Annex 8

Monitoring the ecological impacts of post-market genetically modified (GM) crops using the Breeding Bird Survey (BBS) – a power analysis

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INTRODUCTION

We are interested in the power of Breeding Bird Survey (BBS) data to detect changes in populations of farmland birds with a percentage area change in land-use (e.g. 40% conversion of maize crop to GM maize), using change from standard to Environmental Stewardship (ES) stubble management as a proxy for GM crop uptake. This can be justified on the basis that most of the ES stubble area reflects a change in crop management (from herbicide-sprayed to unsprayed), rather than a change in the cropping regime. In this way, it is conceptually not dissimilar to a change from conventional to GM crops, but retaining the same crop type, and the known effects of ES stubble considered here, although statistically significant, are not large. A major caveat, however, is that there is no evidence as to whether the magnitude of any biological effect of a switch to a GM crop might compare to that of a switch from standard to ES management of stubble for any given species or for an generic bird. In this analysis, we assume a similar magnitude of effect on bird population growth rates for a GM crop as for an ES stubble. However, “GM crop” areas are simulated (by resampling BBS data) to match the regional distributions of maize, beet and potatoes in order to approximate realistic bird data sets for the geographical distribution of each crop. Note that this assumes that the uptake of GM varieties of each crop follows the current distribution of cropping. Using bird species for which we have previously demonstrated statistically significant relationships between ES stubble and population growth rate (Baker et al. 2012), we then investigate the power to detect these relationships given the spatial distributions expected for GM crops and the six-year time period that has elapsed since the inception of ES in 2005. We do this using data from the whole of England together and dividing the data set into arable, pastoral and mixed farmland. We also consider power after three years of a change in management by using data up to 2008 only.

METHODS

Breeding Bird Survey (BBS)

The BBS (1994-present) is a UK-wide volunteer based survey for breeding birds that involves the survey of c. 2000 randomly selected squares throughout England. Volunteers walk two roughly parallel 1km transects through each square twice during the breeding season. Each transect is divided into five 200m sections with birds and habitat recorded separately in each of these sections (Crick *et al.* 1992, Risely *et al.* 2010). BBS squares used here included all lowland farmland squares (Land Cover Map 2000 Environmental Zones (Haines-Young *et al.* 2000)) that had been surveyed in ≥ 2 years between 2002 and 2010. Squares where the combined area of arable and pastoral land was < 50% of the square were deemed non-agricultural squares and removed from the dataset. The major land-use type for each square was categorised as either arable (ratio of arable:pastoral areas ≥ 2), pastoral (pastoral:arable ≥ 2) or mixed (all other squares) based on the CEH Land Cover Map 2000. Although BBS began in 1994, we chose to start the analysis in 2002 because this provided sufficient time prior to the start of ES to produce an effective baseline and avoided consideration of earlier data potentially subject to considerable noise from many environmental influences that are irrelevant to ES (including the 2001 Foot-and-Mouth outbreak). A second set of analyses used data from 2002-2008 only (i.e. three years of potential effect of land-use change as opposed to five), but with otherwise identical methods.

The analysis was restricted to species that rely on agricultural land for some part of their life-cycle (i.e. breed or winter on farmland) (e.g. Vickery *et al.* 2008) and to those that were previously found to respond significantly to ES stubble management (Baker *et al.* unpublished report to Natural England). Consequently, this analysis includes linnet, skylark and yellowhammer. For these species (farmland specialists), data from all transect sections were included in the analysis (not just ‘Farmland’) because birds recorded in the non-farmland parts of a survey square are, nevertheless, likely to have been influenced by the farmland nearby.

Environmental Stewardship data

Spatially referenced data containing the ES and Countryside Stewardship Scheme agreement details for each holding were supplied by Natural England (NE) and were used to assess the amount of stubble options per BBS square per year using the methods of Davey *et al.* (2010) (Table 1).

Data sampling

In order to generate a BBS data set in which the total area of ES stubble options were representative of potential GM cropping scenarios, samples were drawn randomly, with replacement, from the set of existing BBS squares for each region until a required area of stubble was reached that reflected a predicted regional area coverage of a given GM crop, while also maintaining the regional sample sizes found in the source data set. This was done by separately sampling squares that included ES stubble and those that did not. The regional random samples were then combined together for analysis.

