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# The effects of organic agriculture on biodiversity and abundance: a meta-analysis

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**Summary**

**1.** The efficiency of agricultural subsidy programmes for preserving biodiversity and improving the environment has been questioned in recent years. Organic farming operates without pesticides, herbicides and inorganic fertilizers, and usually with a more diverse crop rotation. It has been suggested that this system enhances biodiversity in agricultural landscapes. We analysed the effects of organic farming on species richness and abundance using meta-analysis of literature published before December 2002.

**2.** Organic farming usually increases species richness, having on average 30% higher species richness than conventional farming systems. However, the results were variable among studies, and 16% of them actually showed a negative effect of organic farming on species richness. We therefore divided the data into different organism groups and according to the spatial scale of the study.

**3.** Birds, insects and plants usually showed an increased species richness in organic farming systems. However, the number of studies was low in most organism groups (range 2–19) and there was significant heterogeneity between studies. The effect of organic farming was largest in studies performed at the plot scale. In studies at the farm scale, when organic and conventional farms were matched according to landscape structure, the effect was significant but highly heterogeneous.

**4.** On average, organisms were 50% more abundant in organic farming systems, but the results were highly variable between studies and organism groups. Birds, predatory insects, soil organisms and plants responded positively to organic farming, while non-predatory insects and pests did not. The positive effects of organic farming on abundance were prominent at the plot and field scales, but not for farms in matched landscapes.

**5.** *Synthesis and applications.* Our results show that organic farming often has positive effects on species richness and abundance, but that its effects are likely to differ between organism groups and landscapes. We suggest that positive effects of organic farming on species richness can be expected in intensively managed agricultural landscapes, but not in small-scale landscapes comprising many other biotopes as well as agricultural fields. Measures to preserve and enhance biodiversity should be more landscape- and farm-specific than is presently the case.

*Key-words*: density, diversity, farming systems, organic farming, species richness

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## Introduction

Organic agricultural methods are believed to be more environmentally sound than intensive agriculture, which is dependent on the routine use of herbicides, pesticides and inorganic nutrient applications in the production of crops and animals. Recent research suggests that organic agriculture results in less leaching of nutrients and higher carbon storage (Drinkwater *et al*. 1995), less erosion (Reganold, Elliott & Unger 1987) and lower levels of pesticides in water systems (Kreuger, Peterson & Lundgren 1999; Mäder *et al*. 2002), but some of these results have been questioned (Trewawas 1999; Goklany 2002).

Organic farming is reported to increase diversity in the agricultural landscape, including, for example, carabid beetles (Dritschilo & Wanner 1980; Kromp 1989; Pfinner & Niggli 1996), vascular plants (Hyvönen & Salonen 2002) and birds (Freemark & Kirk 2001). Based on such studies, it has been argued that organic agricultural methods generally increase biodiversity (Paoletti *et al*. 1992; Schönning & Richardsdotter-Dirke 1996; Ahnström 2002). This is particularly relevant because modern agriculture has resulted in a loss of diversity in the agricultural landscape (Fuller *et al*. 1995; Krebs *et al*. 1999; Stoate *et al*. 2001; Benton *et al*. 2002; Benton, Vickery & Wilson 2003), and it has been suggested that large-scale conversion to organic farming could partly ameliorate this loss. In the present study we used meta-analysis to evaluate the proposition that organic agricultural methods generally enhance biodiversity, operationally defined as species richness in a variety of organism groups.

Meta-analysis is a method for analysing and synthesizing the results of several independent studies examining the same question (Gurevitch *et al*. 1992; Cooper & Hedges 1994; Arnqvist & Wooster 1995; van Zandt & Mopper 1998; Osenberg *et al*. 1999; Gurevitch & Hedges 2001). The statistical procedures allow quantitative analyses of treatment effects, and account for the fact that all studies are not equally reliable. Meta-analysis is especially useful for examining general patterns of treatment effects, such as, for example, the evidence for interspecific competition in field experiments (Gurevitch *et al*. 1992). The usefulness of meta-analysis has sometimes been questioned (Blinkhorn 1998). None the less, it is regarded as an appropriate method for examining the general evidence for or against a specific hypothesis, and to suggest further studies explicitly testing the patterns found in the meta-analysis.

