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Altering perceived predation risk and food availability: management prescriptions to benefit farmland birds on stubble fields

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Summary

1. European farmland bird populations have fallen dramatically and sympathetic management of key habitats is one crucial way to help boost these populations. Maximising the value of habitats for foraging birds has largely focused on practical measures to increase food abundance but energy intake, the key determinant of habitat quality, is also affected by food accessibility and perceived predation risk. We tested the importance of manipulating perceived predation risk and access to food on the distribution of birds on stubble fields, a key wintering habitat for many UK species and used by many species in different parts of the world.

2. Recent evidence suggests simple reductions in vegetation height alter perceived predation risk for some species. Light cultivation, by scarification of the soil surface, could potentially alter both perceived predation risk (via changes in vegetation structure) and food availability (by opening up the soil and bringing seeds to the surface) and so be a single solution to enhancing suitability of stubble fields for birds. In experiment 1, we investigated the effects of changing vegetation height (via topping) and scarification on vegetation structure, seed density and distribution of farmland birds, using a 2x2 factorial within-field design. In experiment 2, we tested the temporal effects of scarification on bird distribution, using a similar within-field design.

3. Scarified plots supported higher abundances of invertebrate feeders (e.g. thrushes). Plots that were scarified within the past 7-13 days were used more by invertebrate feeders and granivores (e.g. yellowhammer) than plots scarified 2-3 months ago. Both results were probably a consequence of food availability being temporarily increased by scarification making prey more accessible.

4. Granivorous passerines and invertebrate feeders preferred plots with shorter stubble whilst the abundance of skylarks *Alauda arvensis* L., partridges, pigeons and meadow pipits *Anthus pratensis* L. was higher on plots with taller stubble. This was probably due to differing anti-predation strategies.

5. *Synthesis and applications*. Prescriptions that generate fine-scale heterogeneity should benefit a range of species. Although our work was confined to stubble fields, the importance of simultaneous consideration of predation risk and access to food is likely to apply across European farmland landscapes

and elsewhere, and could apply to other arable crops and potentially to grassland systems. On stubble fields specifically, topping of part of the field in the autumn could be combined with successive strip scarification treatments throughout the winter, to provide optimal conditions for a range of species. This could be incorporated as a management option in agri-environment schemes such as the English Environmental Stewardship Scheme.

Key-words: agri-environment schemes, vigilance, biodiversity conservation, agricultural intensification, Common Agricultural Policy

Introduction

Animals select foraging sites based on a trade-off between energy gain and predation risk (Lima & Dill 1990). All else being equal, animals will feed in patches with lower predation risk and will only feed in higher risk patches when they are rewarded with higher energy gains (Moody *et al.* 1996; Butler *et al.* 2005a) although they can be forced to feed at suboptimal sites due to density dependence or competition (Sutherland 1996). Higher energy gains can be achieved most simply through higher food abundance but also through increases in food availability mediated through detectability of food as well as accessibility (Whittingham & Markland 2002). In this paper, we concentrate on varying both perceived predation risk and food availability on crop stubble fields. Although our work was undertaken in the UK, stubble fields are selected by farmland birds in many different regions of the world (e.g. UK - Wilson *et al.* 1996; Moorcroft *et al.* 2002; Portugal - Moreira *et al.* 2005; Spain – Lane *et al.* 2001; Kenya – Gichuki 2000; Argentina - Leveau & Leveau 2004).

Vegetation structure can influence both the energy gain and perceived predation risk of a patch (Lima & Dill 1990) and is therefore likely to be an important patch characteristic influencing habitat selection. Recently Butler *et al.* (2005b) demonstrated that stubble height affects within-field distribution of farmland birds in different ways according to their predator escape strategies. In general, smaller birds (e.g. yellowhammer *Emberiza citrinella* L., reed bunting *Emberiza schoeniclus* L.,) that typically fly to cover upon attack by a predator (Whittingham & Evans 2004), tended to use the half of each stubble field that was cut short in preference to the other half of the field that contained longer stubble. In contrast, species which rely on crypsis to avoid predation (e.g. partridges) tended to prefer longer stubble in which they could hide.

Agricultural intensification is widely recognized as the major cause of European farmland bird declines over recent decades (e.g. Donald, Green & Heath 2001) and agri-environment schemes are now being promoted to try and halt, and hopefully reverse, these declines (Kleijn &

Sutherland 2003; Vickery *et al.* 2004). One element of intensification has been the trend towards homogenisation of sward structure both within and between fields and it has been argued that this is an important component contributing to farmland bird population declines (Benton *et al.* 2003; Wilson *et al.* 2005). In this study we focus on creating within-field habitat heterogeneity on stubble fields. Although we focus on just one crop type our results should apply equally to other tillage crops and to grass fields.

