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Why are birds more abundant on organic farms?

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Abstract

Recent reviews have concluded that bird diversity is greater and abundance is around 50% higher on organic than on conventionally-managed farms. Promoting organic farming could, therefore, enhance populations of farmland birds many of which have fallen dramatically in Europe over recent decades. No attempt has been made, however, to quantify the importance of different aspects of the organic farming regime. We attempt a novel approach to answering this question by using data from existing literature to quantify the relative contributions of the five main differences between the farming systems. Though sample sizes are small, results suggest lack of pesticides and increased area of non-cropped habitats on organic farms make a significant positive impact on farmland birds (22 and 15% increases in important bird parameters, respectively). In contrast increased heterogeneity in cropping and fertiliser applications on organic farms may both be slightly detrimental to farmland birds when compared with conventional farm methods. The evidence for spring-sowing is minimal and thus we can only speculate as to their effects. Our work is useful in two ways: (i) we have shown that both heterogeneity in cropping and fertiliser applications are unlikely to underlie the reported increases of birds on organic farms; (ii) we hope to encourage work in areas that plug knowledge gaps in the current story, e.g. effects of spring-sowing on birds.

Key words: Biodiversity, farmland bird diversity, farming systems, fertilisers, pesticides, non-cropped habitats.

Introduction

Organic farming has been shown to benefit a wide range of farmland biodiversity, including many insects and vascular plants, but it is the effect on farmland bird diversity and abundance which has perhaps received the most attention. Two recent reviews have concluded that both abundance and diversity of many bird species is higher (up to 50% [1]) on farms managed organically than on conventional farms [1,2]. Farmland birds have undergone huge declines over the last 50 years, something which has largely been attributed to agricultural intensification [3,4]. Less intensive farming systems like organic farming could, therefore, be expected to help ameliorate such declines.

However, the mechanisms by which bird abundance and diversity are increased on organic farms remain largely unclear. While organic farming is typified by a lack of most artificial inputs (both pesticides and fertilisers), many other differences also exist between the two systems including increased non-cropped habitats, more spring-sowing of crops and higher levels of mixed farming on organic farms, all of which have been shown individually to affect farmland bird biodiversity. However, while one preliminary study described, non-empirically, the possible effects of each component part [5] and another has shown that non-cropped habitats explain some of the increase in bird abundances on organic farms [6], our study is the first to attempt a quantitative estimate of the relative importance of these individual components, something which may significantly aid future agri-environment strategies.

Our aim, therefore, is to review the literature in an attempt to gain preliminary estimates of the individual importance of five main differences between organic and conventional farming systems on farmland bird populations. The reasons behind the selection of the differences will also be discussed.

Methods

After a preliminary review of the relevant literature, five main differences between organic and conventional systems which impact upon farmland bird population parameters were selected for further investigation 1) pesticides, 2) fertilisers, 3) non-cropped habitat, 4) timing of crop sowing and 5) within-farm heterogeneity. These five differences will from this point be referred to as the "five predictors". Reasons for selection of these predictors are discussed in the Results section below.

Appropriate search terms were entered into "Web of Science®" (www.wos.mimas.ac.uk) including 'pesticides AND birds'; 'fertilisers AND birds'; 'mixed farming AND birds'; 'spring-sown AND birds'; 'hedges AND birds'; 'woodland edge AND birds' as well as combinations of the words 'hedgerows', 'boundaries' and 'birds'. Resulting papers were then checked for relevance, with preference being given to papers where an effect size of any of the five predictors on bird abundance and/or vital rates was reported. The number of examples directly linking abundance or vital rates of a particular species with any of the five predictors was limited (n = 10). There were many examples linking other factors (e.g. foraging location, invertebrate abundance) with the predictors but it proved difficult to relate this information to abundance or vital rates. No effect sizes could be identified for either "fertilisers" or "timing of crop sowing", and in these cases qualitative data on the likely direction of the relationship was included.

Different strategies had to be employed to each paper to extract the relevant information, as methods and measures varied greatly. A full description of how this was carried out is outlined in Appendix 1.

