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Short communication

The effects of GMHT crops on bird abundance in arable fields in the UK

D.E. Chamberlain *, S.N. Freeman, J.A. Vickery

British Trust for Ornithology, The Nunnery, Thetford, Norfolk IP24 2PU, UK

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Abstract

Bird surveys were carried out in summer 2000 and winter 2000/2001 on 24 sugar beet fields, 11 maize fields, 10 spring rape fields and (for winter-only) 23 winter rape fields divided into conventional and genetically modified herbicide tolerant (GMHT) treatments. These fields were a sub-sample of those used in the farm scale evaluation (FSE [Firbank, L.G, Heard, M.S., Woiwod, I.P., Hawes, C., Haughton, A.J., Champion, G.T., Scott, R.J., Hill, M.O., Dewar, A.M., Squire, G.R., May, M.J., Brooks, D.R., Bohan, D.A., Daniels, R.E., Osborne, J.L., Roy, D.B., Black, H.I.J., Rothery, P., Perry, J.N., 2003. An introduction to the farm-scale evaluations of genetically modified herbicide tolerant crops. J. Appl. Ecol. 40, 2–16.]). The study aimed to compare bird abundance between GMHT and conventional crop treatments. In the summer, the abundance of yellowhammers *Emberiza citrinella* and of granivores collectively was significantly greater on conventional than GMHT sugar beet. Abundance of granivores and species richness was significantly greater on conventional than GMHT maize, but only after the application of herbicides to the GMHT treatment. No significant differences were detected in spring oilseed rape. No significant differences were detected prior to herbicide application in any crop. In winter, granivores were more abundant on bare plough following conventional sugar beet treatment than following GMHT treatment. Woodpigeon *Columba palumbus*, blackbird *Turdus merula* and corvids were more abundant on maize stubbles following GMHT treatment. These differences were in accord with likely differences in food availability ascertained from previous research carried out under the FSE.

Keywords: Agricultural change; FSE; Herbicide; Invertebrates; Power analysis; Weed seeds

1. Introduction

Recent advances in recombinant DNA technology have led to the development of genetically modified herbicide tolerant (GMHT) crops. These differ from conventionally managed crops in that broad-spectrum herbicides (e.g. glyphosate) can be applied, thus killing all plants save the GMHT crops. This is attractive to farmers because it is both more effective and less costly than conventional management, but also because fewer applications are needed (e.g. the need for pre-emergence spraying is removed). However, concerns over potential environmental costs related to the introduction of GMHT crops have been raised. These include the loss of farmland biodiversity due to the complete removal of weeds from crops (Hails, 2000).

The potential effects of GMHT crops on farmland biodiversity have been investigated by the UK government's Department of Environment, Food and Rural Affairs under the Farm-Scale Evaluations (FSE) project (Firbank et al., 2003). This considered the effects of GMHT crops compared to conventionally managed crops on a range of taxa in a large-scale field experiment. The most striking differences were for arable weeds and seed rain from these weeds, both of which were significantly greater in conventional sugar beet and spring oilseed rape compared to equivalent GMHT crops after the application of herbicide, although there were actually more weeds in the GMHT crop prior to herbicide treatment (Heard et al., 2003). However, GMHT maize crops had a higher abundance of weeds and greater seed rain than

* Corresponding author. Tel.: +44 1842 750050; fax: +44 1842 750030.
E-mail address: dan.chamberlain@bto.org (D.E. Chamberlain).

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conventional maize due to the conventional application of the herbicide atrazine (which is no longer in use in the UK). For winter oilseed rape, conventional crops had significantly greater biomass and seed rain from dicotyledons, whereas GMHT crops had greater biomass and seed rain from monocotyledons (Bohan et al., 2005). Differences were less clear-cut for invertebrates, but many larger species tended to be less abundant on GMHT rape and beet crops, including bees, butterflies and the carabid, *Harpalus rufipes* (Brooks et al., 2003; Haughton et al., 2003; Bohan et al., 2005). For maize crops, *H. rufipes* abundance and the abundance of bees in field margins was greater for GMHT than conventional crops (Brooks et al., 2003; Roy et al., 2003).