Inversion ploughing of arable fields in autumn, using the mouldboard plough, is a widespread technique that buries surface seeds in the ground and thus reduces the weed burden on fields (Cunningham *et al.* 2005). The numbers of earthworms in the soil tends to decline following ploughing, either through direct mortality or the destruction of the earthworm burrows (Jordan *et al.* 1997). As a consequence of these reductions in food abundance, various groups of birds avoid ploughed fields while often gathering in numbers on stubble fields (e.g. Wilson *et al.* 1996). In the UK, availability of winter stubbles can help to increase subsequent breeding densities (Whittingham *et al.* 2005; Gillings *et al.* 2005). Many of the species that favour stubble fields in winter in the UK and elsewhere are of current conservation concern (Gregory *et al.* 2002). Consequently, the provision of over-wintered stubble has been included as a management option in the British Government’s Arable Stewardship Pilot Scheme (Bradbury *et al.* 2004), Countryside Stewardship Scheme and Environmental Stewardship Scheme (Grice *et al.* 2004).

Stubble quality, in terms of available weed seeds and grain, has been reduced by a combination of effective herbicide programmes, competition from the preceding cereal crop, and efficient harvesting, with most wheat stubble fields supporting no birds, and few fields holding high densities of birds (Vickery *et al.* 2005). There is therefore the potential to improve resource delivery by stubbles. Increasing food abundance is a key goal (Stephens *et al.* 2003) and management options, such as reducing herbicide inputs in the previous crop, are available in agri-environment schemes to achieve this (Evans, Vickery & Shrubb 2004). However, there are also methods to alter perceived predation risk, such as stubble height manipulation, which could further improve the value of stubble fields for farmland birds. In addition, many stubbles are quickly depleted of surface seeds, and methods to bring new flushes of seeds from the seed bank to the surface may provide temporary new sources of food. The ground surface of stubble fields is often extremely hard (Gillings 2003) and so disturbance of the soil is likely to enhance accessibility of sub-surface invertebrates, such as earthworms, and thus explain the higher foraging rates of invertebrate-feeding birds such as lapwing *Vanellus vanellus* L. on ploughed compared with unploughed fields (Gillings 2003). Although inversion ploughing brings some seeds to the surface from the seed bank the benefits for birds are outweighed by the large numbers of surface seeds that are buried, in contrast light cultivation techniques result in far fewer surface seeds being buried but still results in seeds being brought to the surface (Cunningham *et al.* 2005). This probably explains why birds prefer lightly cultivated (non-inversion minimally tilled) fields to fields prepared by inversion ploughing (Cunningham *et al.* 2005). Neither stubble height manipulation nor cultivation (i.e. disturbing the soil) is explicitly considered by the current stubble management options available under environmental management schemes.

In this study we vary stubble height in the same way as Butler *et al.* (2005b). It is possible that light cultivation, as well as bringing seeds from the seed bank to the surface and increasing accessibility to soil invertebrates, could create variable stubble height and thus create within-field stubble heterogeneity without the need for explicit stubble height manipulation. There is therefore a need to understand how varying stubble height manipulation directly (as investigated by Butler *et al.* 2005) and light cultivation interact to alter vegetation structure, food availability and farmland bird distribution and also to examine how any beneficial effects of cultivation for birds may alter with time.

The overall aim of our work is to make recommendations for stubble field management that benefits farmland birds. In experiment 1 we tested the null hypothesis that farmland bird distribution was affected by neither stubble height manipulation nor light cultivation (using a 2 x 2 factorial within-field design). This experiment also enabled us to contrast the effects of stubble height manipulation and light cultivation. Experiment 2 tested the null hypothesis that use of lightly cultivated patches did not alter with time (two treatments: 2-3 month old cultivated patch vs 1-13 day cultivated patch) using a within-field design. We strongly support measures that increase food abundance for farmland birds (e.g. reducing herbicide inputs) and we view our work as providing additional techniques to improve habitats for birds.

Methods

STUDY SITES

Experiment 1. Experiment 1 was carried out from December 2004 to March 2005 on 16 stubble fields (15 following wheat and one following oats) from nine lowland farms in central England (one farm with three fields, five farms with two fields and three farms with a single field). Each field was either over-wintering as stubble prior to spring sowing of an arable crop or had been entered into rotational set-aside.

The stubble on one half of each field was cut (earliest field in late December, latest in early February) using a standard topper to lower vegetation height. Additional chaff generated by topping was left on the fields. The stubble on the other half of each field was left untouched to act as a control area. The section of field to receive stubble height reduction was allocated randomly. Within a few days of topping, half of each field (perpendicular to the topping treatment) was lightly cultivated with discs or tines (‘scarified’). These treatments created four plots per field: tall scarified, tall non-scarified, short scarified and short non-scarified. Each plot thus covered approximately 25% of the area of each field.

The area of each field was obtained from the landowner (mean field size ± 1 se = 11.3 ± 2.1 ha). The boundary characteristics of each plot were recorded in order to calculate a boundary height index (Whittingham *et al.* 2003), a characteristic which can affect the attractiveness of fields to some species, e.g. skylark. The external perimeter of each plot was divided into sections according to the following categories: 0 – no vertical structure; 1 – a low (< 2 m) hedgerow, wall or bank without trees; 2 – a tall (> 2 m) hedgerow, wall or bank without trees; 3 – a hedgerow with trees or a line of trees; 4 – woodland edge or other boundary type such as a garden, scrub or farm buildings. The length of each section (m) was multiplied by its category score and the boundary height index calculated by dividing the sum of these values by the total plot perimeter length.