Organic agricultural methods may also increase the abundance of many species and organism groups compared with conventional methods. For example, the application of herbicides in conventional farming systems will, by their nature, decrease weed abundances. This may have subsequent deleterious effects on insects and birds, depending on these plant species (Chiverton & Sotherton 1991). Similarly, the use of pesticides will not only decrease pest insects but also the predators that feed upon them (Winston 1997).

In this study, we asked the following questions? (i) Does organic farming generally increase species richness within organism groups? (ii) Does organic farming generally increase the abundance of the studied organism groups? (iii) Do the effects of organic farming differ between organism groups? For example, do pest organisms increase more than non-pest groups in organic farming systems? (iv) Do the results differ depending on the spatial scale of the study (plot, field or farm)?

## Materials and methods

### DATA SOURCES AND DEFINITIONS

We investigated the literature published before December 2002 through computer searches on the databases available at the Swedish University of Agricultural Sciences (SLU, Uppsala, Sweden). We used the following key-words: biodiversity, biological diversity, conventional farming (agriculture), organic farming (agriculture). We also followed the literature in the field and searched the reference lists of relevant articles. For a study to be included in the analysis, it had to give data on species richness and diversity or abundance at at least a nominal scale. We found 66 publications comparing organic and conventional farming systems (see Appendices 1–3). Although we cannot be certain that we found all available studies, we regard our sample as representative and non-biased, although the 'file drawer problem' (non-significant studies are published less often than those reporting significant results; Arnqvist & Wooster 1995) may be relevant to our study. For consistency, we chose not to include any unpublished results.

For simplicity, we used species richness as a quantitative index of biodiversity in our analysis, although it is only one of several measures of biodiversity (Noss 1990). In some studies, only a diversity index (Shannon–Wiener H′) was reported. As this index tends to be closely related to species richness, we used this information in the qualitative analyses (see below). Abundance is the total number of individuals per unit area or, for many insects, per trap, or, for plants, percentage plant cover.

Organic (sometimes called ecological) agriculture can be defined as farming systems where the use of pesticides, herbicides and chemical fertilizers is prohibited. These systems rely on crop rotations, natural nitrogen fixation, biologically active soil, recycled farm manure and crop residues, and biological or mechanical weed and pest control (Swedish Control Association of Ecological Farming 2002; Soil Association 2003). Conventional agriculture encompasses farming systems where pesticides, herbicides and chemical fertilizers can be used. Integrated farming systems, with some application of pesticides and inorganic fertilizers, were not included in the present study, apart from some cases where they were included in the conventional treatment (Mäder *et al*. 2002).

The two farming systems may differ greatly between and within studies. Despite the potential differences within the two farming systems, we did not subdivide them, in order to avoid using more than two treatments in the meta-analysis.

All studies were classified according to the scale of the study, and whether the authors had attempted to control for differences in landscape characteristics between organic and conventional farms or fields, as



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follows. (i) Plot (or single field): studies of plots or fields on experimental fields or farms. (ii) Field on farm: studies of fields on conventional or organic farms without explicit control for landscape characteristics. (iii) Farm/field in matched landscape: studies in which farms or fields on farms were selected in a way that explicitly accounted for landscape structure or composition. Although the average spatial scale increases from the plot to farm/field in matched landscape categories, individual studies in adjacent categories may overlap in spatial scale to some degree.

Bird studies often reported results by species and were treated in a special way. We used the average effect across all species as the independent measure of the effect of the farming system, as single species could be considered dependent for a number of reasons, for example closely related species are likely to have similar ecology. We did not attempt to estimate any quantitative effect size for the British bird data (BTO 1995) because the British Trust for Ornithology (BTO) abundance index values are difficult to compare with the abundance values in the other studies.

### DATA TREATMENTS AND CALCULATIONS

For each study, we tabulated the mean species richness or abundance for organic and conventional agricultural methods. We also tabulated the $n$-values and calculated the respective SD of the means from the information provided in the study. Frequently, SD were given directly in the study, but often these had to be calculated from other measures, such as SED (Yeates *et al*. 1997) or error bars in figures (Feber *et al*. 1997). The pooled SD were calculated according to van Zandt & Mopper (1998). In several cases, we combined years or sites (see Appendices 1 and 2) in an appropriate ANOVA model, usually with year as a split-plot factor and site as a block factor, to calculate one single measure of the effect size. We pooled SD per organism group and habitat or study. More details of individual studies are given in Appendices 1–3. Data were extracted from statements in the text, tables or by measurements in the published graphs.

