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Minimal effects of wind turbines on the distribution of wintering farmland birds

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Summary

1. Energy production from wind power is increasing rapidly in Europe to help combat the threats from global warming. For example, the European Commission have set a target for 20% of EU energy to come from renewable sources by 2020. In recent decades, biodiversity on European farmland has fallen dramatically due to agricultural intensification. Agri-environment schemes (AES) have been implemented across the EU, in part at least, to combat these declines. Significant numbers of turbines are, and will be, built on farmland. There is, therefore, a potential conflict between wind turbines and AES on farmland.

2. Various mechanisms potentially cause wind turbines to alter bird distribution including noise and physical structure.

3. We show that turbine location (controlling for other effects such as boundary location and crop type) did not affect the distribution of four functional groups of wintering farmland birds (seed-eaters, corvids, gamebirds and Eurasian skylarks) at differing distances from wind turbines ranging from 0–150 m to 600–750 m. The only species for which distribution was related to the presence of wind turbines was the largest and least manoeuvrable (common pheasant *Phasianus colchicus* L.).

4. In a further analysis of data collected at 0–75 m and 75–150 m from turbines, we found no evidence to suggest that farmland birds in our study avoided areas close to wind turbines.

5. *Synthesis and applications*. This is the first evidence suggesting that the present and future location of large numbers of wind turbines on European farmland is unlikely to have detrimental effects on farmland birds (at least for those species included in our study). This should be welcome news for nature conservationists, wind energy companies and policy-makers. However, our work is only a first step, as there may be potential influences of wind turbines on bird distribution during the breeding season.

Key-words: climate change, disturbance, sustainable agriculture, farmland biodiversity, agri-environment schemes, noise pollution, wind energy

Introduction

Global climate change has resulted in worldwide calls for 'renewable' energy sources to reduce carbon emissions. Wind power provides the largest share in the renewable energy sector in Europe. The Global Wind Energy Council is forecasting that the global wind market will grow by over 155% to reach 240 gigawatts of total installed capacity by 2012 (http://www.gwec.net/). The European Commission have set a target for 20% of EU energy to come from renewable sources by 2020 (EC proposal 52008PC0019). The major land use within the European Union is agriculture [44% of land area was categorized as farmed in 1997, with woodland as the next largest landholding area at 32% (EC website, http://ec.europa.eu/agriculture/envir/report/en/terr_en/report.htm)], and thus, it seems likely that many of these turbines will be located on farmland. For example, in the UK it is predicted that approximately 10% of electricity production by 2020 will come from onshore wind power sites (http://www.bwea.com); from interpolation using current technology parameters (c.2·5MW turbines), this equates to approximately 4400 new turbines. Within the EU, a large amount of resources are

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given over to agri-environment schemes (AES) designed to enhance the environment on farmland (e.g. between 1993 and 2003, €24 billion was spent by the EU on AES; Kleijn & Sutherland 2003). One of the major goals of these schemes is to enhance biodiversity on farmland (Whittingham 2007), which has been widely reported as declining (e.g. Krebs *et al.* 1999; Donald, Green & Heath 2001).

There are major concerns regarding the impacts of wind turbines on animals, especially birds (e.g. Osborn *et al.* 2000; Percival 2005), but other taxa such as bats have also been shown to be affected (e.g. Arnett *et al.* 2008). Much terrestrial research into the effects of wind turbines on birds has focussed on geese, waders and raptors: all groups that are likely to suffer relatively high potential direct mortality risk (Barrios & Rodriguez 2004; De Lucas, Janss & Ferrer 2004; Percival 2005). In the UK, raptor, wader and wintering goose populations are highest in upland and coastal areas, and there is increasing conservation concern regarding the impact of windfarms on these species in these areas. Consequently, applications to build new turbines are increasingly focusing on other sites, particularly lowland farmland landscapes in central and eastern England (see British Wind Energy Association website, http://www.bwea.com/ukwed/, which shows maps of existing and future windfarm sites).

It is not uncommon for farmland bird species to fly at altitudes above 20 m (the bottom reach of the turbines in our study), but there is virtually no evidence-based evaluation in the published literature of the potential displacement that could result from wind turbines. One study from the USA found that songbird species living in a grassland–farmland mixture occurred at up to four times higher densities farther than 180 m from wind turbines during the breeding season (Leddy, Higgins & Naugle 1999); however, this study did not appear to control for differences in habitats at differing distances from wind turbines. We could find no evidence from the European literature of the effects on songbirds during the winter. Farmland bird populations have declined severely across Europe; for example, a 40% decline between 1980 and 2005 was recorded across 20 EU countries (http://www.ebcc.info/index.php?ID=299). Consequently, the population index of farmland bird species across Europe was recently adopted by the European Union as a structural and sustainable development indicator.