Thus, in detail, the expected total area of a particular crop (i.e. maize, potatoes or sugar beet) falling within BBS squares for each region was calculated, assuming a similar spatial distribution to that of ES stubble management options. The expected amount of a crop within the BBS squares for a region was a function of the total region area, the total crop area and the number of BBS squares in the region, i.e. the percentage of a Region covered by BBS (Table 2):

% coverage = Number_Squares / Region_Area

The expected amount of habitat within BBS squares was a function of the total area of habitat (e.g. GM maize) (Table 3) and the % coverage of the randomly distributed BBS squares (also assuming random distribution of cropping):

$$E(\text{Area in all BBS Sq}) = \text{TotalCropArea(e.g. Maize)} \times \%\ \text{coverage}$$

The area expected within BBS squares with x % of habitat is calculated as (Tables 3, 4, 5, 6):

$$E(\text{Area in BBS Sq}) = (\text{TotalArea(e.g. Maize)} \times x\ \%) \times \%\ \text{coverage}$$

The data for each region were divided into Stubble > 0 (Stubble) and Stubble = 0 (NoStubble) and random samples of BBS squares were drawn from the ‘Stubble’ data with replacement until the total area of ES stubble option approximately equalled the total area expected to occur within all BBS squares (±10%) for that region. Random samples were then drawn, with replacement, from the ‘NoStubble’ data and added to the selected ‘Stubble’ data set until the combined sample size was equal to the actual number of BBS squares in the region. This needs to be done as a separate step to ensure that the sample size remains the same as in the original BBS dataset. This was repeated for all regions and scenarios, with 100 samples drawn for each region/scenario combination. The data were combined into a national data set for analysis, where total number of BSS squares was equal the total number from the original data set, but the Stubble Area was different, reflecting the area expected given a particular GM cropping scenario.

For several of the scenarios the samples reached the total number of squares in the region before the required area of cropping was achieved. Where this occurred for only a few replicate samples these samples were deleted and new samples were randomly generated until 100 samples with the required area and number of squares was reached. However, for some scenarios/crops (e.g. sugar beet at 60 and 80% in the East of England) these cropping areas were not possible to sample given the number of squares available and so these scenarios were omitted from the analysis.

Statistical analysis

We used a log-linear approach (Freeman & Newson 2008) that models the change in abundance between consecutive years (i.e. population growth rate) and can incorporate the effects of covariates, such as ES stubble options, on the population growth rate. This approach was chosen because it allowed us to maximise the use of the available data by including squares that were not surveyed in every year or where zero counts were recorded in some years (cf. an offset model of proportional change). The model follows Freeman & Newson (2008)

$$\ln(\mu_{i,t+1}) = R_t + \alpha P_{i,t} + \ln(\mu_{i,t}) \qquad (1)$$

where μ_i is the expected species count at site i at time t, R_t is the population growth rate between the period t to $t+1$, $P_{i,t}$ is the amount of a given ES management variable in square i at time t and α introduces the effect of ES management on population growth at a site (Douglas *et al.* 2010). An assumption of this model is that data for $P_{i,t}$ are available in all years up to the penultimate visit to the square, including missing years, which was true for the ES/CSS agreement data. The models were run using the GENMOD procedure in SAS (SAS 9.2, SAS Institute Inc. 2008), assuming a Poisson distributed error structure throughout and accounting for overdispersion using a scale parameter (PSCALE, the Pearson chi-square goodness-of-fit statistic of the full model divided by the degrees of freedom) in all models. The significance of effects of each land use scenarios on population growth rates, and consequently abundance, was assessed using likelihood ratio statistics.

The (log-transformed) number of transect sections was included as an offset in all models (Robinson *et al.* 2001) because some squares had <10 200m sections surveyed (e.g. non-farmland species and squares with inaccessible sections). Additionally, most ES options are targeted at either arable or pastoral farmland (e.g. stubble or grassland management) and the uptake of options is likely to be correlated with the overall percentage of arable or pastoral land in the landscape, which could influence bird population trends in its own right (e.g. Robinson *et al.* 2001). To control for this effect, the percentage of arable habitat per square was included in the model.

The data sets were analysed for all squares combined and also by land-use category (e.g. arable, pastoral and mixed).

RESULTS

All BBS squares

These results indicate that significant changes in the population growth rates of linnet and yellowhammer in response to changes in land-use (representative of potential change in cropping due to the introduction of GM crops) are likely to be detected for most cropping scenarios, although power (i.e. the proportion of significant results generated from randomly sampled datasets) increased as the postulated area of GM crop increased.