All the studies where an effect size and pooled SD could be calculated were included in a meta-analysis of effect sizes according to Cooper & Hedges (1994), with modifications as in van Zandt & Mopper (1998). The effect size used was Hedges' $g$, which is the difference between the means for the organic and conventional treatments divided by the pooled SD, multiplied by a term correcting for small sample bias, i.e.:

$$g = \frac{\bar{X}_{org} - \bar{X}_{conv}}{S} \times \left(1 - \frac{3}{4m - 1}\right)$$

where $m = n_{org} + n_{conv} - 2$. Using the formula in Cooper & Hedges (1994), variances for effect sizes were estimated. Then a weighted average effect size $T$ for a fixed effect model and the homogeneity test statistic $Q$ were calculated as in Cooper & Hedges (1994). If $Q$ was significant, effect sizes were heterogeneous and differed among the included studies. In these cases, we used a random effects model to estimate effect sizes (Cooper & Hedges 1994) because a significant heterogeneity among studies means that there is no fixed common effect size that the individual studies estimate. Also, when studies were heterogeneous, we divided the studies into taxonomical or functional units for separate analysis (see Tables 1 and 2 below).

In several studies, it was not possible to estimate the SD of the means for organic and conventional methods. These were included in a second analysis, which used only the direction of differences between the two farming systems (+ or –). We used the sign test (binomial test; Siegel 1956) to examine whether the frequency of studies where organic farming had a higher value of species richness or abundance than conventional farming differed from that expected by chance. Studies with equal species richness or abundance in the two farming systems were deleted.

An effect size was considered significant if the 95% confidence limits of the average effect size $T$ did not include 0 (Cooper & Hedges 1994). For the effect to be considered general, the homogeneity statistic $Q$ should be insignificant for the studies included in the analyses.

A major problem was defining which estimates of effect sizes were independent from each other. If studies were conducted on different organisms at different sites and by different research teams, they could clearly be considered as independent observations. However, other situations were more problematic. In several studies, a number of organism groups was studied at the same site, or the same organism group was studied in two adjacent habitats, for example within a field and in the field margins or in two different crops (see Appendices 1 and 2). It was not certain if the interactions between the studied organisms were strong enough to make such observations clearly dependent. Therefore, we considered different organism groups studied at the same site as largely independent observations. In the case of adjacent habitats, the degree of dependence depends on the magnitude of individual movements between the different habitats. Although in some of these cases our data are likely to be dependent, nevertheless we decided to treat results from adjacent habitats as independent data points. The exclusion of these data would only affect our results marginally. Another problem was that some organism groups have been studied more frequently than others because they are very relevant to organic farming, for example natural enemies of pests, such as carabids, and vascular plants (21% and 35% of studies regarding species richness, respectively).

## Results

### SPECIES RICHNESS

Organic agricultural methods usually increased species richness compared with conventional methods (Table 1).



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**Table 1.** A meta-analysis of the effects of organic agricultural methods on species richness. Positive effect sizes indicate higher species richness in organic farming systems. See text for calculation of the Hedges' *g* statistic. The studies in the meta-analysis are listed in Appendices 1 and 3, and also available from the web site http://www.cul.slu.se. Only studies published before December 2002 are included. The number of positive studies column and the associated *n* column include all studies, and those in which no quantitative effect size, only increases or decreases in species richness, was given. When $Q$ (heterogeneity of effect sizes among studies) is significant, the results are shown for a random effects model. *$P < 0{\cdot}05$ for average effect size ≠ 0, for heterogeneity of effect sizes ($Q$) and for binomial test of the number of positive studies; CL, confidence limit