Should wind turbines affect the distribution of farmland birds, then it would be logical to spatially separate agri-environmental measures aimed at birds and the location of wind turbines. There is thus a potential conflict between uptake of AES and the placement of wind turbines on lowland farmland in the UK. This is likely to apply to many other European countries in which farmland birds are also a major target of AES (Kleijn & Sutherland 2003).

We tested whether wind turbines affect the distribution of lowland farmland birds during the winter, a critical time in the annual cycle (Payne & Wilson 1999). To our knowledge, our study is the first to address the issue of whether wind turbines located on lowland agricultural fields affect the distribution (and hence habitat quality) of European farmland birds. A priori, the most likely mechanism of altering habitat quality is via disturbance. Birds might perceive wind turbines as disturbance for a number of reasons. Increased noise levels have been shown to affect bird distribution and behaviour in a variety of habitats (e.g. Reijnen *et al.* 1995; Reijnen, Foppen & Meeuwsen 1996; Habib, Bayne & Boutin 2007), and within cities, this has been shown to be linked with decreased ability to communicate vocally (e.g. Katti & Warren 2004). Other work has shown that increased noise levels are associated with higher predation risk by birds (Quinn *et al.* 2006) which is likely to result in changing patch quality (e.g. Butler, Bradbury & Whittingham *et al.* 2005). Wind turbines create noise and the amount varies with wind speed or r.p.m. (rotations per minute). The noise created by a 3-MW turbine can be about 100 dB at 14 rpm and 108 dB at 20 rpm (Klug 2002), although more modern wind turbines emit less noise. Work on farmland has shown that bird distribution is affected at levels of noise higher than around 40–50 dB (Reijnen *et al.* 1996). It is thus plausible that noise from wind turbines could result in lower habitat quality close to wind turbines (e.g. Habib *et al.* 2007). Alternatively, (i) birds might avoid flying near turbines to avoid potential collision, resulting in an effective 'exclusion' zone around turbines; (ii) human presence around turbines could affect birds, although on lowland English farmland this seems unlikely given the amount of disturbance by farmers, walkers, etc.; (iii) birds that prefer 'open' landscapes might avoid tall structures irrespective of potential collision risk. In general, disturbance reduces habitat quality for birds, and thus, all other things being equal, birds may preferentially use patches away from wind turbines as predicted by the Optimal Foraging Theory (Sutherland 1996).

Methods

Bird survey data were collected from farmland immediately surrounding two operational windfarms in East Anglia in January and February 2007. Each had eight turbines arranged in two parallel rows separated by 900 m (four and four at site 1; three and five at site 2) and spaced at 300-m intervals. The turbines were all Repower MM82 2·0 MW tri-blade type with a hub height of 60 m and total tip height of 100 m. Both sites have been operational since early 2006 and the wind turbines were all 'turning' throughout our surveys.

Many factors are known to affect the distribution of farmland birds, for example, crop type, non-cropped habitats (such as grass margins, hedge dimensions, trees within hedges, woodland, etc.) and spraying of pesticides (Hinsley & Bellamy 2000; Whittingham & Evans 2004; Whittingham *et al.* in press). Our study sites were relatively homogenous in nature, comprising cereal fields (47%; mostly winter wheat), oil seed rape (23%; patchily distributed and similar visually to bare plough) and bare plough (30%), but with variation in the distribution of ditches and hedges.

The windfarms were located on fenland arable farmland managed by five landowners. Maps of each site were overlaid with 150-m grids after bird counts had been undertaken. Each 150 × 150-m grid block was scored for its distance to the nearest turbine as follows: < 150 m, 150–300 m, 300–450 m, 450–600 m, 600–750 m. No blocks greater than 750 m from a turbine were surveyed because of access issues. The predominant crop type and presence of boundary features (hedge or vegetated ditch) was recorded for each block (Table 1). We

Table 1. Descriptions of predictors included in statistical models. Asterisk (*) indicates that the visit was not significant and its inclusion or omission made little difference to the final models, Table 2 is presented without visit (see Methods for further details)