There are potential effects of GMHT crop management on both invertebrate and weed seed food resources for birds. Removal of weed plants could have important implications for granivorous birds as many rely on their seeds in winter and associated invertebrates in summer (Watkinson et al., 2000). Hence further intensification caused by the introduction of GMHT crops could potentially have severe impacts on the bird community. However, there also may be potential environmental benefits of the introduction of GMHT crops in that fewer sprayings may encourage minimum tillage systems (Cunningham et al., 2004; Holland, 2004), spring sowing and delayed herbicide application (Freckleton et al., 2004).

The findings of the FSE have been used to make recommendations on the likely impacts of GM crops on farmland biodiversity. These findings have influenced government policy on the commercial introduction of GMHT crops. In this paper, we present results from a study that considered the differences in bird occurrence between GMHT and conventional crops on FSE sites.

2. Methods

2.1. Sites

Sites were distributed throughout England and Scotland (locations given in Firbank et al., 2003). Each site consisted of one or more experimental fields (no single site had more than one field of the same crop type) that were divided equally into GMHT and conventional treatments by a bare strip. Mean experimental field area was 11.1 ha. Each treatment followed recommended spraying regimes for that particular crop type. A full description of the experimental design is given in Perry et al. (2003). Three different crop types were surveyed in the summer: sugar beet, maize and spring oilseed rape with respective sample sizes of 24, 11 and 10 (two additional rape sites and one maize site were covered but were vandalised during the course of the survey period and so were not included in the analysis). In the winter, an additional 23 winter oilseed rape sites were surveyed.

2.2. Bird surveys

Fieldwork was undertaken in the summer of 2000 and winter 2000/2001. In the summer a mapping survey of all birds in the experimental field was undertaken. In the winter, fields were surveyed using the whole-area search method (Buckingham et al., 1999; Atkinson et al., in press). For each season, observers were required to reverse survey routes taken on consecutive visits. Observers were unaware of the treatment on either half of the crop.

(i) For the summer survey, each site was visited five times between April and August. On each visit the locations of all birds seen in the experimental field were recorded onto maps following standard recording protocols used in the BTO's common birds census (CBC-Marchant et al., 1990). This included birds involved in any activity apart from flying over the site, unless flight was likely to be associated with the field itself (song flights or hunting flights). Particular care was taken in recording bird locations in relation to the GM/conventional divide in the experimental field. Individual registrations that made up each territory were assigned to either half of the experimental field. Those recorded in the field divide were not included.

(ii) Winter bird surveys involved walking parallel transects up and down the field (including the margins), the transects being close enough to ensure all birds were flushed. The maximum separation of transects was 50 m, but this was reduced for taller crops (as assessed by individual surveyors). The location of all birds was recorded directly onto a field map using standard CBC activity codes. The map included the location of the strip separating the conventional and GMHT-treated halves of the field (this was not always evident in the field in the winter). Double counting individuals, when a bird is flushed from one part of a field to another, was avoided when possible by noting a bird's location when it was observed to move within an experimental field. In common with the breeding season survey, no data were collected in excessively wet or windy conditions. Five visits were carried out (one per month between October and February) on the majority of sites although there were 10 sites where no final visit was undertaken due to restrictions imposed by a foot and mouth disease outbreak. The crop type (using the term in a broad sense to include stubble, fallow, etc.) was recorded at each visit. It typically varied over the course of the winter. For example, a number of sites began with sugar beet in October which was harvested in the autumn and was left either as stubble or bare plough until late winter or, in a few cases, sown with another crop (e.g. winter cereal). Note that this did not apply to winter rape crops, all except one of which had already been sown by the start of the winter bird survey.

2.3. Modelling abundance

Bird counts (abundance) were analysed separately for summer and winter, and using Poisson regression. There were clear differences in the response of plants and invertebrates in different crops to GMHT (Firbank et al., 2003), so data from the different crop types were analysed separately.