For linnet, when all squares are considered, the power to detect changes in population growth rates was high when the cropping patterns reflected those of potato and sugar beet, with significant positive associations between land use change and population growth rates occurring in >80% of the simulated data sets, and this applied to all the change scenarios tested (i.e. from 20 to 80% conversion) (Fig.1a). When simulating a maize cropping pattern and percentage conversion scenario, the power to detect changes in the population growth rate of linnet was lower than under the other cropping scenarios, but still showed a preponderance of significant results (Fig. 1a). The shape of the relationship between power and crop conversion scenario suggests that power would still remain high with lower areas of crops converted to GM (i.e. <20%) for potato and sugar beet cropping patterns, although for maize the power might fall to below 50% when the areas converted falls below 20%.

For skylark, the power to detect significant changes in population growth was low at or below 40% conversion of potato cropping patterns to GM and in any scenario for maize cropping patterns (Fig. 2a). However, the power to detect changes in population growth rate for skylark populations in response to changes in sugar beet cropping patterns was consistently high, exceeding 75% significant results when assuming both a 20% and a 40% conversion to GM (Fig. 2a). The shape of the relationship between power and crop conversion scenario suggests that the power to detect changes in population growth rate would still remain high with lower areas of sugar beet converted to GM (i.e. <20%).

For yellowhammer, the power to detect significant changes in population growth rates in response to land-use changes was highest for sugar beet and maize cropping patterns, with only the 20% conversion scenario for maize cropping patterns producing <75% significant associations. Only one scenario, 20% conversion of potato crop to GM, produced <50% significant associations with population growth rate, whilst, at the higher conversion scenarios (i.e. 40, 60 & 80%), significant results were in the majority (Fig. 3a). Given the shape of the relationship between power and the percentage of crops converted to GM, the power to detect changes in population growth rate with changes in land-use of <20% is likely to be low for both potato and maize cropping patterns; however, power is likely to remain high with sugar beet cropping pattern at <20% conversion to GM.

See Appendix Table A1 for a full summary of the results.

BBS squares by land-use type

The analysis was also run with the BBS squares divided by their land-use classification (i.e. arable, pastoral or mixed) and this revealed some interesting patterns that combine to produce those described above.

For linnet, when the patterns of cropping are representative of potato (Fig. 1b) or sugar beet (Fig. 1d) crops, the power to detect significant changes in population growth rate was consistently higher in arable-dominated squares (>75%) and lower in mixed squares (<35%; see Appendix Table A2 for details). Simulations of maize cropping patterns (Fig. 1c) indicate low power to detect changes in population growth rates for this species across all three land-use types, and also revealed some stochasticity in power across the different land-use scenarios (see Discussion). These results suggest that the power to detect changes in population growth rates with crop conversion scenarios of <20% is only likely to remain above 50% for potato and sugar beet cropping patterns in arable-dominated squares.

For skylark, the power to detect changes in population growth rates was generally low when the analysis considered land-use types separately. For the simulation of potato cropping patterns (Fig. 2b), the results for all but the highest land-use change scenarios (80% in arable and 60 & 80% in mixed) produced fewer than 50% significant associations. For maize (Fig. 2c) cropping patterns, the greatest power to detect changes in population growth rate was found in pastoral squares, although only the 80% land-use change scenario exceeded 75% significant population growth rates; tests in arable squares had the lowest power. With sugar beet cropping patterns, the power exceeded 50% in both arable and mixed for both scenarios (20 & 40% conversion), but was low in pastoral-dominated survey squares. The power to detect significant changes in population growth rates with crop conversion scenarios of <20% will probably be low for all crops in each land-use category for skylark.

For yellowhammer, the power to detect changes in population growth rate was greatest in arable squares for potato (Fig. 3b), with power exceeding 75% in the two highest conversion scenarios, and sugar beet (Fig. 3d) cropping patterns, here with power exceeding 75% in the two lowest conversion scenarios. For maize (Fig 3c) cropping patterns, power was similar between arable and pastoral squares, although it appeared to increase at a higher rate in arable, reaching 75% significant correlations at 40% conversion of maize crop to GM (as opposed to 60% in pastoral squares). The power to detect significant changes in population growth rate in response to land-use changes was very low for yellowhammer in mixed squares for all three crops. For crop conversion scenarios of <20% the power to detect significant changes in population growth rates is only likely to exceed 50% with sugar beet cropping patterns in arable-dominated squares for this species.

Analyses using data only from 2002-2008 (three years of potential effect of land management) produced no new or different patterns, simply lower power to detect change, so they are not reported in detail. While the simulations here provide proof-of-concept for the principle of using ESN data to inform about effects of changes in management, the specific variation in the time required for the effects considered here to reach detectability is not informative as to the time needed in other land-use contexts, such as real GM cropping.