Experiment 2. Experiment 2 was carried out on a sub-set of the fields used in experiment 1 (five fields on four farms). In early March 2005, the half of the field that had not been scarified as part of experiment 1 was scarified. This created one half of the field that had undergone scarification some time ago (on average 66 days ago, range 49-90) – OLD, and half the field that was scarified within 13 days of the survey visit – NEW (note: called 'Date of scarification' in Table 2).

BIRD COUNTS

Experiment 1. Fourteen fields were visited on six occasions between December 2004 and February 2005 and two fields on five occasions; each visit to a field was made on a separate day. Bird abundance and distribution were estimated by walking parallel transects (which ran perpendicular to the boundary of the short and tall plots) at 50 m intervals and counting all birds that flushed, recording which plot they had flushed from. Care was taken to avoid double counting by noting where previously flushed birds landed. Counts were undertaken between one hour after dawn and one hour before dusk to avoid periods when birds were leaving or arriving at roost sites. Periods of wet or windy weather were avoided due to the effects of these conditions on bird activity. Birds flying over fields but not landing on them were not included in analyses.

Experiment 2. Five fields were visited on seven occasions in March 2005; each visit to a field was made on a separate day. Birds were surveyed as above. Surveys began the day after the second scarification treatment and were completed (i.e. seventh visit completed) on average 10 days (range 7-13) after the second scarification treatment. Thus, we were able to get an idea of the short-term impact of scarification.

VEGETATION SAMPLING

Vegetation characteristics (stubble height and other vegetation height) in the four plots in experiment 1 (post-treatment) were recorded from five samples placed randomly within each plot (i.e. 20 samples per field), although not close (within 20 m) to the boundary (as distance to boundary could affect seed depletion rates, e.g. by animals living in hedges). Samples were collected within a few days of the soil samples (see below).

At each sample point, the mean vegetation height, the mean stubble height and the percentage of bare earth within a 50 x 50 cm quadrat were recorded. Mean vegetation height and mean stubble height was calculated from four height measurements, taken from the stem nearest the four corners of each quadrat. Measurements were taken from 14 of the 16 fields (two fields were ploughed before measurements were taken).

SOIL SEED DENSITIES

Seeds were collected from surface soil scrapes (20 x 20 cm) from each of the four plots within each field in experiment 1. To restrict sampling to the part of the seed bank likely to be accessible to small passerines (Robinson 1997), only soil on or immediately below the surface was collected (approximately 3mm below the surface). Five samples were taken per plot (i.e. 20 samples per field) between 40 m and 60 m from the field boundary. All five samples from the plot were pooled and mixed. These were then placed in resealable polythene bags and stored within 24 h at 4 ^{o}C (to prevent germination) until they could be analysed (usually within a week).

The bulked samples were weighed and a random subsample (25% of original mass) was removed. Seeds from each subsample were extracted by washing the soil through sieves of decreasing mesh size (1 mm and 500 µm). The contents of the sieves were then washed into a white sample tray and allowed to dry before being hand sorted, with each seed being counted and identified using an appropriate guide (Flood & Richardson 1986; Jones, Taylor & Ash 2004) and reference material collected in the field. Soil samples were collected in January and February 2005, to give an idea of the effects of scarification on seed availability. On average soil samples were collected 24 ± 3.7 (± 1 se) days since scarification occurred.

ANALYSIS

Most bird species were not recorded in sufficient numbers to permit statistical analysis of abundance at the species level (Appendix S1a & S1b). Species were therefore assigned to functional groups, based on ecological and taxonomic characteristics (Butler *et al.* 2005b) with particular emphasis on foraging requirements and predator escape strategy (see Appendix S1 for details of groupings). To examine temporal effects of scarification (‘timing of visit’ in Tables 1 and 2) the surveys in both experiments were grouped into two temporal categories: EARLY, experiment 1 the first three surveys, experiment 2, the first four surveys; LATE, all subsequent surveys in both experiments (generally three for both experiments).