In the abundance models, the average bird count per visit was predicted via a log-linear model, specifically:

$$\log(c_{ij}) = S_i + T_j + \log(N_{ij})$$

where C_{ij} is the expected total count (summed across all visits) in the field at site i under treatment regime j, and S_i and T_j are the additive factors representing site and treatment effects (and note that in all cases natural logarithms are used). The offset $\log(N_{ij})$, where N_{ij} is the number of such visits made, adapts the model such that the average count per visit is a linear combination (on the log scale) of these two effects. The model is completed by assuming a Poisson distribution for the total observed counts. Models were fitted using the GENMOD procedure in SAS (SAS Institute, 1998). Treatment was either GMHT or conventional, and the site effects, though of less interest in themselves, maintain the 'paired' structure of the experimental plots and are employed to allow for variation due to features of location (altitude, distance from the coast, etc.).

For reasons of parameter identifiability the treatment effect for GMHT was set to zero. Therefore, on inverting the appropriate link function the estimated site effects $\hat{S}_i$ produce estimates of abundance on the GMHT treated half of the site in question. Further, exp $(\hat{T}_j)$ gives the ratio in abundance on the conventionally farmed equivalent.

The scaled deviance was used to correct standard errors and hypothesis tests for over-dispersion. F-tests were then used to assess the statistical significance (two-tailed tests at $P = 0.05$) of variation between treatments, after allowing for the effects of site.

Typically, the GMHT crop was sprayed at a different time to the conventional crop. Therefore, each half of a treated field was recorded as 'sprayed' or 'unsprayed' in the breeding season. To take into account this timing of treatment, the data were split into two sets, permitting comparison of unsprayed GMHT versus conventional crops (via the 'EARLY' data set) and sprayed GMHT versus conventional crops (via the 'LATE' data set).

For the winter data set, we considered treatment effects according to both the current and former crop, as there were likely to have been differences in winter food resources according to the previous crop (Heard et al., 2003). Only field types with a minimum sample size of five sites were considered. These were 14 for bare plough (beet), 6 for bare plough (spring rape), 6 for maize stubble, 7 for rape stubble and 23 for winter rape. There were some cases where crop types differed between each treatment half on a given visit date, particularly sugar beet where 29% of visits ($n = 109$ visit days) had different crop types in each treatment half due to different harvesting dates. The figures were much lower for maize at 3.6% (55), spring rape at 10.9% (55), and winter rape at 5.6% (107). Data collected from these fields were not analysed.

Count data were analysed for all species recorded on a minimum of five sites. There were eight individual species that met this criterion in at least one sample: red-legged partridge, *Alectoris rufa*; woodpigeon, *Columuba palumbus*; skylark, *Alauda arvensis*; meadow pipit; *Anthus pratensis*; dunnock, *Prunella modularis*; blackbird, *Turdus merula*; linnet, *Carduelis cannabina*; yellowhammer, *Emberiza citrinella*. Species groups were analysed in the same way: thrushes, corvids and granivores. Species richness (i.e. number of species rather than number of individuals) was also analysed with Poisson models. The number of sites in the models varied from species to species because all species did not occur at all sites. Sites with zero counts on both treatments for a given species were not analysed as they do not contribute to the estimated treatment ratio from the log-linear model (their inclusion gives rise to numerical problems).

3. Results

A summary of all model results for species occurring on at least five sites in the summer is given in Table 1. Mean count for each species and species group for GMHT and conventional treatments in each crop type and season are given in Appendix A. Sample sizes were generally small apart from a few common species (e.g. skylark, red-legged partridge) and when considering taxonomic groups. There were no significant differences detected in the early (pre-spray) treatment (Table 1a). In the late data set, abundance of yellowhammers and granivores was significantly greater on conventional than GMHT sugar beet, and abundance of granivores and species richness was significantly greater on conventional than GMHT maize (Table 1b). Variation between sites was only significant for skylark and granivores in the late data set.

Parameter estimates for species occurring on at least five sites in winter are given in Table 2. Granivores were significantly more abundant on (previously) conventional than (previously) GMHT sugar beet bare plough. Woodpigeon, blackbird and corvid abundance were significantly higher on GMHT than conventional maize stubble. Variation between sites was significant for woodpigeon and corvids on maize stubble, for granivores on bare plough (former sugar beet), spring rape stubble and winter rape and for species richness on spring rape stubble. There were certain cases where Poisson model fits were very poor (high over-dispersion) which was caused by a small number of very large flocks.