DISCUSSION

With analyses of population growth rates based on geographically explicit data on land-use, BBS has the potential, with high statistical power, to detect effects of land-use change of the order of those that could conceivably occur given plausible uptake of post-market GM crops. However, it should be noted that the biological effect of GM crop uptake on any given bird species is not known: mechanisms of any effects are certain to be different to those by which ES stubble affect bird populations and there is no reason to suspect that the effect size will be the same. In addition, there is no reason to suppose that the species considered here will be affected, except that they are associated with open-field habitats. These species are included here because of their known relationships with ES stubble and only as proof of concept.

If the magnitude of the effect of converting existing crop varieties to GM crops were to be similar to that of converting existing stubbles into ES stubbles then these results suggest that BBS should be able to detect changes in abundance of some species/crop combinations even if the area of crop converted is at the lower end of the range tested here (e.g. linnet/potato and yellowhammer/maize). It is also possible that, for some species and for particular crops, changes in population growth rates could be detected with lower areas of crops converted to GM (e.g. for all species with sugar beet cropping patterns). This analysis suggests that, for some species, changes in population growth rates might be better detected in particular landscapes in isolation (e.g. skylark – maize in pastoral squares), rather than across all lowland farmland. However, for most combinations of species, crop types and scenarios, measuring population response across all survey squares will give the greatest chance of detecting population changes in response to changes in land-use.

All three crops considered showed a strong regional bias, with potato and sugar beet predominantly grown in the East of England and the Midlands and maize predominantly grown in the South (South West > South East) and Midlands. These regional differences in sampling probably explain differences in the power to detect significant changes in population growth rates for each crop/scenario between the different species, i.e. reflecting species regional distributions and regional response to ES stubble options. For example, maize is predominantly grown in the south (especially the South West) and consequently the simulated dataset for maize contain a large proportion of samples drawn from these regions. However, the abundance of linnets is lower in these regions when compared to the less sampled eastern regions (East of England and East Midlands) (Gibbons et al. 1991) and this might reduce to power to detect significant changes in growth rate with changes in maize cropping. Conversely, for the scenarios representing patterns of potato and sugar beet cropping, where the majority of the crop occurs in the Eastern and the East Midlands regions, a large percentage of the land area sampled overlaps with the areas of highest linnet abundance (Gibbons et al 1991) potentially increasing the power to detect any population changes. A similar effect could apply to skylark, which shares a broadly similar range to that of linnet. Note more generally, however, that these regional variations again relate to proof of concept rather than the power of the approach to detect the effects of specific crops on specific species. They show that sensitivity of a given species as an indicator of change will depend on its abundance and distribution relative to the distribution of the GM crop of interest in general, as well as its biological sensitivity to the ecological impact of the change in cropping.

We recommend that BBS data, analysed as for this report, can be used to monitor post-market effects of GM crops, acknowledging that the probability that effects will be detectable increases as the time lag since crop roll-out grows. Thus, general surveillance under the BBS forms the basis for a potential monitoring system, with specific data analysis in addition to standard reporting of trends and changes. However, this would be considerably more powerful given evidence predicting likely biological effects on particular species, which would allow those species to be selected for analysis, as we have done here for ES stubble. Some such evidence may be available in the literature, i.e. following knowledge of species' ecologies (for example where herbicide regimes are changed under GM management), but specific field trials are likely to be needed to identify where subtle effects of management with no obvious direct impact on a species' food sources or habitat might occur (e.g. for starch potato).

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Table 1.

ES option category	Land use	No. Squares	Mean	± 95% CI	Option codes
Stubble (km^2)	Arable	482	0.018	± 0.002	EF6, EG4, EG5, HF6, HG4, HG5, OF6, OG4, OG5, OHF6, OHG4, OS1,OS2, OS3
	Pastoral	214	0.009	± 0.003	
	Mixed	361	0.013	± 0.002	

Table 1. ES and CSS stubble options included in the ‘Stubble’ category for the analysis. The number of BBS squares containing these options, the mean area/length/number (±95% CI) of each option across all squares where these options occur and the specific ELS, OELS, HLS and OHLS (and CSS) options grouped under each category are shown for the original data, i.e. before any resampling. For details of the specific options related to each option code refer to the relevant scheme handbook (Natural England 2010a, 2010b, 2010c).