Results

1) Pesticides

Selection criteria and background: Organic farming is typified by the exclusion of most artificial pesticide inputs (fungicides, herbicides, insecticides and growth regulators). Pesticides can impact farmland bird populations in two main ways: 1) directly, acting physiologically on adults, juveniles and/or eggs and 2) indirectly through reduction in food resources (seeds and insects). While direct effects have been widely documented, these mostly concern the deleterious effect of organochlorines (e.g. DDT) on sparrowhawks (*Accipiter nisus*) and other bird species pre-1980s [7, 8]. However, such directly toxic pesticides have now been banned in many countries (e.g. in the UK for more than two decades), and insufficient evidence exists regarding similar effects of new generation pesticides on bird populations. Therefore, only the indirect effects of pesticides on farmland bird populations and vital rates will be considered further in this review.

Pesticides have major indirect effects on birds via the killing of both invertebrates important for food and also agricultural weeds which provide seed resources and also cover for invertebrates. It is important to note that only data regarding pesticide effects on broods was found, and effect size estimates do not include effects of pesticides on adults through reduced food supply, something which would almost certainly augment the results.

Several pieces of evidence support the negative relationship between insecticide spraying and vital rates of farmland bird populations. Probably the best example comes from a fully replicated study of the grey partridge (*Perdix perdix* L.) [9]. This study showed that pesticide spraying affected the invertebrate food of partridge chicks, which was correlated with chick survival, and was the main cause of population decline. More recent examples come from another farmland bird specialist, the yellowhammer (*Emberiza citrinella*). Morris *et al.* [10] showed that arable fields sprayed during the summer were used less frequently than fields not sprayed during the summer by adult yellowhammers foraging for food for their young. Hart *et al.* [11] showed that the availability of arthropods was depressed up to 20 days after an insecticide spraying event and that this negatively affected yellowhammer chick survival. Both herbicide spraying and fungicide spraying have also been shown to be negatively correlated with invertebrate populations [10] and weed populations [12] and so these are also likely to negatively affect farmland bird populations. It is clear, therefore, that the lack of pesticides used on organic farms will positively affect invertebrate and weed populations and that these lower trophic levels are likely to linearly relate to higher trophic levels like farmland birds.

Calculations: Three examples were found where pesticide spraying was related directly to brood size in bird species - Rands [9] reported a 66% increase in brood size for grey partridge and a 37% increase for red-legged partridges (*Alectoris rufa*) in fields with unsprayed vs. sprayed margins, while Boatman *et al.* [13] reported a 17% increase for yellowhammers. Data from a fourth study on chestnut-collared longspurs (*Calcarius ornatus*) [14] could be included by assuming the same parameters as for yellowhammers [13], giving an estimated 20% increase in brood size on organic farms. The mean average effect size across these four papers was fairly high - 35% higher brood size on unsprayed vs. sprayed fields and/or field margins (although this figure is amended below). This conclusion that pesticides exert a large effect on population change is supported by earlier work showing grey partridge chick survival is the most important demographic process driving population change [15].

An important caveat to these findings, however, is that organic fields and margins are not directly comparable with the "unsprayed" areas considered in the studies reviewed. While organic farming does not permit the majority of chemical applications, other management techniques are employed to control insect and plant pests, such as mechanical weeding (known as tining), something not accounted for in the simple "unsprayed vs. sprayed" comparison. Organic fields will likely have less seed and insect resources than an "unsprayed" conventional fields due to the impact of tining and other management techniques. Therefore, to counter this and improve our estimated effect size we calculated the mean difference in insect and seed abundances between organic and unsprayed systems from the literature and used this as an adjustment factor for our calculations. For insect abundances, only data concerning important bird food insects were included (e.g. Heteroptera, Lepidopteran larvae) [16]. Full results and papers involved are listed in Appendix 2. The mean difference in seed resources between the systems was calculated as 36%, and for insect resources 41%. In other words 64% of the increase in seed densities in organic systems is due to lack of spraying, and 59% of the increase in insect densities.

We have adjusted down the calculated effect sizes for the effects of pesticides on bird abundance and vital rates in accordance with these results: a 36% reduction as an upper limit (based on seed result) and 41% reduction as a lower limit (based on insect result). This equates to a mean effect size of between 21 and 23% on brood size for pesticide applications alone (Table 1).

2)Fertilisers

Selection criteria and background: Fertilisers are likely to impact farmland bird populations through changes in: a) weed and therefore seed abundances; b) insect abundances; and c) habitat structure. While organic and conventional crops both receive fertiliser applications, the type of inputs used differs substantially and this may alter their impact on a-c above. Only natural fertilising compounds are permitted in organic agriculture (e.g. manure, lime, clays), while artificial N-rich compounds are the fertiliser of choice in conventional agriculture. While levels of application in the two systems are often similar [17], it is widely recognised that the nitrogen in "organic" fertiliser is less available than that in artificial fertilisers making overall uptake lower [18]. No evidence exists relating fertiliser type directly to bird vital rates, but direction of relationship may still be determined by considering the effect of the two types of fertiliser on important farmland bird food resources and habitat structure.