Predictor name	Description
Distance from turbine	Variable from 1 to 5. 150 × 150 m blocks of land were surveyed at varying distances from wind turbines in the following categories: (1) < 150 m; (2) 150–300 m; (3) 300–450 m; (4) 450–600 m; (5) 600–750 m.
% boundary	Variable from 0 to 100%. Each block visited at each survey visit was scored as a '1' if it had a boundary feature present (e.g. hedge, ditch), and a '0' otherwise. Total blocks in each distance category were collated (e.g. visit 1 recorded boundary features in nine out of 16 blocks; thus, % boundary = 0·56).
% cereals	Variable from 0 to 100%. The large majority of crops were either oil-seed rape or winter wheat, and thus, the proportion of cereals was used as a predictor of differences due to crops. The proportion of cereals was recorded in the same way as % boundary.
Visit	Variable included as Julian date.*
Site	Random effect with two levels. 1 = Glassmoor; 2 = Deeping St Nicholas.

took the proportion of winter wheat as an indicator of crop type (% cereals in Table 1). Both sites were flat (no slopes > 2 degrees).

Eleven bird survey visits were made to the two sites (five at site 1, and six at site 2). Surveys were performed at least 2 days apart between 0900 and 1500 h, at least 1 h after dawn and before dusk (to avoid times when birds may have either departed to roost or before they had arrived from roosts). Surveys were not conducted in reduced visibility conditions such as mist, fog and persistent rain or when turbines were not operating (e.g. at very low wind speeds). Before each survey, a route of line transects was planned, covering a distance of approximately 7·5 km, with approximately a third of the blocks in each distance category (thus, 82·5 km of transects were walked in total). Different combinations of blocks and different routes were selected at random for each survey. The routes were walked at a speed of 2·5–3 km h^{-1}. All birds flushed by the observer and birds within *c.*100 m were identified by sight and sound, and individual positions marked onto a map. The large majority of birds were recorded by flushing and care was taken to avoid duplicate counts of these birds through observations of movements of previously flushed individuals.

We analysed data for those bird species that were recorded in sufficient abundance on their own, and for other species (where appropriate), we assigned them to functional groups based on ecological and taxonomic characteristics (Butler *et al.* 2005; see Supporting Information Table S1 for species assignment to functional groups). Note that common species names throughout this study follow Gill & Wright (2006) and associated updates (http://www.worldbirdnames.org/index.html). The effect of turbine proximity (distance) on the abundance and distribution of the four species/functional groups was tested using Generalized Linear Mixed Models (GLMMs) under a binomial distribution using a logit link function in GenStat version 8 (VSN International Ltd., Oxford). Distance was specified as a continuous variable, but the results did not change when the analysis was repeated with distance considered as categorical. Due to the logistics of each site, it was not possible to include the same number of blocks in each 'distance from turbine' category in each visit (see Supporting Information Table S2). Therefore, we controlled for this variation in our analysis by including the number of blocks visited in each distance category during each survey as the binomial denominator and the number of blocks containing each functional group as the response variable. For example, if granivores were present in 4 blocks out of 14 visited in the 150–300 m distance category on a survey, then 4 was specified as the response variable and 14 as the denominator (thus, 14 was equivalent to the number of 'trials' undertaken in a binomial model). This method of abundance analysis represents a biologically realistic approach as birds in flocks are unlikely to select foraging habitats independently of conspecifics, but frequency of occurrence is often related to total number of individuals recorded, which is likely to indicate the relative value of a foraging site (see Perkins *et al.* 2000; Moorcroft *et al.* 2002).

A two-level factor 'site' was included as a random effect in all models to control for variation resulting from unmeasured site-specific parameters. To control for seasonal effects, the term 'visit', which correlated with Julian date, was incorporated into the model and considered as a continuous variable. Crop type and presence of boundary features were standardized by the number of blocks visited in each distance category during each survey and were included as fixed effects (see Table 1).

The significance of distance, crop type and boundary were assessed using the change in deviance (ΔD), which is distributed asymptotically as χ^2 on removal of each term from a model including all of the predictors. Models were also re-run with visit excluded as it did not explain any of the variation in the distribution of most functional groups, and its exclusion gave very similar results (Table 2). Our approach was designed to test the effect of distance from turbines whilst checking that any result is not an artefact of some confounding

Table 2. Results of binomial error models for four functional groups of birds surveyed at two windfarm sites in East Anglia (each with eight wind turbines). Results of the deletion of each predictor from a model containing all predictors (i.e. a full model) are presented. Wald statistics are presented (degrees of freedom was 1 in every case), along with significance values (P; note that P values are calculated using the chi-squared distribution) and the direction of the relationship is shown in brackets (+ or –) if the relationship was significant. *$P < 0{\cdot}05$; **$P < 0{\cdot}01$