| | Average effect size (Hedges' *g*) (± 95% CL) | *n* | *Q* | No. of positive studies | *n* |
|---|---|---|---|---|---|
| Total | 1·152 (± 0·524)* | 32 | 170* | 53* | 63 |
| By organism group | | | | | |
| Birds | 1·495 (± 1·236)* | 2 | 0 | 3 | 3 |
| Arthropods | 0·929 (± 0·589)* | 19 | 71·7* | 21* | 28 |
| Predatory insects | 0·843 (± 0·590)* | 15 | 43·8* | 15 | 21 |
| Carabidae | 0·941 (± 0·861)* | 11 | 34·7* | 10 | 13 |
| Non-predatory arthropods | 1·046 (± 1·982) | 4 | 26·2* | 6 | 7 |
| Soil organisms | 0·306 (± 0·559) | 5 | 3·3 | 7 | 10 |
| Plants | 2·684 (± 1·976)* | 6 | 81·6* | 22* | 22 |
| By scale of study | | | | | |
| Plot or single field | 2·917 (± 1·769)* | 8 | 55·8* | 15* | 17 |
| Field on farm | 0·703 (± 0·550)* | 11 | 19·3* | 24* | 27 |
| Field/farm in matched landscape | 0·818 (± 0·791)* | 13 | 79·6* | 14 | 19 |

The average effect size (Hedges' *g*) for the studies providing quantitative estimates of species richness in the two farming systems was 1·152, with a 95% confidence limit of ±0·524, which means an average effect size clearly different from 0. The mean effect size measured as the log ratio was 0·29, indicating that organic farming on average increased species richness by about 30%. However, the effect sizes of the 32 studies were heterogeneous (Table 1). We therefore separated the studies into different organism groups: birds, arthropods, soil organisms and vascular plants. A further subdivision of the arthropod group ($Q$ significant; Table 1) was made into predatory and non-predatory insects. In addition, Carabidae were analysed on their own, because they have been the subject of many studies. We found positive effects of organic farming on species richness of all organism groups except non-predatory insects and soil organisms (Table 1).

When all the studies with qualitative data were included, the positive effect of organic farming on species richness was as strong as in the former case. Fifty-three of the 63 studies (84%) showed higher species richness in organic agriculture systems.

Studies at all three spatial scales showed a higher species richness under organic management than in conventional agriculture (Table 1), but the effect was much larger for studies at the plot scale. In all three cases the heterogeneity between studies was large, but we could not find any obvious way of subdividing the three groups further.

### ABUNDANCE

The effects of organic farming on density varied between different organism groups ($Q = 522$, $P < 0{\cdot}001$), and the average effect size estimated by the random model was 0·700 (± 0·272) (Table 2). A positive effect of organic farming on abundance was found in 96 of 117 studies. Measured as a log ratio, mean effect size was 0·40, indicating that organisms on average were around 50% more abundant in organic farming systems. Because the effect sizes were heterogeneous, we subdivided the data into several taxonomically and ecologically different groups.

Only five studies provided quantitative data on weed numbers or cover, and all of them showed a higher weed density on organic farms (Table 2). Soil organisms were generally more abundant in organic agriculture systems (Table 2), but the heterogeneity among studies was large. However, when only studies of earthworms were examined, this was no longer the case. The eight earthworm studies with quantitative data had a small average effect size, the 95% confidence limit included 0, and the results were homogeneous. Nevertheless, the sign test suggested a significant positive effect on earthworms of organic farming (12 of 13 studies). Microarthropods and fungi responded positively to organic management, while there were no clear effects on microbial activity or biomass.

Insects had a small average effect size and the 95% confidence interval included 0, with a large heterogeneity among the studies (Table 2). We divided the data into non-predatory and predatory insects, and also examined the Carabidae separately. None of the groups was homogeneous and only the predatory insects showed a positive response to organic farming. Spider abundance was also higher in organic farming systems. Further inspection of the insect data showed that one study (Moreby & Sotherton 1997) created the heterogeneity in the predatory insects and Carabidae. When this study was removed, the two organism groups showed homogeneous positive responses to organic farming.