Table 1
The effects of GMHT and conventional crop management on bird abundance in different crop types in the summer

Species	Crop	No. of sites[a]	D[b]	Parameter estimate T_j[c]	Site effects[d]
(a) EARLY data set					
Red-legged partridge	Beet	8	1.88	-0.789 ± 0.539	ns
Skylark		11	0.81	-0.094 ± 0.336	ns
Blackbird		6	3.38	-0.105 ± 0.460	ns
Thrushes		6	3.63	-0.201 ± 0.857	ns
Corvids					ns
Granivores		15	1.07	-0.261 ± 0.316	ns
Species richness		17	1.18	-0.037 ± 0.300	ns
Species richness	Maize	6	1.46	-0.876 ± 0.642	ns
(b) LATE data set					
Red-legged partridge	Beet	14	2.92	-0.739 ± 0.271	ns
Skylark		14	0.92	0.227 ± 0.256	*
Dunnock		5	1.72	0.878 ± 0.691	ns
Blackbird		11	2.15	-0.095 ± 0.309	ns
Yellowhammer		5	0.42	$1.386 \pm 0.791^{*}$	ns
Thrushes		11	1.91	-0.045 ± 0.413	ns
Granivores		18	1.04	$0.495 \pm 0.230^{*}$	*
Species richness		24	0.93	0.070 ± 0.174	ns
Granivores	Maize	6	1.31	$1.674 \pm 0.719^{*}$	ns
Species richness		9	0.95	$0.981 \pm 0.382^{*}$	ns
Granivores	Spring rape	6	2.52	-0.438 ± 0.455	ns
Species richness		7	1.08	-0.147 ± 0.326	ns

[a] The number of sites indicates the number where at least one individual of the species in question was recorded. Total number of sites surveyed was 24 for sugar beet, 11 for maize and 10 for rape.

[b] The dispersion D is calculated as deviance/degrees of freedom.

[c] Parameter estimates are for the treatment effect and are given as untransformed means ± S.E. of the conventional treatment, relative to 0, the GMHT treatment (so negative values indicate GMHT > conventional). Asterisks indicate a significant change in deviance when the treatment term was added to the effects of site, where $^{*}P < 0.05$ (F-test).

[d] Site effects are also indicated where ns = not significant.

Table 2
The effects of GMHT and conventional crop management on bird abundance in different field types in the winter

Species	Field type	Former crop	No. of sites[a]	D[b]	Parameter estimate T_j[b,c]	Site effects[b,c]
Red-legged partridge *Alectoris rufa*	Bare plough	Sugar beet	5	7.44	0.268 ± 1.005	ns
Woodpigeon *Columba palumbus*			5	41.18	-2.086 ± 1.134	ns
Meadow pipit *Anthus pratensis*			6	2.78	-0.738 ± 0.612	ns
Skylark *Alauda arvensis*			7	10.06	-0.197 ± 0.893	ns
Granivores			9	4.26	$1.720 \pm 0.350^{***}$	***
Thrushes			5	1.69	-0.337 ± 0.760	ns
Species richness			13	1.41	0.511 ± 0.306	ns
Species richness	Bare plough	Spring rape	5	0.54	-0.847 ± 0.509	ns
Woodpigeon *Columba palumbus*	Stubble	Maize	6	8.52	$-3.613 \pm 0.790^{***}$	***
Skylark *Alauda arvensis*			5	5.48	-1.030 ± 1.219	ns
Blackbird *Turdus merula*			5	0.60	$-2.398 \pm 0.807^{*}$	ns
Corvids			5	4.92	$-2.431 \pm 0.505^{**}$	**
Granivores			6	3.65	-0.499 ± 0.587	ns
Thrushes			5	0.85	-0.956 ± 0.486	ns
Species richness			6	1.93	-0.300 ± 0.410	ns
Linnet *Carduelis cannabina*	Stubble	Spring rape	6	41.98	-0.721 ± 0.501	ns
Granivores			6	25.14	-0.690 ± 0.347	*
Species richness			7	0.88	0.446 ± 0.301	*
Skylark A*lauda arvensis*	Winter rape	n/a	5	4.00	-0.716 ± 0.520	ns
Granivores			8	6.35	0.400 ± 0.431	*
Species richness			10	1.00	-0.154 ± 0.278	ns

[a] The number of sites indicates the number where at least one individual of the species in question was recorded. Total number of sites surveyed was 14 for bare plough (beet), 6 for bare plough (spring rape), 6 for maize stubble, 7 for rape stubble and 23 for winter rape. Sample sizes were less than five for other field types.