The effect of stubble height reduction and scarification (experiment 1) and date of scarification (experiment 2) on the abundance and distribution of seven functional groups (granivorous passerines, invertebrates feeders, skylarks, corvids, partridges, pigeons, meadow pipit – for further details see Supplementary material) was tested using logistic regression in GLIM 4.0 (NAG 1993). The term ‘field’ was included in all models to allow within-field comparisons, while controlling for variation resulting from unmeasured site-specific parameters (we present the results of models including ‘field’ as a fixed effect; however, we obtained very similar results when these models were repeated in Genstat with ‘field’ as a random effect, and these alternative models did not alter any of the conclusions drawn – we chose to present the results this way as the *P*-values associated with the random GLMM procedure in Genstat are approximate, R. Payne pers.comm.). To investigate whether the relative abundance of birds on plots changed with time since scarification, the term ‘timing of visit’ (see above) was incorporated into the model. The term ‘topping’ was included to account for the effects of manipulation of stubble height. The term ‘scarification’ was included in the analysis for experiment 1 to indicate whether a plot was scarified or not, and the term ‘Date of scarification’ was included in the analysis of experiment 2 to account for the time since scarification (see above). In experiment 1, the number of times each of the four plots (tall non-scarified, tall scarified, short non-scarified, short scarified) was noted to have one or more of each functional bird group present was specified as the response variable and the number of surveys in each season was identified as the binomial denominator (specifying a binomial error structure with logit link function, (Crawley 1993) e.g. if skylarks were present on 2 visits out of 6 in tall non-scarified then 2 was specified as the response variable and 6 as the denominator). In experiment 2, a similar method was used except there were only two plots (OLD or NEW SCARIFICATION). This method of abundance analysis represents a biologically realistic approach as birds are unlikely to select foraging habitats independently of conspecifics in a flock 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).

As expected, given the random allocation of stubble height reduction and scarification plots, GLMs showed that there were no significant differences in boundary height index between the four plots used in both experiments 1 and 2 ($P = 0.98$ and $P = 0.38$ respectively). The significance of each predictor in the analyses of both experiments was assessed using the change in deviance (ΔD), which is distributed asymptotically as χ^2, on removal of each term from a model including all predictors. 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, overdispered fit (Crawley 1993). All probabilities quoted are two-tailed. Means and standard errors are presented in the form mean ± 1 standard error.

Only one sample per plot per field was used in the analysis of vegetation structure and seed density data.

Results

Effect of scarification and stubble height manipulation on bird distribution

A total of 34 bird species (5154 individuals) were recorded at the study sites during the survey period in experiment 1 (Appendix S1a) and 26 species (1631 individuals) in experiment 2 (Appendix S1b).

In experiment 1, scarification had a positive effect on the distribution of invertebrate feeders and skylarks (Table 1). A total of 1371 invertebrate feeders and 339 skylarks were recorded on scarified plots whilst only 251 and 288 individuals respectively were recorded on plots that did not receive a scarification treatment (Figure 1). In both cases the interaction between timing of visits and scarification was also significant, with more records occurring on scarified patches on early visits than on later visits (Table 1). The results of experiment 2 supported the idea that the effect of scarification changed with time. Granivorous passerines, invertebrate feeders and corvids all preferred recently scarified plots to older scarified plots (Table 2, Figure 2, Appendix S1b). A total of 177 granivores, 491 invertebrate feeders and 135 corvids were recorded on recently scarified plots whilst only 7, 183 and 40 individuals respectively were recorded on plots that were scarified 3-4 months ago (Figure 2).

Meadow pipits preferred non-scarified and also more recently scarified plots (Tables 1 and 2). The interaction between topping and scarification was significant with meadow pipits preferring plots with the most vegetation (non-scarified tall) (Table 1, Figure 1).

In experiment 1, both granivorous passerines and invertebrate feeders tended to make greater use of shorter stubble patches that had been topped (Table 1). In contrast, skylarks, partridges, pigeons and meadow pipits all preferred longer stubble in control patches (Table 1), as did corvids in experiment 2 (Table 2). The interaction between scarification and topping was strongly significant for partridges. Whilst both longer stubble treatments were used by partridges to a similar extent, most of the variation that contributed to this significant interaction came from the greater use of short stubble that had been scarified.

How does scarification affect vegetation structure?

In experiment 1, stubble height was significantly reduced by both topping ($F_{1,40} = 259.8$, $P < 0.001$) and scarification ($F_{1,40} = 24.8$, $P < 0.001$) (statistics derived from a GLM: natural log stubble height = scarification + topping + field). The height of vegetation other than stubble (grass, weed spp. etc.) was also affected by both scarification ($F_{1,40} = 19.8$, $P < 0.001$) and topping ($F_{1,40} = 20.2$, $P < 0.001$) (statistics derived from a GLM: natural log vegetation height = scarification + topping + field). The amount of exposed bare earth was strongly influenced by scarification ($F_{1,40} = 103.5$, $P<0.001$) but was not affected by topping ($F_{1,40} = 0.15$, $P = 0.70$) (statistics derived from a GLM: arcsine percentage bare earth = scarification + topping + field). Summary information for the effects of scarification and topping on the different measures of vegetation structure is presented in Appendix S2. Overall, stubble stalks on plots which were scarified were reduced in height by an average of 24% compared with stubble heights on plots which had not been scarified (mean height of scarified short stubble = 4.8 ± 2.7cm; mean height of non-scarified short stubble = 6.3 ± 3.4 cm; mean height of scarified long stubble = 12.5 ± 9.4 cm; mean height of non-scarified long stubble = 16.8 ± 5.5 cm). Other vegetation was affected in a similar way. The sward was broken up by scarification so that there was more than double the amount of exposed bare earth on scarified plots compared with plots that remained unscarified (mean % bare earth scarified short stubble = 69.7 ± 2.8; mean % bare earth non-scarified short stubble = 24.8 ± 3.8; mean % bare earth scarified long stubble = 62.6 ± 3.3; mean % bare earth non-scarified long stubble = 36.4 ± 4.9).