Table 2

Region	Land Area (ha)	No. BBS Sq.	% Coverage
North East	8573.13	92	0.0107
North West	14105.31	195	0.0138
Yorkshire and The Humber	15407.63	160	0.0104
East Midlands	15606.47	261	0.0167
West Midlands	12998.31	299	0.0230
East of England	19108.56	492	0.0257
South East (including London)	20641.88	583	0.0282
South West	23837.39	466	0.0195

Table 2. The area of land within each former Government Office Region (from www.statistics.gov.uk), the number of BBS squares per region and the percentage coverage of BSS squares for each region.

Table 3

Region	Potatoes area (ha)					Sugar beet area (ha)					Maize area (ha)				
	100%	80%	60%	40%	20%	100%	80%	60%	40%	20%	100%	80%	60%	40%	20%
North East	1457	1165.6	874.2	582.8	291.4	19	15.2	11.4	7.6	3.8	242	193.6	145.2	96.8	48.4
North West	7722	6177.6	4633.2	3088.8	1544.4	142	113.6	85.2	56.8	28.4	14267	11413.6	8560.2	5706.8	2853.4
Yorkshire & The Humber	16310	13048	9786	6524	3262	8372	6697.6	5023.2	3348.8	1674.4	5348	4278.4	3208.8	2139.2	1069.6
East Midlands	16225	12980	9735	6490	3245	26244	20995.2	15746.4	10497.6	5248.8	10516	8412.8	6309.6	4206.4	2103.2
West Midlands	15883	12706.4	9529.8	6353.2	3176.6	2719	2175.2	1631.4	1087.6	543.8	22057	17645.6	13234.2	8822.8	4411.4
Eastern	32300	25840	19380	12920	6460	80732	64585.6	48439.2	32292.8	16146.4	8240	6592	4944	3296	1648
South East (incl. London)	3709	2967.2	2225.4	1483.6	741.8	111	88.8	66.6	44.4	22.2	22356	17884.8	13413.6	8942.4	4471.2
South West	6333	5066.4	3799.8	2533.2	1266.6	155	124	93	62	31	62800	50240	37680	25120	12560
England	99939	79951.2	59963.4	39975.6	19987.8	118493	94794.4	71095.8	47397.2	23698.6	145827	116662	87496.2	58330.8	29165.4

Table 3. The area of potato, sugar beet and maize cropping in England (by region and nationally, taken from Defra June Survey results) for 2010 and the area broken down by percentage.

Crop	PercentArea	Area	Region
Maize	100	2.597	North_East
Maize	20	0.519	North_East
Maize	40	1.039	North_East
Maize	60	1.558	North_East
Maize	80	2.078	North_East
Maize	100	197.235	North_West
Maize	20	39.447	North_West
Maize	40	78.894	North_West
Maize	60	118.341	North_West
Maize	80	157.788	North_West
Maize	100	55.536	Yorkshire_and_The_Humber
Maize	20	11.107	Yorkshire_and_The_Humber
Maize	40	22.214	Yorkshire_and_The_Humber
Maize	60	33.322	Yorkshire_and_The_Humber
Maize	80	44.429	Yorkshire_and_The_Humber
Maize	100	175.868	East_Midlands
Maize	20	35.174	East_Midlands
Maize	40	70.347	East_Midlands
Maize	60	105.521	East_Midlands
Maize	80	140.694	East_Midlands
Maize	100	507.377	West_Midlands
Maize	20	101.475	West_Midlands
Maize	40	202.951	West_Midlands
Maize	60	304.426	West_Midlands
Maize	80	405.902	West_Midlands
Maize	100	212.160	East_of_England
Maize	20	42.432	East_of_England
Maize	40	84.864	East_of_England
Maize	60	127.296	East_of_England
Maize	80	169.728	East_of_England
Maize	100	631.413	South_East
Maize	20	126.283	South_East
Maize	40	252.565	South_East
Maize	60	378.848	South_East
Maize	80	505.130	South_East
Maize	100	1227.685	South_West
Maize	20	245.537	South_West
Maize	40	491.074	South_West
Maize	60	736.611	South_West
Maize	80	982.148	South_West

Table 4. The area of GM maize that would be expected to fall within the BBS squares by region assuming different scenarios of uptake (20%, 40%, 60%, 80%).