[b] Other details as in Table 1.

[c] $^{*}P < 0.05$, $^{**}P < 0.01$, $^{***}P < 0.001$ (F-test).

4. Discussion

There were three generalisations that could be drawn from the FSE in terms of food resources that are likely to be exploited by birds: (i) weed abundance was higher in GMHT than conventional crops prior to herbicide treatment of the GMHT crop; (ii) weed abundance and seed resources were higher in conventional than GMHT in spring rape and sugar beet but lower in maize after broad-spectrum herbicide had been applied to the GMHT crop (Heard et al., 2003; Bohan et al., 2005; Firbank et al., 2006); (iii) similar patterns were apparent for invertebrates, but differences were less clear-cut (Brooks et al., 2003; Haughton et al., 2003; Roy et al., 2003; Bohan et al., 2005) and often involved species that rarely feature in the diet of birds e.g. bees (Wilson et al., 1999; Holland et al., 2006).

To what extent could significant differences detected in bird abundance between treatments be related to likely food sources in the crops? In the summer, there were no significant differences detected in the early (pre-spray) period, although this was the period when fewest birds were recorded overall. In the late data set, there were higher numbers of yellowhammer and granivores in the conventional than GMHT treatments on sugar beet, which could possibly be a response to greater weed and seed resources. However, abundance of granivores and also species richness was significantly higher in conventional than GMHT treatments on maize, which is the opposite of what could be expected given the likely resources. A possible reason for this may be due to ease of access to the ground for foraging passerines following removal of weed cover by use of atrazine in the conventional half of maize fields.

Birds were generally more abundant in the winter (Appendix A), particularly on stubbles, and a higher proportion of significant differences were found. Granivores were more abundant on bare plough (post-sugar beet) following conventional treatment. Woodpigeon, blackbird and corvids were more abundant and thrushes more likely to occur on maize stubbles following GMHT treatment. Furthermore, estimates were higher on former GMHT than conventional maize stubbles in every case analysed (negative parameter estimates in Table 2). Therefore, birds were found in higher numbers on the treatment that was likely to have had the higher food and especially seed resources in winter. Whether this could represent a causal response for non-granivorous birds is doubtful as thrushes and corvids feed mainly on earthworms, but these did not differ significantly between GMHT and conventional crops (J. Perry, pers. comm.). Nevertheless, these are intriguing differences.

The FSE was designed, among other things, to assess the potential effects of GMHT crops on invertebrate and weed populations at the field level. The FSE was not initially designed to consider birds as the scale (in time or space) was considered too small to provide adequate data. Despite this, the small sub-sample of FSE sites that were surveyed for birds generated sufficient data to detect a number of significant differences between treatments. In the winter, these differences were all in the direction predicted from measured differences in food resources in GMHT and conventional crops.

Due to the high costs and practicalities, a further larger scale experiment focussing on GMHT crops (or other crops/cropping systems or technologies) is unlikely and any future studies addressing the potential impact on birds will almost certainly have to use mathematical and process-based modelling (Bradbury et al., 2001; Stephens et al., 2003). It will be important to integrate the results of such models with wider considerations of both landscape scale (e.g. Robinson et al., 2001; Robinson et al., 2004) and the context of agricultural change as well as the socio-economic factors influencing the uptake of this technology (e.g. Watkinson et al., 2000). We suggest that further bird research would be worthwhile in assessing potential impacts of GMHT crops on bird populations. The winter results suggest that weed seed resources at this time may be crucial in determining crop preference by birds, a finding supported by several other studies of farmland birds in winter (e.g Buckingham et al., 1999; Moorcroft et al., 2002; Hancock and Wilson, 2003). The weed seed data collected under the FSE will be a prime source of information for any future mathematical models relating field use by birds to weed seed food resources. Intensive field surveys of foraging birds are needed to complement such models and provide an understanding of the underlying mechanisms driving any observed effects of GMHT crops on bird numbers and/or behaviour. Until the potential impacts of GMHT crops on bird populations are properly assessed, we urge caution in any consideration of the widespread commercial planting of GMHT crops in Britain. More generally, we recommend rigorous trials such as FSE should, at the very least, be considered before any major technological change in farming.