How does scarification affect seed availability for birds?

Seed density (number of seeds per kg of soil) taken from soil samples from the top few millimetres of earth, on average 24 days post-scarification, was not significantly influenced by either scarification ($F_{1,46} = 0.01$, $P = 0.96$) or by topping ($F_{1,46} = 0.01$, $P = 0.98$) (statistics derived from a GLM: natural log seeds per kilogram = scarification + topping + field). Seed densities tended to be lower on scarified plots, but there was a large amount of variation in the data (see Appendix S2).

In order to determine whether any differences in bird distribution in experiment 2 (see below) were due to seed availability changes caused by scarification, we measured seed densities in NEW and OLD SCARIFIED plots but found no significant differences ($F_{1,13} = 1.14$, $P = 0.30$; see also Appendix S2) (statistics derived from GLM: natural log seeds per kilogram = scarification + topping + field).

It is possible that the result in experiment 1 was a product of differences in seed depletion between plots because they were not sampled until, on average, 24 days after scarification. To investigate this we carried out another GLM (natural log seeds per kilogram = scarification + topping + field + time between scarification and soil sampling) and found that seed density was again not influenced by either scarification ($F_{1,45} = 0.01$, $P = 0.98$) or topping ($F_{1,45} = 0.01$, $P = 0.97$).

Discussion

This study has shown that both vegetation height manipulation (topping) and scarification can bring about differential spatial and temporal use of stubble fields by a range of farmland bird groups. In general the effects of stubble height manipulation were stronger and affected more species than scarification (strength of effects in Table 1 all greater for topping than scarification) suggesting that scarification should not be used as a single solution to alter vegetation height and food accessibility, but should be used in combination with topping to provide optimal conditions for farmland birds. Our study also found that the benefits of scarification for farmland birds were most marked within a few days of treatment.

Effects of scarification on bird distribution

We found evidence that invertebrate feeders (e.g. thrushes, starlings *Sturnus vulgaris* L.) and corvids (e.g. rooks *Corvus frugilegus* L.) made more use of scarified plots than control plots (Figure 1). This is possibly because they can exploit invertebrates (e.g. earthworms, leatherjackets) in freshly disturbed soil. We also found that these groups tended to exploit scarified plots to a greater degree soon after treatment had occurred rather than after a few weeks ('Timing of visit * scarification' in Table 1; 'Date of scarification' in Table 2). Perhaps some invertebrates are killed and exposed by cultivation or are more easily accessible in disturbed soil (Jordan *et al.* 1997; Gillings 2003).

Skylarks and granivorous passerines also showed positive responses to scarification, but the underlying reasons are less obvious. Seed sampling on plots in both experiments showed no significant effects of scarification on seed density. However, it is possible that scarification may have brought seeds to the surface that would otherwise have remained buried and thus although seed density *per se* (in the top part of the soil) was unaffected, seeds may have become more accessible for granivorous bird species, at least temporarily.

Meadow pipits prefer to forage by picking surface-dwelling invertebrates from ground vegetation, they often crouch when predators approach and within our study they made little use of hedges (Perrins 1988). This may explain why meadow pipits preferred the non-scarified plots because they contained the most vegetative cover (see results and Appendix 2). Perhaps meadow pipits also preferred non-scarified plots to a greater degree initially (i.e. interaction between 'timing of visit' and 'scarification' in Tables 1 and 2) because as plant cover increased on scarified plots with time they became more attractive. Partridges were found to have a strong preference for long stubble by Butler *et al.* (2005b) and in this study. We suspect they were able to make greater use of short-scarified plots than short unscarified plots because scarification created small-scale ridges and furrows in the earth, the heterogeneity of which might have increased cover for partridges.

Effect of stubble height manipulation on bird distribution

We found that topping had similar effects to those reported by Butler *et al.* (2005b). In experiment 1, both granivorous passerines and invertebrate feeders made greater use of shorter stubble patches than longer stubble, whereas skylarks, partridges, pigeons and meadow pipits all showed the opposite pattern. It is unlikely that seed abundance or invertebrate abundance differed between plots that received the topping treatment and those that did not, because the treatment was applied at random. The most likely explanation for the difference in use of the short and long stubble patches is due to perceived predation risk. The granivorous passerines and invertebrate feeders recorded in this study are likely to rely on early detection of predators to retreat to protective cover (Lima & Dill 1990; Whittingham & Evans 2004), often feeding near field edges and using surrounding hedgerows and trees as refuges (Robinson & Sutherland 1999). The level of visual obstruction offered by the vegetation within a foraging patch is therefore likely to have a far greater influence on their perception of predation risk than the degree of protection it offers. Whittingham *et al.* (2004) showed that, at equal food densities, chaffinches foraging in a short (3 cm) artificial stubble responded to attack by a model predator approximately 24% faster than those foraging in a long (13 cm) artificial stubble. This was despite spending 13% more time with their heads raised (i.e. being more vigilant) in the long stubble, which resulted in a 13% decrease in intake rate. Further aviary experiments varied the food abundance on the two patches and gave chaffinches the choice of foraging in either the short or long stubble (Butler *et al.* 2005a). There needed to be approximately 2.5 times more food in the long stubble before the increase in potential energetic gain outweighed the increase in predation risk and chaffinches showed parity of use between the short and long stubble patches. In addition, two studies of starlings feeding on invertebrates in grass showed they spent more time being vigilant, reduced their feeding rate and were slower to respond to a model hawk in long vegetation (13cm) than in short vegetation (Devereux *et al.* 2004; Devereux *et al.* 2006). These results suggest that the preferential selection of short plots by granivorous passerines and invertebrate feeders in this study occurred because they are likely to have associated short plots with both a lower predation risk and greater potential energetic gain.