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**Table 2.** A meta-analysis of the effect of organic agricultural methods on the abundance of organisms. Notation as in Table 1. The studies are listed in Appendices 2 and 3. M&S indicates the study by Moreby & Sotherton (1997), which alone contributed to the significant heterogeneity in the organism groups indicated (see text)

| | Average effect size (Hedges' *g*) (± 95% CL) | *n* | *Q* | No. of positive studies | *n* |
|---|---|---|---|---|---|
| Total | 0·700 (± 0·272)* | 71 | 522* | 96* | 117 |
| By organism group | | | | | |
| Birds | 0·708 (± 0·686)* | 7 | 18·5* | 12* | 12 |
| Insects | 0·122 (± 0·300) | 30 | 85·4* | 29* | 42 |
| Predatory insects | 0·486 (± 0·457)* | 14 | 27·4* | 16* | 21 |
| Predatory insects (without M&S 1997) | 0·656 (± 0·367)* | 12 | 14·8 | 16* | 19 |
| Carabidae | 0·799 (± 0·865) | 9 | 19·2* | 9 | 12 |
| Carabidae (without M&S 1997) | 1·052 (± 0·688)* | 8 | 11·5 | 9 | 11 |
| Non-predatory insects | −0·133 (± 0·373) | 16 | 47·4* | 13 | 21 |
| Pest species | −0·398 (± 0·441) | 7 | 10·4 | 3 | 7 |
| Spiders | 0·646 (± 0·483)* | 3 | 5·93 | 4 | 7 |
| Soil organisms | 1·022 (± 0·551)* | 26 | 144* | 44* | 49 |
| Earthworms | 0·286 (± 0·362) | 8 | 6·94 | 12* | 13 |
| Micro-arthropods | 0·609 (± 0·434)* | 4 | 5·28 | 6 | 7 |
| Fungi | 2·176 (± 1·536)* | 5 | 49·0* | 7 | 8 |
| Microbial activity/biomass | 0·395 (± 0·559) | 5 | 3·9 | 7 | 8 |
| Vascular plants | 1·305 (± 0·358)* | 5 | 15·4* | 7* | 7 |
| By scale of study | | | | | |
| Plot or single field | 0·567 (± 0·308)* | 16 | 23·3 | 30* | 33 |
| Field on farm | 1·278 (± 0·358)* | 30 | 122* | 43* | 51 |
| Field/farm in matched landscape | 0·029 (± 0·273) | 25 | 93·6* | 23* | 33 |

The Moreby & Sotherton (1997) study has an exceptionally high *n*-value compared with other studies ($n = 28$; see Appendix 2) and hence this study should be given a high weight in the meta-analysis. The observed heterogeneity in these two predator groups most probably reflects real variation among studies.

For organisms defined as potential pests, i.e. pest butterfly species, aphids, herbivorous insects and plant-feeding nematodes, there was no significant effect of farming system, although the negative effect size suggests that conventional farms actually supported higher abundances. The response was homogeneous, but the number of studies was low ($n = 7$). On average, bird species were more common on farms with organic management, although there was large variation between species and heterogeneity between the studies (Table 2; see Appendix 2).

In studies that did not take the surrounding landscape into account, i.e. studies made at the two smaller spatial scales, there was a clear positive effect of organic farming on abundance of the different organism groups. Studies that in some way took the landscape structure into consideration and were made at the landscape scale had an effect size including zero. However, the sign test suggested a significant positive effect of organic farming at all three scales (Table 2).

## Discussion

### EFFECTS OF ORGANIC FARMING ON SPECIES RICHNESS

Our meta-analysis clearly shows that organic agricultural methods tend to increase species richness of weeds, plants in field margins and other agricultural habitats, and natural enemies such as carabids. This has been found in a large number of studies (Table 1; see Appendices 1–3). On average, the increase in species richness was around 30% compared with conventional farming. Thus, the original suggestions by Paoletti *et al*. (1992) and Schönning & Richardsdotter-Dirke (1996) that organic farming enhances biodiversity is supported by our more rigorous meta-analysis.

However, biodiversity in agricultural landscapes is obviously affected by many factors other than the farming system. Non-cropped areas, such as field margins, edge zones, habitat islands, hedgerows, natural pastures, wetlands, ditches, ponds and other small habitats, are important refuges and source areas for many organisms. Maintenance of biodiversity in agricultural landscapes will depend on the preservation, restoration and management of such habitats (Stopes *et al*. 1995; Baudry *et al*. 2000; Tscharntke *et al*. 2002)