Species or functional group	Distance from turbine	% boundary	% cereals
Granivores	0·26, $P = 0{\cdot}61$	4·19, $P = 0{\cdot}04$ (+)*	0·45, $P = 0{\cdot}50$
Eurasian skylark	0·53, $P = 0{\cdot}47$	3·82, $P = 0{\cdot}05$ (–)*	0·14, $P = 0{\cdot}71$
Corvids	2·64, $P = 0{\cdot}10$	1·39, $P = 0{\cdot}24$	5·46, $P = 0{\cdot}02$ (+)*
Gamebirds	1·56, $P = 0{\cdot}21$	0·05, $P = 0{\cdot}82$	0·19, $P = 0{\cdot}66$
Common pheasant only	8·04, $P = 0{\cdot}005$ (+)**	0·23, $P = 0{\cdot}63$	1·05, $P = 0{\cdot}31$

effect caused by differences between crop type and boundary at varying distances from turbines. Thus, we acknowledge there are more sensitive ways to test for the effects of boundaries and crop types on our data set but this was not the aim of our analysis. The fit of the model to the assumptions of a binomial distribution can be approximated by comparing the ratio of residual deviance/residual degrees of freedom (Crawley 1993). Ratios close to one indicate a reasonable fit to the data, whereas ratios greater than 2·5 indicate a poor, over-dispersed fit (Crawley 1993). All probabilities quoted are two-tailed. Means and standard errors are presented in the form mean ±1 standard error.

Results

Thirty-three bird species were observed during surveys of the two windfarms totalling 2845 individuals (Supporting Information Table S2). Three additional species were seen flying over the site (western barn owl *Tyto alba* L., lesser black-backed gull *Larus fuscus* L. and black-headed gull *Larus ridibundus* L.). The proportions of each species at different distances from the wind turbines are given in Supporting Information Table S1.

Overall, for all functional groups, there was no effect of turbine proximity on the probability of the functional group's occurrence in a block (Fig. 1, Table 2). Granivores were more likely to occur in 150 × 150 m blocks that contained boundary features (e.g. hedges and vegetated ditches) but their occurrence was not related to turbine proximity ($\chi^2 = 0{\cdot}26$, $P = 0{\cdot}56$). Eurasian skylarks *Alauda arvensis* L. tended to avoid blocks containing boundary features ($\chi^2 = 3{\cdot}82$, $P = 0{\cdot}05$) but were not affected by turbine proximity ($\chi^2 = 0{\cdot}53$, $P = 0{\cdot}47$). Corvids were more likely to be found in blocks containing a higher proportion of cereal crops ($\chi^2 = 5{\cdot}46$, $P = 0{\cdot}02$) but were not affected by turbine proximity ($\chi^2 = 2{\cdot}64$, $P = 0{\cdot}10$). Gamebirds were unaffected by turbine proximity ($\chi^2 = 1{\cdot}56$, $P = 0{\cdot}21$) or any of the other predictors. However, when inspecting the raw data, it was apparent that the two gamebird species responded differently. Turbine proximity had no effect on red-legged partridges *Alectoris rufa* L. ($\chi^2 = 0{\cdot}24$, $P = 0{\cdot}62$) but the probability of common pheasant *Phasianus colchicus* L. presence increased with increasing distance from turbines ($\chi^2 = 8{\cdot}04$, $P = 0{\cdot}005$; see Fig. 2).

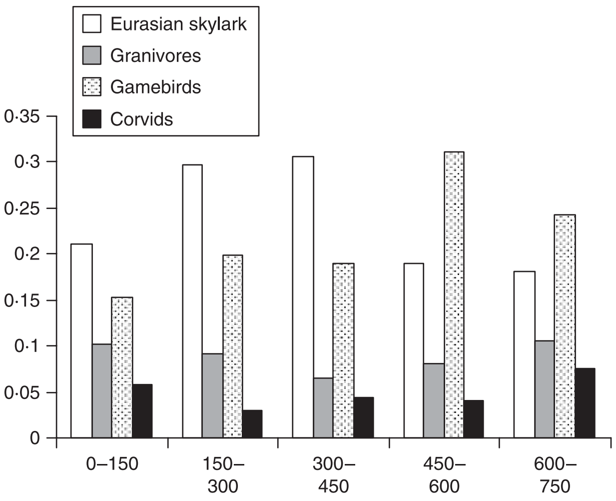

Fig. 1. Proportion of visits in which one or more of each functional group was recorded in different distance bands from wind turbines. For example, 21% of visits to patches within 150 m of wind turbines contained one or more Eurasian skylarks, but only 18% of visits to patches 600–750 m from wind turbines recorded one or more Eurasian skylarks. Raw data are presented here but the inclusion of crop type and boundaries did not alter the conclusions drawn (Table 2).