Crop	PercentArea	Area	Region
Potato	100	15.635	North_East
Potato	20	3.127	North_East
Potato	40	6.254	North_East
Potato	60	9.381	North_East
Potato	80	12.508	North_East
Potato	100	106.753	North_West
Potato	20	21.351	North_West
Potato	40	42.701	North_West
Potato	60	64.052	North_West
Potato	80	85.403	North_West
Potato	100	169.371	Yorkshire_and_The_Humber
Potato	20	33.874	Yorkshire_and_The_Humber
Potato	40	67.748	Yorkshire_and_The_Humber
Potato	60	101.622	Yorkshire_and_The_Humber
Potato	80	135.497	Yorkshire_and_The_Humber
Potato	100	271.344	East_Midlands
Potato	20	54.269	East_Midlands
Potato	40	108.538	East_Midlands
Potato	60	162.807	East_Midlands
Potato	80	217.075	East_Midlands
Potato	100	365.357	West_Midlands
Potato	20	73.071	West_Midlands
Potato	40	146.143	West_Midlands
Potato	60	219.214	West_Midlands
Potato	80	292.285	West_Midlands
Potato	100	831.648	East_of_England
Potato	20	166.330	East_of_England
Potato	40	332.659	East_of_England
Potato	60	498.989	East_of_England
Potato	80	665.319	East_of_England
Potato	100	104.755	South_East
Potato	20	20.951	South_East
Potato	40	41.902	South_East
Potato	60	62.853	South_East
Potato	80	83.804	South_East
Potato	100	123.805	South_West
Potato	20	24.761	South_West
Potato	40	49.522	South_West
Potato	60	74.283	South_West
Potato	80	99.044	South_West

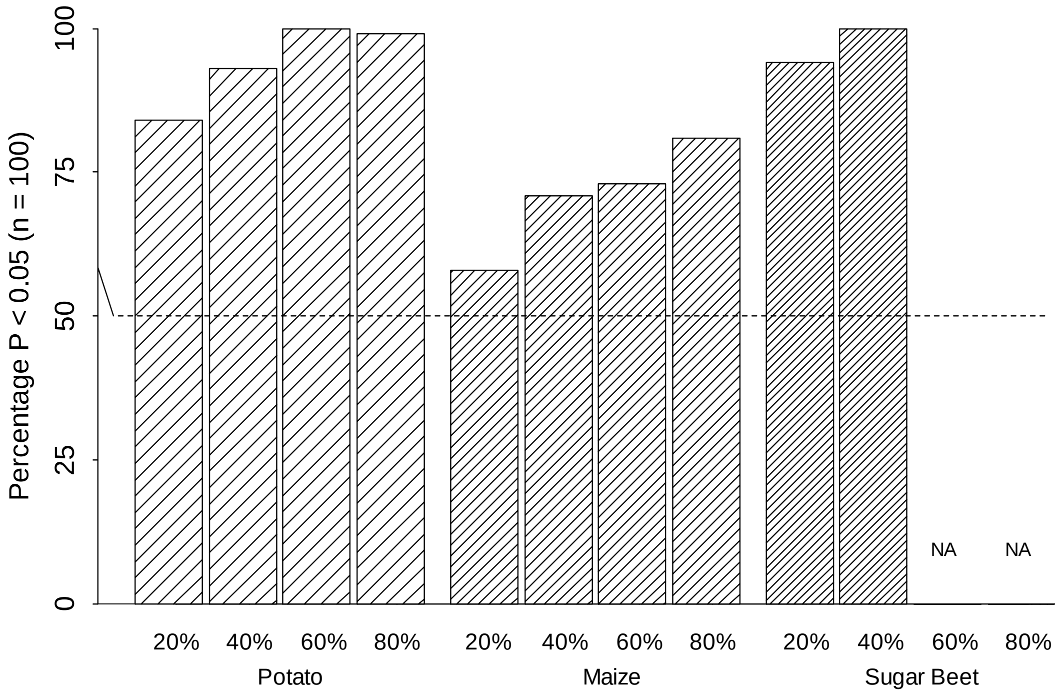
Table 5. The area of GM potatoes that would be expected to fall within the BBS squares by region assuming different scenarios of uptake (20%, 40%, 60%, 80%).