While many studies discuss the effect of fertilisers on weed and insect abundances, these tend to be "fertiliser vs. no fertiliser" comparisons rather than "organic vs. conventional fertiliser" comparisons. Studies which do exist tend to concern only insects,

Table 1. Estimates of the magnitude of the effects of each of the five predictors on farmland bird parameters.

Predictor	No. studies	Direction of effect*	Estimation of magnitude of effect
1. No pesticides used on organic farms	3	+	21-23**%** increase in brood size on organic farms resulting from zero-spraying (after adjustment – see Appendix 2)
2. Organic fertilisers used on organic farms	0	(-)	Data only available for the effects on invertebrates and plants. While limited studies suggest conventional farming promotes invertebrates no studies showing a direct link with bird populations were found
3. More non-crop habitat on organic farms	7	+	15**%** increase in bird abundance on organic farms as a result of more hedgerows and woodland
4. More spring sowing on organic farms	5	+	Cannot be quantified as no predictive equations exist in the literature but the relationship is likely to be positive
5. Increased habitat heterogenity on organic farms	2	-	4.5**%** decrease in farmland bird abundance as a result of increased habitat heterogeneity on organic farms

* + indicates parameter improves bird vital rates, - indicates the opposite.

and often not species of particular value to farmland birds (e.g. pest or beneficial predator species). However, the majority of these studies suggest that insect abundances will be lower in organic systems, and that organic fertilisers appear to confer some degree of increased insect resistance [19]. In a recent multi-crop experiment [20], for example, beneficial invertebrates (e.g. Carabidae, Hemiptera) were more often in greater abundance in conventionally fertilised crops than organically fertilised crops (12 vs. 6 instances). Culliney and Pimentel [21] had a similar result with abundances of flea beetles, alate aphids and caterpillars all significantly lower on some Brassica crops (e.g. collards) fertilised with "organic" fertilisers than on chemically fertilised plants.

These results tally with the finding that insectivorous birds are generally more abundant on intensively managed grass fields than on fields which receive lower amounts of fertiliser input or no input at all [22, 23] something believed to be a result of the increase in large below-ground invertebrate species which occurs with increased fertiliser use [24, 25]. Organic fertiliser in moderate amounts can also benefit below-ground invertebrate populations [26].

The difference in effect on weed and therefore seed abundance is less well documented. However, if we assume organic systems contain less available nitrogen than conventional systems (an over-simplification, but broadly accepted [17, 18]) it could be expected that organic systems will have lower weed/seed abundance than conventional systems for a number of reasons: (1) increased fertiliser use has been linked with enhanced growth of many weed species [27, 28] and (2) dormancy in a number of weed species seeds is broken by increased N application [29].

No information could be found relating fertiliser type to habitat structure, but as increased inputs are likely to promote weed density (as outlined above), structural complexity will likely increase with increased fertiliser use, something which has been shown to be detrimental to foraging ability in farmland birds [30, 31]. Therefore, while not quantifiable, the use of solely organic fertiliser may have a small, but negative impact on farmland bird vital rates by, on average, reducing food supplies in crops (both seeds and insects).

3) Non-cropped habitats

Selection criteria and background: Differences in the availability of non-crop habitats between paired organic and conventional farms have been reported by various studies, with organic farms often possessing higher, wider hedgerows [32, 33] and greater areas of woodland [34]. While an increase in such components is not a requirement of organic conversion, farmers entering into such schemes may have a more 'wildlife-friendly' attitude and already hold greater proportions of these habitats than average. Whatever the reason, organic farms tend to provide significantly greater areas of non-cropped habitats than conventional farms and this is likely to benefit farmland birds.

Taller and wider hedgerows have been positively associated with a wide range of different farmland bird species [35, 36] and fields bordering woodland are also positively associated with a range of bird species found on farmland [37].