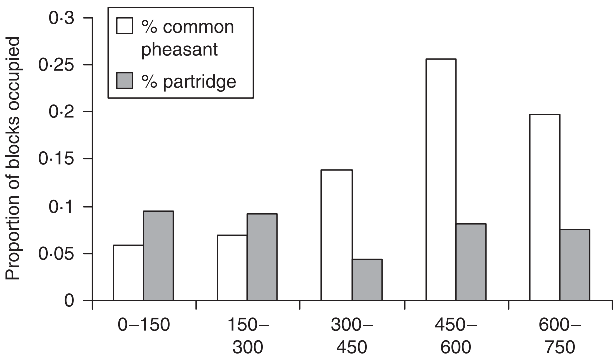

Fig. 2. The probability of finding common pheasants (% common pheasant) in a block increased with increasing distance from wind turbines, but there was no difference for red-legged partridges (% partridge).

One potential criticism of our study is that we did not look at distances less than 150 m from turbines. In order to address this issue, we subdivided our data from survey maps into two further units. One category included only blocks within 75 m of a turbine and the other blocks between 75 and 150 m from a turbine. We then analysed the data in the same way as for the main data set with turbine distance included as a two-level factor, site as a two-level factor and proportion of boundary and proportion of cereals both as variables (data are presented in Supporting Information Table S3). There was no significant effect of turbine distance on granivores ($\chi^2 = 1{\cdot}08$, d.f. = 1, $P = 0{\cdot}35$) or gamebirds ($\chi^2 = 1{\cdot}98$, d.f. = 1, $P = 0{\cdot}19$). However, both corvid species ($\chi^2 = 4{\cdot}39$, d.f. = 1, $P = 0{\cdot}04$) and Eurasian skylarks ($\chi^2 = 8{\cdot}41$, d.f. = 1, $P < 0{\cdot}005$) were more likely to occur in blocks *close* to turbines than those further away.

Discussion

Overall, our study suggests that wind turbines of the size we studied (2·0 MW, 60 m from ground level at hub height, 100 m at top of blade and 20 m at bottom of blade) had little impact on the distribution of farmland birds on our study sites during winter. To our knowledge, this is the first examination of the effects of wind turbines on the distribution of lowland farmland birds.

There has been considerable interest in halting and reversing recent farmland bird population declines both in the media and by the UK and other EU governments (Fuller 2000; Vickery *et al*. 2004). Measures to effect this change both in the UK and more widely in the other EU countries (Sutherland &

Kleijn 2003) have been implemented through government-funded AES (Whittingham 2007). Our work suggests that the benefits of AES for wintering farmland birds are unlikely to be compromised by the presence of wind turbines at least for those species in our study.

We recorded four species of granivorous farmland birds that are currently 'red-listed' as of high conservation concern: yellowhammer *Emberiza citrinella* L., Eurasian tree sparrow *Passer montanus* L., common reed bunting *Emberiza schoeniclus* L. and corn bunting *Miliaria calandra* L. (Gregory *et al.* 2002). Although individual counts of some granivorous species were low, we cumulatively recorded 400 individual seed-eaters. Two pieces of evidence suggest that the distribution of granivorous birds is not affected by wind turbines. First, across the group as a whole (including seven species), we found no statistical relationship between the distance from turbines and occurrence. Secondly, none of the seven individual species (see Supporting Information Table S1) shows a pattern indicative of avoidance of areas close to turbines.

Visual inspection of individual species presence and abundance in each of the remaining three functional groups (see Supporting Information Tables S1 and S2) also failed to reveal any patterns of avoidance of wind turbines. Inspection of the individual species counts not included within the four functional groups did reveal two species with low counts in the 0–150 m area. Interestingly, both species (mallard *Anas platyrhynchos* L. and common wood pigeon *Columba palumbus* L.) were larger less manoeuvrable species; however, not too much should be inferred from their abundances (Supporting Information Table S2) given the low number of presences recorded (Supporting Information Table S1). In other words, a few large flocks may have biased the results.