Partridges, skylarks and meadow pipits adopt different predator avoidance strategies to granivorous passerines and invertebrate feeders. Instead of retreating to cover, partridges often remain still and rely on crypsis to avoid predator detection (Madge & McGowan 2002). The usual raptor avoidance behaviour of skylark and meadow pipits is also to crouch, often not breaking cover until the last minute (Cramp 1985). Whilst the shorter stubble may have provided less visual obstruction and allowed earlier predator detection, it is likely to have offered less protection to partridges, skylarks and meadow pipits once a predator had been detected. The greater abundance of partridges, skylarks and meadow pipits on long stubble suggests they associated lower predation risk with these plots.

Both corvids and pigeons may have shown a preference for longer stubble because it provides cover from predators (Whittingham & Evans 2004). Neither of these groups showed any preference in the study by Butler *et al.* (2005b) but, by chance, the length of the stubble was slightly longer in this study.

It is also possible that predator behaviour may have been influenced by stubble height. Sparrowhawks *Accipiter nisus* L. are the main predators of adult farmland birds (Götmark & Post 1996). Sparrowhawks hunt more successfully when they can launch attacks closer to their prey

(Quinn & Cresswell 2004), which is likely to be affected by vegetation structure, and studies of kestrels *Falco punctatus* L. have shown that foraging activity and hunting success are higher over less densely vegetated habitats (Shrubb 1980). The effect of stubble height manipulation on hunting behaviour by farmland bird predators, both avian and mammalian, needs further investigation of its influences on actual predation risk for farmland birds.

Although there is evidence for the effects of various forms of non-inversion tillage on various taxa (Cunningham *et al.* 2004; Holland 2004), it is not known exactly how the two treatments reported here would affect other taxa, such as insects, small mammals and weed populations, which play an important role in stubble field dynamics. Future work should examine how these various factors interrelate and also whether these manipulations have consequences for soil erosion risk on stubble fields, and consequently for particulate and nutrient loading of water draining from these fields.

Can scarification be used to vary stubble field heterogeneity?

Scarification altered vegetation height (see results and Appendix S2). However, it did not reduce sward height to the same extent as topping and, in general, the effects of stubble height manipulation were stronger and affected more species than scarification (strength of effects in Table 1 all greater for topping than scarification). If scarification destroyed the stubble structure created by topping this would not be the case, as birds would not demonstrate the clear differences between topped, or untopped, patches that had received scarification and those plots that did not (see Fig 1). Our study provides clear evidence that both topping and scarification have separate effects.

Conservation recommendations

We have shown that scarification and stubble height manipulation can influence foraging site selection by a range of farmland bird species, many of which are of current conservation concern. Our work adds to that of Butler *et al.* (2005b) by showing that changes to vegetation height are likely to have a greater effect on bird distribution than light cultivation. The effects of scarification are short-lived; for invertebrate feeders and granivorous bird species, newly scarified patches were used more than patches scarified 2-3 months ago. Invertebrate feeding species also showed a very rapid drop off in use of scarified patches after just a few days. It is possible that stubble height manipulation at the beginning of the winter could be combined with successive strip scarification treatments to benefit farmland birds throughout the winter. Our results could potentially be applied to other tilled crops, such as oil seed rape, and also to grass fields, so long as food items are sufficiently abundant. Grass height can be managed via mowing or grazing to create within-field structural heterogeneity. Livestock use of fields creates areas of disturbed bare earth (poaching) which may enhance food accessibility for insectivorous birds species, although further work is needed to confirm this.

Incorporating targeted management options into agri-environment schemes such as the English Government's new Environmental Stewardship Scheme may represent a cost-effective means to achieve these two treatments. In this experiment, farmers were paid £5-22 per hectare for topping and £20-22 per hectare for scarification: although payments for strip scarification are likely to be more costly. The results we report here apply to the soil types of our study farms which were mainly clay; we recommend repeating these treatments on lighter soil types, where scarification may have different effects on food accessibility for birds.