Calculations: Across four studies, an increase in hedge height resulted in an average increase in bird abundance of 9% (hedge height differences between organic and conventional systems estimated using relationships given in Fuller *et al.* [33]) (see Appendix 1 for a more detailed explanation of how this figure, and those below, was derived). Hedge presence resulted in a mean increase of 5% estimated from two studies, and increased woodland edge resulted in an increase of 1% in bird abundance. It is important to note that these changes are those recorded across all the species in each study, thus some species will tend to avoid woodland edges (e.g. yellowhammer [37]), whereas other species prefer woodlands as a breeding habitat (e.g. great tit [38]). However, as we are attempting to explain the observed result of increased bird abundance on organic vs. conventional farms (across all bird species) then these sorts of species-specific differences are important to include in our study. Overall the increased non-cropped habitats associated with organic farms (hedgerows and woodland) resulted in an increase of 15% abundance (Table 1).

4) Timing of crop sowing

Selection criteria and background: Organic farms tend to carry out more spring sowing than do conventional farms [39], with an estimated 27% increase post-organic conversion [40, 41]. Spring-sown cereal crops are likely to impact farmland bird populations in two ways. Firstly as they are sown in spring, plants remain short enough during the breeding season for birds to use them for nesting. Indeed this has been shown to be a very important resource for skylarks (*Alauda arvensis*), a species which has been in significant decline in recent decades. Wilson *et al.* [42] showed that in intensively managed autumn-sown cereal fields skylarks only made around one nesting attempt as opposed to two or three in spring-sown cereals. Secondly, as the crops are harvested in autumn, fields are often left as stubble over winter. Stubble fields are an extremely important food resource for farmland birds over winter, with many species selecting stubble fields over other types of field available in the winter [43].

However, the proposed benefits of an increase in spring-sowing on organic farms have three important caveats. First, higher levels of spring sowing do not always mean higher levels of winter stubble. Chamberlain *et al*. [44] found higher levels of bare till on organic farms, but no difference in stubble abundance. Second, whilst some stubble fields hold high densities of birds the large majority of stubble fields in some studies contain very few birds or none at all [31]. Third, although organic wheat fields have been shown to provide higher densities of seeds than conventionally managed wheat fields, the use made by birds of the two field types did not differ consistently [31]. Some species preferred conventional fields (e.g. yellowhammer, grey partridge, skylark), whilst others preferred organic fields, e.g. linnet (*Carduelis cannabina*) and reed bunting (*Emberiza schoeniclus)* [31].

Spring-sown cereals have also been shown to increase invertebrate populations relative to winter-sown cereals (including several groups important in the diet of farmland birds) [45, 46] but no direct relationships could be found between invertebrates and bird abundance or vital rates.

We could find no quantitative predictions of the importance of spring sowing on bird abundance and/or vital rates. As outlined above, the relationship is almost certainly a positive one - spring sowing will promote farmland bird populations. However, owing to the three main caveats discussed previously (organic farms do not always possess more stubble, stubble on organic farms does not necessarily possess more food resources, and much stubble remains unused). However, it seems unlikely that this is the over-riding factor in the increased bird abundances on organic farms.

5) Within-farm heterogeneity

Selection criteria and background: Organic farms, especially in the lowlands, are more likely to be mixed farms than those managed under conventional systems, i.e. be farms with both crop and livestock production [39, 40]. Livestock play an important role in the supply of nutrients and this cannot be compensated for by artificial fertilisers on organic farms. Thus organic farms often have greater habitat heterogeneity than conventional farms. Such heterogeneity is likely to benefit a variety of bird species by providing both arable and grass areas within close proximity (i.e. at the farm scale), something which is important, particularly during the breeding season [47]. Indeed, at the landscape scale Atkinson *et al*. [48] reported higher abundances of farmland birds in mixed farming areas.

However, the devil may be in the detail. Increased habitat heterogeneity typically equates to increased grassland area but decreased arable area and this decrease may not be a positive. Data from Shepherd *et al.* [40] indicates that the amount of arable crops decreases by 15% post-organic conversion whilst the area under grass management increases. Data from a paired study of 89 farms [33] also showed that the proportion of grassland was almost double on organic farms (37.7%) compared with conventional farms (17.2%).

Importantly data presented in Robinson *et al.* [47] shows that the proportion of arable land is positively related to farmland bird abundance across most species in their study. Thus although mixed farming does increase under organic farming it seems likely this will have a negative effect on farmland birds by decreasing the amount of cereals on organic farms. A possible caveat here is that there is some difference between management on farms converted to organic in upland and lowland areas but we did not find any evidence of this.