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Appendix A

Mean ± S.E. bird abundance per site per visit in GMHT and conventionally (CON) managed crops for different crop types.

Species	Crop	No. of sites	GMHT	CON
(a) Summer, EARLY data set				
Red-legged partridge	Beet	8	0.750 ± 0.189	0.313 ± 0.162
Skylark		11	0.909 ± 0.211	0.864 ± 0.234
Blackbird		6	0.833 ± 0.380	0.750 ± 0.310
Thrushes		6	0.917 ± 0.455	0.750 ± 0.310
Granivores		15	0.856 ± 0.181	0.700 ± 0.188
Species richness		17	0.873 ± 0.127	0.824 ± 0.154
Species richness	Maize	6	1.111 ± 0.226	0.333 ± 0.167
(b) Summer, LATE data set				
Red-legged partridge	Beet	14	0.873 ± 0.260	0.389 ± 0.142
Skylark		14	0.607 ± 0.129	0.768 ± 0.188
Dunnock		5	0.200 ± 0.133	0.450 ± 0.174
Blackbird		11	0.615 ± 0.107	0.562 ± 0.235
Yellowhammer		5	0.117 ± 0.073	0.507 ± 0.136
Thrushes		11	0.645 ± 0.122	0.638 ± 0.231
Granivores		18	0.532 ± 0.114	0.905 ± 0.219
Species richness		24	0.754 ± 0.084	0.814 ± 0.115
Granivores	Maize	6	0.194 ± 0.125	1.056 ± 0.288
Species richness		9	0.361 ± 0.118	0.972 ± 0.240
Granivores	Rape	6	1.456 ± 0.139	1.061 ± 0.407
Species richness		7	0.867 ± 0.165	0.843 ± 0.262

Species	Field use	Former crop	No. of sites	GMHT	CON
(c) Winter data set					
Red-legged partridge	Bare plough	Sugar beet	5	1.300 ± 0.436	1.900 ± 1.418
Woodpigeon			5	35.200 ± 17.871	2.400 ± 2.400
Meadow pipit			6	1.458 ± 0.725	1.333 ± 0.615
Skylark			7	1.631 ± 1.085	1.679 ± 0.564
Granivores			9	0.944 ± 0.488	5.150 ± 3.422
Thrushes			5	0.290 ± 0.101	0.200 ± 0.155
Species richness			13	0.475 ± 0.121	0.869 ± 0.115
Species richness	Bare plough	Spring rape	5	0.620 ± 0.185	0.340 ± 0.189
Woodpigeon	Stubble	Maize	6	42.472 ± 31.603	0.944 ± 0.419
Skylark			5	1.867 ± 0.672	1.000 ± 1.000
Blackbird			5	1.300 ± 0.300	0.067 ± 0.067
Corvids			5	9.610 ± 5.463	0.850 ± 0.789
Granivores			6	1.033 ± 0.443	0.583 ± 0.248
Thrushes			5	0.530 ± 0.230	0.200 ± 0.127
Species richness			6	1.008 ± 0.154	0.733 ± 0.231
Linnet	Stubble	Spring rape	6	37.333 ± 12.497	18.567 ± 6.175
Species richness			7	0.564 ± 0.185	0.914 ± 0.204
Skylark	Winter rape	n/a	5	1.827 ± 1.550	0.987 ± 0.397
Granivores			8	1.922 ± 1.432	5.189 ± 2.722
Species richness			10	0.650 ± 0.109	0.485 ± 0.152

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