Our study did not assess the collision risk to farmland birds from wind turbines as has been reported for larger birds like raptors (Barrios & Rodriguez 2004). However, it seems likely that larger birds, which are generally less manoeuvrable in flight, are likely to be at higher risk of collision than small farmland birds. Two recent studies have both shown that ducks and geese make far less use of areas within several hundred metres of wind turbines at sea (Desholm & Kahlert 2005; Larsen & Guillemette 2007). The results of our study also show that the largest (and least manoeuvrable) species, common pheasant, which we were able to analyse, tended to use areas farther from wind turbines less than would be expected by chance.

Our analysis suggests that turbines were not a major deterrent to birds using areas within 150 m and supports our main findings at a larger scale. The underlying reason for the increased use of areas close to turbines by corvid species and Eurasian skylarks is not clear, although it may be related to food. Nevertheless, it is clear that a range of farmland birds are not influenced by wind turbines even at close proximity.

A potential criticism of our study is whether the data collected has sufficient power to detect effects of turbines. This is difficult to refute comprehensively but several points suggest this is not the case. First, the data on the effect of turbine distance on common pheasants was significant but the sample size was relatively small compared to other species/groups included in the analysis. Secondly, the results showing that both Eurasian skylark and corvids preferred areas close to turbines at small spatial scales were statistically significant: thus even within one distance category sufficient data existed to pick up a significant result. Thirdly, inspection of the raw data (see Supporting Information) did not reveal any consistent patterns of turbine avoidance across species/species groups.

With large numbers of windfarms needing to be built on lowland areas, the cumulative impacts on farmland bird species has the potential to be a significant constraint to development. At the European level, both the Environmental Impact Assessment (EIA) and Strategic Environmental Assessment (SEA) Directives [and the associated UK EIA regulation – Town and Country Planning (EIA) Regulations (1999)] specify the need to assess the cumulative environmental impacts of development projects. Our study has provided a first step in assessing the potential impact of wind turbines on farmland birds. Our study suggests, at least during the winter period, that there is likely to be little impact of wind turbines on the farmland bird species included in our study, and this should be welcome news for nature conservationists, wind energy companies and policy-makers. However, we recommend that further studies of the effects of wind turbines on farmland birds, particularly during the breeding season, are carried out.

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Supporting Information

Additional Supporting Information may be found in the online version of this article:

Table S1. Presence/absence of species of farmland birds in blocks at different distances from 16 wind turbines located on two different sites in East Anglia. As an illustration, 29 'blocks' in the distance band 0–150 m contained one or more Eurasian skylarks. The total number of blocks in the 0–150 m distance band was used as the binomial denominator (137 in this case) and '29' as the numerator in the Eurasian skylark model (e.g. 29/137 = 21·17% of blocks visited in the 0–150 m band were occupied by Eurasian skylarks (these proportions are presented in the % columns, see Methods for further details). Note: the proportion of blocks occupied within each distance class per speices are presented but these do not sum up to 100%.

Table S2. Counts of farmland bird species at different distances from 16 wind turbines located on two different sites in East Anglia (note that these data include birds seen or flushed during surveys across the farmland sites; birds seen flying across sites are not included here). The number of 150 m^2 blocks visited in each distance category varied due to the shape of the sites and access issues. The total number of blocks visited in each distance category were as follows: 0–150 m (137 visits); 150–300 m (131 visits); 300–450 m (137 visits); 450–600 m (74); 600–750 m (66). The statistical modelling (see Table 2) controlled for this variation by using binomial error models (see Methods). Note: as an illustration, 61 Eurasian skylarks were counted in the distance band 0–150 m from a wind turbine and a total of 226 Eurasian skylarks were counted across all distance bands.

Table S3. Proportion of blocks occupied by each functional group within (a) 75 m of a turbine and (b) 75–150 m from a turbine. Note that although the number of blocks with a presence recorded was the same as in Table S1 (e.g. 29 for Eurasian skylarks), the number of 75 m blocks close to a turbine (4) was much smaller than the number of 75 m blocks within 75–150 m of a turbine (12). Thus, the percentage scores can appear quite different. To further illustrate the data, the number of occupied blocks is shown in brackets (e.g. the 14 in brackets after Eurasian skylark indicates that 14 blocks within 75 m of a turbine were occupied, and the 25 in brackets after the count for Eurasian skylarks indicates that 25 Eurasian skylarks were counted in blocks 75 m from turbines).