Calculations: Using data on changes in grassland area [40] (see above) in conjunction with the equations in Robinson *et al*. [47] regarding the relationship between arable land area and farmland bird abundance, a negative effect on farmland bird abundance of around 4% was due to organic conversion. The Robinson *et al.* [47] study did, however, include mainly seed-eating species and as such may not be entirely representative of the whole farmland bird community. Data from Atkinson *et al.* [48] were then considered as they cover a wider range of farmland birds. This showed that less than 40% of species were associated with landscapes with more than 50% grassland in them. Additional raw data provided by Atkinson (pers. comm.) which was used to draw the graphs in Appendix 1 of Atkinson *et al*. [48] allowed the quantification of the change in bird abundance across 68 species caused by a drop of arable land from 25% arable (average across UK farms [40]) to 21.25% arable (a 15% decline in arable land holding). This gave a decline in abundance of around 5%.

In summary, whilst the increased amount of grassland due to organic conversion may benefit some grassland species (such as whinchat *Saxicola rubetra* L. and redshank *Tringa totanus*) and disadvantage other granivorous species (such as grey partridge, skylark and yellowhammer) the weight of evidence from both Atkinson *et al*. [48] and Robinson *et al.* [47] suggests that the loss of arable land post-conversion seems likely to have a negative impact on farmland birds overall of around 4.5% (Table 1).

Discussion

From the limited data available, two factors have large effects in farmland birds: pesticides (21-23% increase on brood sizes) and non-cropped habitats (15% increases in abundance) (Table 1). Increased habitat heterogeneity appears to have a slight negative impact on farmland bird populations (around 4%) as a result of a reduction in the availability of arable land.

The remaining two predictors cannot be quantified, but a direction of effect can at least be obtained. Increased amounts of spring-sowing on organic farms are likely to substantially enhance skylark populations in the breeding season and could potentially provide more stubble fields in winter; therefore the direction of effect is likely to be positive. The effect of differing fertiliser use between the two farming system seems likely to only manifest themselves in relatively small, but negative, differences in bird food abundance but the information on this is limited. This result is not in agreement with the conclusions from a previous review [5], which suggested organic fertiliser to be beneficial to farmland bird populations. However, the evidence listed in the previous review is very general and does not consider potential differences in effect between fertiliser types (i.e. organic vs. conventional).

Novelty and shortcomings of the review: This is the first study to attempt to quantify the effect of independent aspects of the organic farming regime on bird population parameters. Fuller [5] discussed the predicted response of bird populations to four main management differences in the organic regime but no attempt was made to quantify the importance of each response. Chamberlain and Wilson [6] took a modelling approach to quantify the effect of non-crop habitat on bird parameters but the use of this data in the current review was limited as it considered only one parameter (non-crop habitat).

The present study clearly has a number of shortcomings. Most problems stem from the small number of papers available for inclusion in the review, and the associated issues of sample and publication bias. Results for pesticides are, for example, largely based on examples from game bird species. However, as pesticides act on bird populations by depressing food availability, it could be argued that impacts are likely to be similar regardless of bird species. Seasonality is also an issue. Insufficient data exist to consider impacts of the five predictors on bird populations across all seasons. Studies of pesticides, for example, concern mostly breeding season data, spring-sowing studies consist both breeding and winter season data and studies of habitat heterogeneity are from both summer and winter. However, while we acknowledge that our results would be improved by resolution of this problem, we believe much of the data included concerns the season during which most impact on bird populations will be observed.

The calculations made for non-crop habitat based on abundance should also be treated with some degree of caution. It is likely to be unrealistic to assume the relationship between abundance and actual density is a direct linear one.

The appropriateness of comparing different population parameters also needs consideration. Pesticide effects have been reported mainly on brood size, whereas increases in non-crop habitat mostly relate to changes in abundance. Given abundance incorporates both changes in reproductive output and survival it cannot be directly compared with changes in brood size. Therefore we cannot rank the estimated effect sizes - a 23% increase in brood size is not necessarily "better" than a 15% increase in abundance. However, the effect on both these parameters is large and significant (e.g. studies listed in Table 1 found statistically significant effects of pesticides on brood size and of non-cropped habitats such as hedge presence and hedge height on bird abundance), and therefore it is likely that both make a significant contribution to the observed increases in farmland bird populations on organic farms.