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Table 1. Results of logistic regression analyses for seven functional groups of birds surveyed on sixteen stubble fields at nine lowland farms in central England (experiment 1). Probability values are presented for the effects of field, timing of visit (first three or subsequent visits), topping (either tall or short) and scarification on within-field distribution of birds. Significant effects of topping and scarification are shown in bold with the direction of association (scar = more on scarified plots; Non = more on plots that were not scarified; C = more on tall plots; T = more on short plots; E = more on early visits) between predictor variable and frequency of occurrence. Timing of visit was nested within field and plot (i.e. 16 fields, 4 plots per field). Note: almost identical results were obtained for 'topping', 'scarified', 'field' and the interaction between 'topping' and 'scarified' from a model excluding 'timing of visit' and the interaction between 'timing of visit' and 'scarification'.

	Model goodness-of-fit (res. dev./res. d.f.)*	Field	Timing of visit	Topping	Scarified	Topping * Scarified	Timing of visit * Scarified
Granivorous passerines	1.07	<0.001	>0.25	**<0.01 (T)**	>0.50	>0.75	>0.25
Invertebrate feeders	0.68	<0.001	0.07 (E)	**<0.05 (T)**	**0.05 (Scar)****	>0.10	**<0.05**
Skylarks	1.25	<0.001	>0.10	**<0.001 (C)**	**<0.05 (Scar)**	>0.10	**<0.05**
Corvids	0.99	<0.001	>0.50	>0.50	>0.10	>0.25	0.08
Partridges	0.53	<0.001	>0.75	**<0.001 (C)**	>0.25	**<0.01**	>0.10
Pigeons	0.44	0.005	>0.50	**<0.05 (C)**	>0.50	>0.25	>0.10
Meadow Pipit	0.80	<0.001	>0.75	**<0.001 (C)**	**<0.05 (Non)**	**<0.05**	**<0.05**

*Res. Dev., residual deviance; res. d.f., residual degrees of freedom; ** Note that probability value for effect of scarification on invertebrate feeders was 0.054.

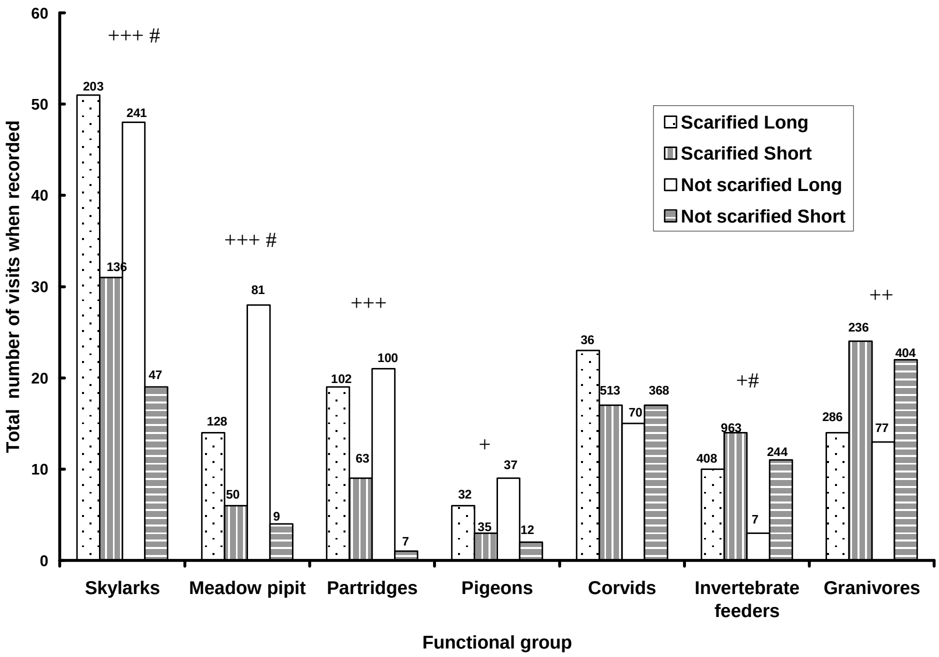
Table 2. Results of logistic regression analyses for seven functional groups of birds surveyed on five stubble fields in March at four lowland farms in central England (experiment 2). Probability values are presented for the effects of field, date of scarification (either NEW – all surveys within 13 days of scarification or OLD – surveys 2-3 months after scarification), timing of visit (either Early, first four visits, or Late - subsequent three visits) and topping (either tall or short) on within-field distribution of birds. Significant effects of topping and scarification are shown in bold with the direction of association (new = more on new scarified plots; C = more on control plots) between predictor variable and abundance. Timing of visit was nested within field and plot (i.e. 5 fields, 4 plots per field). Note: almost identical results were obtained for ‘topping’, ‘date of scarification’ and ‘field’ from a model excluding ‘timing of visit’ and the interaction between ‘date of scarification’ and ‘timing of visit’.

