01	0.99 (0.93–1.05)	0.119	−0.12	0.83 (0.69–1.06)
carabids (crop pre-harvest)	0.158	0.09	1.09 (0.99–1.20)	0.484	0.02	1.02 (0.96–1.09)	**0.044**	0.26	1.30 (1.02–1.66)
carabids (crop post-harvest)	0.345	0.09	0.92 (0.77–1.09)	0.575	0.02	1.02 (0.95–1.11)	0.590	0.16	0.87 (0.64–1.21)
birds (winter 2000/01)	0.162	0.08	1.05 (0.98–1.12)	0.651	−0.01	1.03 (0.89–1.16)	< **0.001**	0.27	1.39 (1.16–1.62)
birds (winter 2002/03)	0.142	0.07	1.03 (0.99–1.06)	0.663	−0.03	0.98 (0.89–1.07)	**0.005**	0.41	1.26 (1.08–1.44)
bats	**0.013**	0.29	1.33 (1.08–1.65)	**0.006**	−0.17	0.84 (0.73–0.97)	**0.026**	0.31	1.35 (1.06–1.75)

[a] Sample mean ratio of the O/N attribute with 95% confidence intervals in parentheses (values greater than 1 indicate O > N).
[b] Excluding cropped plants.

striking result was that plants were far more consistent and pronounced in their response than other taxa, as in Bengtsson *et al*. (2005). For other taxa, even where significant differences were detected, the results were variable with wide confidence intervals. Our findings differ from those of Bengtsson *et al*. (2005) mainly in that predatory invertebrates only infrequently showed a significant response. Bats were not included in the meta-analysis of Bengtsson *et al*. but Wickramasinghe *et al*. (2004) have also suggested that organic farming is beneficial to bats, both through provision of more structured habitats and higher abundance of insect prey.

We have shown that organic farms differ from non-organic farms in habitat extent, composition and management. In addition, the exclusion of synthetic pesticides and fertilizers from organic is a fundamental difference between systems. Given these features, why did the magnitude of differences in species density and abundance vary so much among taxa? One factor may be the differential impacts of temporal and spatial scales on the colonization traits of organisms. Plants are more directly and immediately affected by both pesticide and fertilizer inputs, but have the ability to recolonize from the seed bank immediately following conversion to organic management. For other taxa, recolonization is affected by proximity of population sources both in time and space. Many organic farms are isolated units, embedded in non-organic farmland managed with conventional levels of pesticide and fertilizer inputs, often coupled with relatively low levels of habitat heterogeneity, which inevitably affects species colonization. Furthermore, most existing organic farms probably offer insufficient resources to affect population sizes of species with large spatial needs, notably birds. It would appear that extension of organic farming is a potential means of re-establishing heterogeneity of farmland habitats, and thereby enhancing farmland biodiversity. However, the total area of organic farmland relative to non-organic is small (currently <3% of English farmland is organic). Strategies aimed at increasing both the total extent of organic farming and the size and contiguity of individual organic farms, could help to restore biodiversity in agricultural landscapes.

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