Landscape structure and heterogeneity also contributes to biodiversity in agricultural areas (Marino & Landis 1996; Fahrig & Jonsen 1998; Krebs *et al*. 1999; Weibull, Bengtsson & Nohlgren 2000; Berg 2002; Steffan-Dewenter *et al*. 2002; Benton, Vickery & Wilson 2003; Dauber *et al*. 2003). In central Sweden, the effect of landscape heterogeneity, at the scale of individual farms and larger areas, has been shown to be larger than the impact of organic or conventional agriculture on the diversity of butterflies, predatory insects and field margin plants (Weibull *et al*. 2000; Weibull, Östman & Granqvist 2003). In fact, in this mosaic landscape, with a high proportion of non-cropped areas, we did not find any positive effect of organic



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farming on diversity or species richness. Our studies contributed to the large heterogeneity among studies at the landscape scale (Table 2). We conclude that positive effects of organic farming on species richness and diversity can be expected in intensively managed agricultural landscapes, but not necessarily in small-scaled mosaic landscapes with a mixture of agricultural fields and non-cropped habitats.

Our meta-analysis shows that biodiversity can be expected to benefit from organic agriculture. Additional studies published after we completed our literature search largely confirm this finding (Kremen, Williams & Thorp 2002; Aude, Tybirk & Bruus Pedersen 2003; Hutton & Giller 2003; Hyvönen *et al*. 2003; Mulder *et al*. 2003), although, as in our analysis, there are exceptions (Shah *et al*. 2003).

## EFFECTS OF ORGANIC FARMING ON ABUNDANCE

Our analysis of the literature shows, not surprisingly, that different organisms react in different ways to organic farming. Weeds were more common when herbicides were not used, which is what would be expected. More importantly, the densities of predators, such as carabid beetles and spiders, were usually higher in organic farming systems than in conventional ones. Döring & Kromp (2003) showed that the carabid species most favoured by organic farming were open field species, indicating that organic farming may enhance the abundance and diversity of habitat specialists to a larger extent than generalists.

On the other hand, non-predatory insects and pests did not appear to be more common in organic agricultural systems. Thus, our results, although based on a small number of studies, suggest that natural enemies are negatively affected by conventional management to a much larger extent than other insects and pests. This is supported by a study of biological control of the cereal pest bird-cherry oat aphid *Rhopalosiphum padi* in a mosaic landscape in central Sweden (Östman, Ekbom & Bengtsson 2001, 2003).

Soil animal densities were usually higher under organic agriculture. Higher amounts of organic material in the soil increases earthworm abundance (El Titi & Ipach 1989; Lebbink *et al*. 1994; Zwart *et al*. 1994) and soil fauna in general in agricultural soils (Andrén & Lagerlöf 1983). This is important in all types of farming systems, but the incentive to use organic fertilizers, manure and ley, is higher in organic farming. Variation in botanical composition, topography, crop yields and organic matter quality will also contribute to variation in soil organism densities independent of farming system (Nuutinen & Haukka 1990; Younie & Armstrong 1995; Yeates *et al*. 1997).

It is clear that there are many factors that influence the abundance of organism groups in the agricultural landscape, of which only some are clearly related to the organic farming system. Many of these factors are under the control of the individual farmers, who can manage their land to increase the abundance of beneficial organism groups. For example, creating habitats such as edge zones, hedgerows and permanent grass strips, and preserving natural small refuge biotopes among the cultivated fields, can favour natural enemies (Chiverton 1989). In this case, organic farmers are at an advantage because they do not use pesticides. In other cases, the measures could be just as efficient irrespective of the farming system, for example decreasing tillage and increasing organic matter input to the soil to favour earthworms.

## STUDY DESIGN AND SCALE OF STUDY

The results of our meta-analysis suggest that the difference between organic and conventional farming is more pronounced in studies performed at a small scale that do not take the surrounding landscape into account. This indicates that farming practice only partly explains variation in species richness and abundance in agricultural landscapes. In studies at a landscape scale (field/farm in matched landscape), farming practice appeared to be less important than the effects of the surrounding landscape (Weibull *et al*. 2000; Weibull *et al*. 2003; Tables 1 and 2).

If organic farming has greater effects at smaller scales, this suggests that different processes are involved (Peterson & Parker 1998; Bommarco & Banks 2003). On small plots effects of different farming systems may result from behavioural responses and individual decisions, whereas at larger scales variation between farming systems is more likely to reflect differences in population dynamics.