Crop	PercentArea	Area	Region
SugarBeet	100	0.204	North_East
SugarBeet	20	0.041	North_East
SugarBeet	40	0.082	North_East
SugarBeet	60	0.122	North_East
SugarBeet	80	0.163	North_East
SugarBeet	100	1.963	North_West
SugarBeet	20	0.393	North_West
SugarBeet	40	0.785	North_West
SugarBeet	60	1.178	North_West
SugarBeet	80	1.570	North_West
SugarBeet	100	86.939	Yorkshire_and_The_Humber
SugarBeet	20	17.388	Yorkshire_and_The_Humber
SugarBeet	40	34.775	Yorkshire_and_The_Humber
SugarBeet	60	52.163	Yorkshire_and_The_Humber
SugarBeet	80	69.551	Yorkshire_and_The_Humber
SugarBeet	100	438.900	East_Midlands
SugarBeet	20	87.780	East_Midlands
SugarBeet	40	175.560	East_Midlands
SugarBeet	60	263.340	East_Midlands
SugarBeet	80	351.120	East_Midlands
SugarBeet	100	62.545	West_Midlands
SugarBeet	20	12.509	West_Midlands
SugarBeet	40	25.018	West_Midlands
SugarBeet	60	37.527	West_Midlands
SugarBeet	80	50.036	West_Midlands
SugarBeet	100	2078.657	East_of_England
SugarBeet	20	415.731	East_of_England
SugarBeet	40	831.463	East_of_England
SugarBeet	60	1247.194	East_of_England
SugarBeet	80	1662.926	East_of_England
SugarBeet	100	3.135	South_East
SugarBeet	20	0.627	South_East
SugarBeet	40	1.254	South_East
SugarBeet	60	1.881	South_East
SugarBeet	80	2.508	South_East
SugarBeet	100	3.030	South_West
SugarBeet	20	0.606	South_West
SugarBeet	40	1.212	South_West
SugarBeet	60	1.818	South_West
SugarBeet	80	2.424	South_West

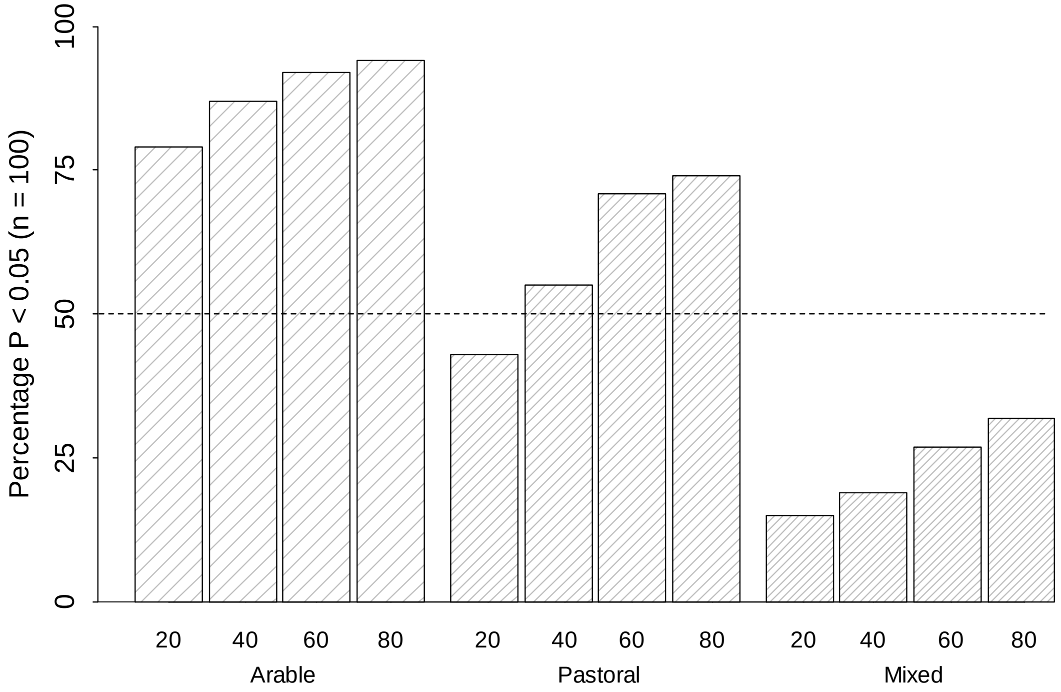
Table 6. The area of GM sugar beet that would be expected to fall within the BBS squares by region assuming different scenarios of uptake (20%, 40%, 60%, 80%).