Conclusions

Our calculations suggest that neither increased mixed-cropping patterns on organic farms nor the use of organic fertilisers are likely to account for the increased abundance of birds on organic farms. Instead pesticide reductions and increased non-cropped habitats had the largest impacts on the increased farmland bird abundance observed on organic farms. We do, however, acknowledge that the effects of spring-sowing are also likely to be beneficial but cannot be quantified due to a lack of available data. Our study suggests gaps in the current knowledge base and future work on birds and organic farms may benefit from focussing on these gaps, e.g. the effect of spring-sowing on birds and studies of pesticides on non-game birds.

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Appendix 1

Methods employed to extract relevant data from papers

1. Pesticides: Data were obtained from three studies on the effect of pesticides on bird vital rates. Rands [9] reported brood size to be lower on sprayed than unsprayed field margins for both grey partridge (4.70±0.35 vs. 7.81±0.60) and red-legged partridge (3.23±0.26 vs.4.43±0.39). This equates to an increase in brood size of 66% for grey partridge and 37% red-legged partridge as a result of spraying alone (amended to 39-42% and 22-24% respectively as described in Pesticide section of main paper and Appendix 2).

Boatman *et al.* [13] reported the probability of brood reduction in yellowhammers to increase from 0.26 when no sprays were carried out within 200 m of the nest to 0.82 when the entire area within 200 m of nest was sprayed (values taken from Table 4 (Model 1) [13]). The values in this model are for the brood to be reduced by at least one chick, therefore we have been forced to make some assumptions about the number of chicks involved in an average scenario. Average clutch size of yellowhammers is 3.4 (n = 1607 - source BTO nest record scheme; http://www.bto.org) therefore assuming the probability of brood reduction decreases by 26% with no spraying, this equates to a mean loss of 0.26 chicks when no sprays are carried out within 200 m of the nest (26% chance of losing one chick) to 0.82 chicks with spraying within 200 m of the nest (82% chance of losing one chick) assuming all chicks lost. The mean of these values is 1.23 chicks, which equates to a 17% increase in brood size (amended value 10-11%). This only includes a subset of yellowhammer nests (n = 64) [14] which were not predated.

Martin *et al.* [14] found hatching success of chestnut-collared longspurs was significantly lower in sprayed plots than in control plots following spraying (67 versus 87%). Assuming the same parameters as for yellowhammers in the Boatman *et al.* [13] study this would result in a 20% increase in brood size of this species on organic farms (amended 12-13%).

2. Fertilisers: No quantitative data could be found regarding fertilisers and bird vital rates.

3. Increased non-crop habitat: We used data from four studies to estimate the effect of increased woodland edge on organic farms. Whittingham *et al.* [37] reported the following relationship: *Logit (farmland bird) = 1.49 x presence of woodland edge on field boundary.* We used the mean relationship for each of ten farmland bird species from 25 sites in England (Table 3 [37]). If a woodland edge was present on a boundary there was a 0.12 higher probability of an average 'farmland bird' having a territory on that boundary than if there was not (calculated using an intercept of zero and woodland edge set to absent = 0, or present = 1). We used 0.12 as the proportion of boundaries next to woodland edges on conventional farms and 0.17 (41% increase from 0.12) on organic farms. These figures were derived from Gibson *et al.* [34] who report a 41% increase in woodland edge on organic farms and the mean number of boundaries next to woodland edge reported in Whittingham *et al.* [37] as a baseline figure (i.e. 0.12). This gives an increase of 1% greater abundance of birds on organic farms.

Boundary height had stronger and more consistent effects across species than boundary width so we have simply used boundary height as our one measure of hedgerow structure. We estimated the difference in hedge height between conventional and organic farms (1.6 vs. 1.9 m) using data from Fuller *et al.* [33] and this information was used in the following equations relating hedge height to bird abundance/occupancy:

1. Logit (farmland bird) = 1 + 1.78 x boundary height [37]
Difference = 12%.

2. No. of species with territories = 1.99 + 0.61 x hedge height [49]
Difference = 6%.

3. Bird abundance = 1.45 + 2.25 x log (hedge height) [35]
Difference = 13%.

4. Log (bird abundance) = 0.033 + (0.009 x hedge height) [50]
Difference = 5%.

Increased hedge abundance has been associated with increased bird abundance and equations are available from two studies. Fuller *et al.* [33] indicated that hedges were 30% more common on organic farms than on conventional farms and this allows estimations to be made in the same way as with hedge height