Many studies comparing organic and conventional farming were poorly designed. Large numbers of studies had low numbers of replicates or failed to include in the design factors other than farming system (see Appendices 1 and 2), for example landscape structure, soil type and farm history. It is questionable whether studies performed at the plot scale are relevant at all to the wider question of whether organic farming enhances biodiversity. The population dynamics of many organisms operate at much larger scales than a few square metres. We recommend that future studies focus on the socio-economic units at which decisions about farm management are made, i.e. at the scale of single farms or larger.

Criteria for the selection or farms or fields to be studied are important. If matched farm pairs are used there is a risk of producing a reduced difference between the farming practices. This is because it is difficult to match organic farms to the most intensively managed conventional farms in large-scale homogeneous landscapes. Similarly, it may not be possible to match conventional farms to the most varied organic farms in small-scale landscapes. On the other hand, if average conventional and organic farms are compared without taking the landscape into account, any difference between the systems can often be attributed to landscape differences rather than farming system.



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In order to compare average farming systems, it is important to preserve systemic differences between organic and conventional management practices. These include: the use/non-use of chemical pesticides; the use/non-use of chemical fertilizers; and the need for a long and varied crop rotation. Conventional farmers can choose to use pesticides sparingly or not at all, farm manure instead of chemical fertilizers and whether to have a diverse crop rotation. Thus the diversity on conventional farms can either be lower or approximately the same as for a neighbouring organic farm. However, the incentives to avoid chemical fertilizer and pesticides and to rely on a varied crop rotation are much more evident in organic farming.

## MANAGEMENT AND POLICY IMPLICATIONS

Recently, the efficiency of agricultural subsidy programmes for preserving biodiversity and improving the environment has been questioned (Kleijn *et al*. 2001). Organic farming, as part of such subsidy programmes, has been proposed as a means to enhance biodiversity in agricultural landscapes (Krebs *et al*. 1999; Reganold *et al*. 2001), although this has been debated (Trewawas 1999). Some studies have not found any positive effects of organic farming on species richness, but we show here that in most cases organic farming can be expected to have positive effects, although this will differ between organism groups and landscapes. Hence, subsidies to organic farming may contribute to the maintenance of biodiversity in agricultural landscapes, but measures should be more landscape- or farm-specific than is presently the case. Subsidy programmes need to be flexible to fit farms with different site-specific conditions, and in different landscape contexts. However, at present too few studies have rigorously examined these issues at the relevant farm and landscape scales.

In studies of farmland biodiversity, the farmers themselves are often ignored. The attitude of individual farmers, rather than which farming system is used, is probably the most important factor determining biodiversity at the farm level. Attempts to enhance biodiversity in agricultural landscapes will need the active participation of interested and well-educated farmers, as well as a subsidy system that is fair and rewards environmentally sound management practices. It is only through interactions with the farmers themselves that scientists will be more likely to propose and test practices that are feasible in reality.

## CONCLUSIONS

Through the use of meta-analysis, we found that studies published before 2003 provide evidence that organic farming usually enhances species richness, most notably of plants, birds and predatory insects (Table 1; see Appendix 1). We propose that the effects of organic farming on species richness will be larger in intensively managed agricultural landscapes than in small-scale diverse landscapes with many non-crop biotopes.

The meta-analysis of organism abundances in relation to farming system showed that the responses are mixed (Table 2; see Appendix 2). Although the number of studies is low in most groups, the results suggest that organic farming may enhance local densities of insect predators and soil fauna, possibly with the exception of earthworms. On the other hand, there is little evidence that other insects and pests are more abundant in organically managed fields, supporting the common perception that pest damage on many crops is usually no greater on well-managed organic farms (Sigvald *et al*. 1994; Lööf 1995 for Sweden). Our meta-analysis supports the notion that a higher diversity and abundance of natural enemies contributes to pest control on organic farms. This could be examined more rigorously through simultaneous studies of the dynamics of pests and natural enemies in different farming systems.

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## Supplementary material

The following material is available from http://www.blackwellpublishing.com/products/journals/suppmat/JPE/JPE1005/JPE1005sm.htm.

**Appendix 1.** Studies included in the meta-analysis of effects of organic farming on species richness

**Appendix 2.** Studies included in the meta-analysis of effects of organic farming on organism abundance and density

**Appendix 3.** References to studies used in the meta-analysis (Appendices 1 and 2)

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