	Model goodness-of-fit (res. dev./res. d.f.)*	Field	Date of Scarification	Topping	Timing of visit	Date of Scarification * timing of visit
Granivorous passerines	1.19	<0.05	**<0.01 (new)**	>0.50	>0.50	>0.50
Invertebrate feeders	0.69	<0.001	**<0.05 (new)**	>0.75	**<0.01 (E)**	>0.10
Skylarks	1.64	<0.001	>0.10	>0.50	>0.25	>0.10
Corvids	1.31	<0.001	**<0.01 (new)**	**<0.05 (C)**	0.07	>0.50
Partridges	0.76	<0.001	>0.25	0.09	>0.75	0.07
Pigeons	0.48	>0.10	>0.50	>0.50	>0.25	>0.10
Meadow Pipit	0.66	<0.001	>0.50	>0.25	>0.75	**<0.001**

Fig. 1. The number of visits on which each of the seven functional groups of birds were recorded on the four plots (experiment 1): scarified tall (dotted bars); scarified short (vertical stripes); non-scarified tall (open bars); non-scarified short (horizontal stripes). A total of 94 visits were made: fourteen fields were surveyed six times and two fields on five occasions. A '+' indicates a significant effect of topping (which alters stubble height) and '#' indicates a significant effect of scarification on within-field distribution (+ or # = $P < 0.05$, ++ or ## = $P < 0.01$, +++ or ### = $P < 0.001$). The total number of individuals seen on each treatment is given above each bar (e.g. a total of 203 skylarks was recorded on the scarified tall plots).

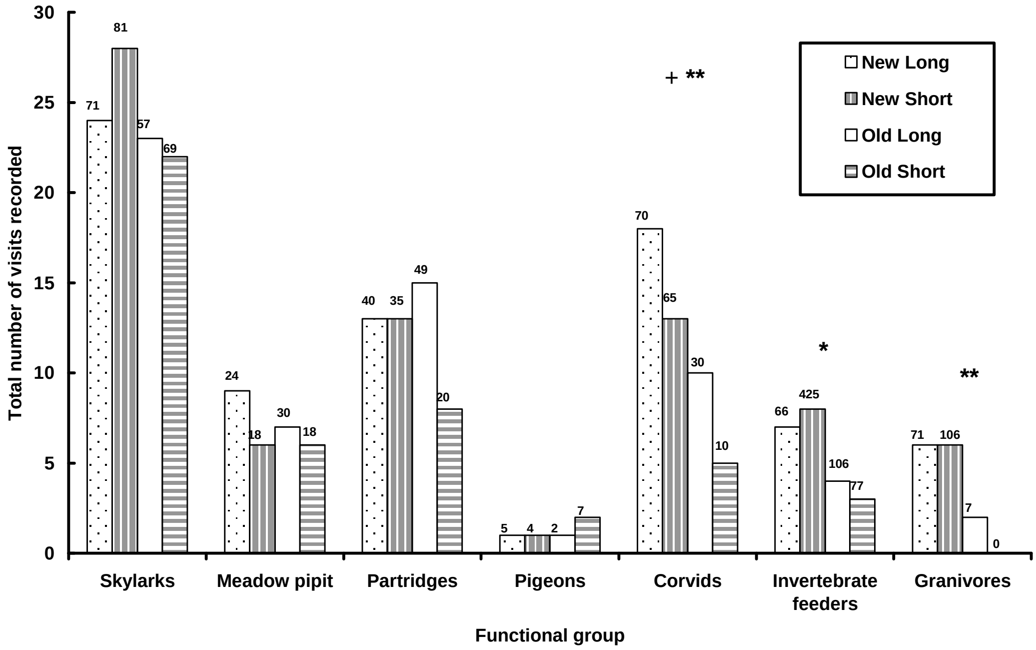
Fig. 2. The number of visits on which each of the seven functional groups of birds was recorded on each of the four plots (experiment 2): NEW tall (dotted bars); NEW short (vertical stripes); OLD tall (open bars); and OLD short (horizontal stripes). NEW plots had recently been scarified whereas OLD plots were scarified 3-4 months ago. A total of 35 visits were made; five fields were each surveyed seven times. A '+' indicates a significant effect of topping (which alters stubble height) and '*' indicates a significant effect of scarification age on with-field distribution of birds (+ or * = $P < 0.05$, ** = $P < 0.01$). The total number of individuals seen on each treatment is given above each bar (e.g. a total of 71 skylarks were recorded on the NEW tall plots).

Fig 1.



Total number of visits when recorded
60
50
40
30
20
10
0
+++ #
203
136
241
47
+++ #
128
50
81
9
+++
102
63
100
7
+
32
35
37
12
36
513
70
368
+#
408
963
7
244
++
286
236
77
404
Scarified Long
Scarified Short
Not scarified Long
Not scarified Short
Skylarks
Meadow pipit
Partridges
Pigeons
Corvids
Invertebrate feeders
Granivores
Functional group

Fig 2.



Total number of visits recorded
30
25
20
15
10
5
0
New Long
New Short
Old Long
Old Short
71
81
57
69
24
18
30
18
40
35
49
20
5
4
2
7
+ **
70
65
30
10
*
66
425
106
77
**
71
106
7
0
Skylarks
Meadow pipit
Partridges
Pigeons
Corvids
Invertebrate feeders
Granivores
Functional group