1. Logit (farmland bird) = 1+ (1.04 x hedge presence)[37]
Difference = 4%.

2. No. of passerine territories = 3.30 + 0.75 x amount of hedge cover at 1 m [49] *Difference = 6%.*

4. Increased habitat heterogeneity: The impact of increased heterogeneity on farmland birds was calculated using data relating changes in the availability of arable land to bird abundance. Robinson *et al.* [47] (Table 3, page 1063), report the average significant relationship between farmland bird abundance and the percentage of arable within a square varying from 0 to 100% as *Log (farmland bird) = 1.9 x % arable in 1 km square*. Shepherd *et al.* [40] estimated a 15% decrease in arable land post organic conversion and this, when used in the Robinson *et al.* [47] equation, gives around a 4.5% decrease in abundance per species on organic farms as a result of decreased arable availability. However, it is important to note that in squares with high proportions of arable, increased arable was not shown to benefit farmland birds at all [47]. Predictive equations were also available in Appendix 1 of Atkinson *et al.* [48] for a change in abundance for a larger number of species than the Robinson *et al.* [47] paper and using the same 15% decrease in arable land post organic conversion, this equates to around a

5% decrease in abundance across 68 species on organic farms.

5. Increased spring sowing: No quantitative data could be found regarding increased amounts of spring sowing and bird vital rates.

Appendix 2

Full details of the data gathered to make amendments to pesticide effect size results in the review as a result of organic data not being directly comparable to data from "unsprayed" systems can be seen in Tables A and B. The literature was searched to find instances where seed and insect abundances in either organic *vs*. conventional or unsprayed *vs*. sprayed systems were recorded. A comparison of these values allowed the mean difference between organic and unsprayed systems (for full details of this see main paper).

Table A. Data comparing seed resources on organic *vs*. conventional and unsprayed *vs*. sprayed fields and margins compiled from nine papers. The difference in the mean effect sizes between the two systems was calculated as 36% - which means 64% of the increase in seed densities in organic systems is due to lack of spraying. This was then be used as an adjustment factor for the results.

Organic *vs*. Conventional			Unsprayed *vs*. Sprayed		
Study	Measure	Result	Study	Measure	Result
McKenzie *et al*. (unpubl.)	Seedbank (top 5 mm)	70% higher in organic	Taylor *et al*. [56]	Weed volume	62% higher in unsprayed
Moorcroft *et al*. [31]	Seedbank (top 5 mm)	39% higher in organic	de Snoo [57]	% Cover weeds	80% higher in unsprayed
	% Cover	44% higher in organic			71% higher in unsprayed
Roschewitz *et al*. [51]	Seedbank (top 10 cm)	64% higher in organic			89% higher in unsprayed
	% Cover weeds	80% higher in organic		Weed biomass	75% higher in unsprayed
	Seed rain	19% higher in organic			82% higher in unsprayed
Hyvönen *et al*. [52]	Weed abundance	15% higher in organic			
Mennalled *et al*. [53]	Weed biomass	83% higher in organic			
Petersen *et al*. [54]	Weed abundance	28% higher in organic			
Moreby *et al*. [55]	% cover	46% higher in organic			
Mean effect		49%	Mean effect		77%
		Difference	36%		

Table B. Data comparing insect resources on organic *vs*. conventional and unsprayed *vs*. sprayed fields and margins compiled from nine papers. The difference in the mean effect sizes between the two systems was calculated as 41% - which means 59% of the increase in insect densities in organic systems is due to lack of spraying. This was then be used as an adjustment factor for the results.

Organic *vs*. Conventional			Unsprayed vs. Sprayed		
Study	Measure	Result	Study	Measure	Result
Reddersen [58]	Bird food insects	37% higher in organic	Taylor *et al*. [56]	Chick food insects	13% higher in unsprayed
Moreby [59]	Heteroptera	19% higher in organic	Moreby *et al*. [62]	Heteroptera	36% higher in unsprayed
Feber *et al*. [60]	Butterfly abundance	44% higher in organic	de Snoo [63]	Butterfly abundance	79% higher in unsprayed
Rundlöf & Smith [61]	Butterflies	18% higher in organic			62% higher in unsprayed
			Rands & Sotherton [64]	Butterfly abundance	64% higher in unsprayed
			Sotherton *et al*. [65]	Chick food insects	56% higher in unsprayed
Mean effect		30%	Mean effect		51%
		Difference	41%		