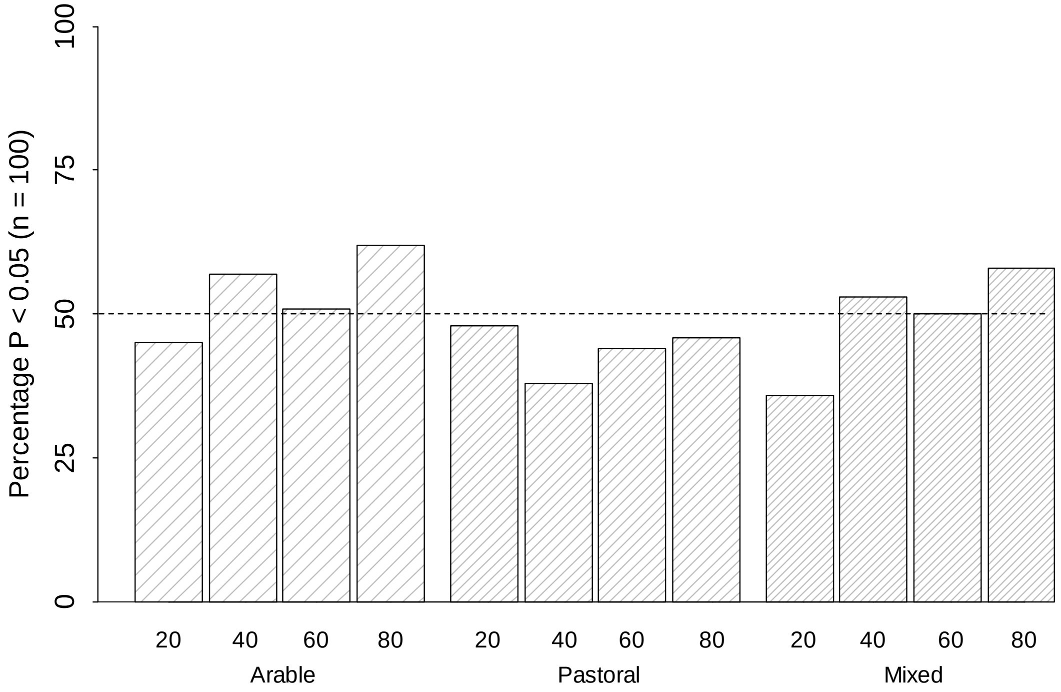
Figure 1

a) Linnet - All BSS squares (lowland England farmland)



b) Linnet - Potato cropping pattern by land-use




c) Linnet - Maize cropping pattern by land-use

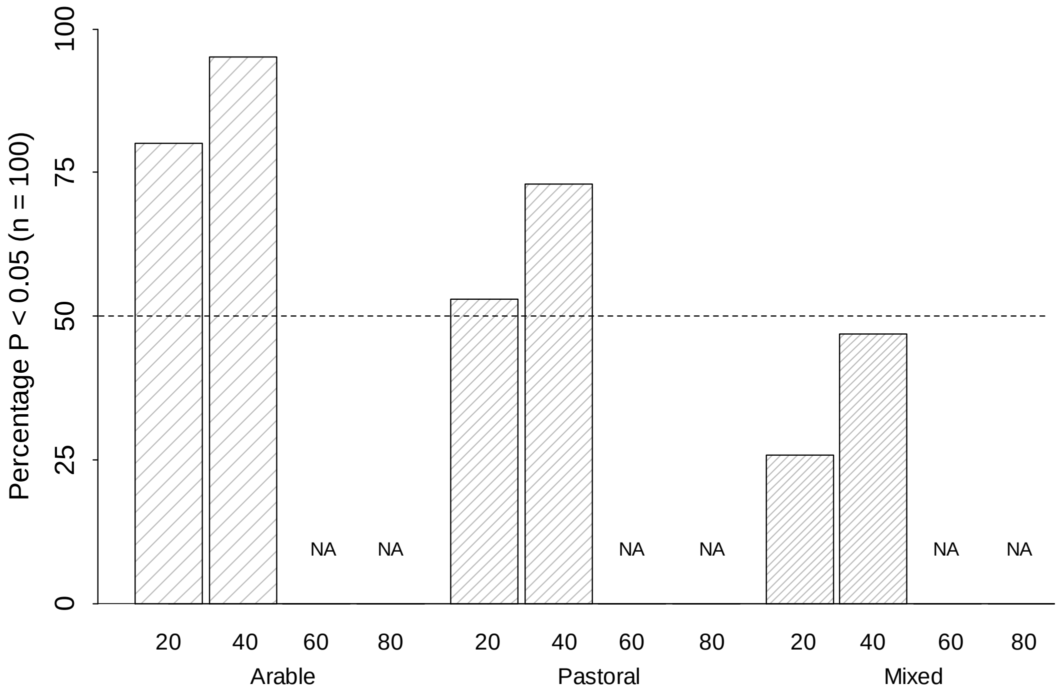
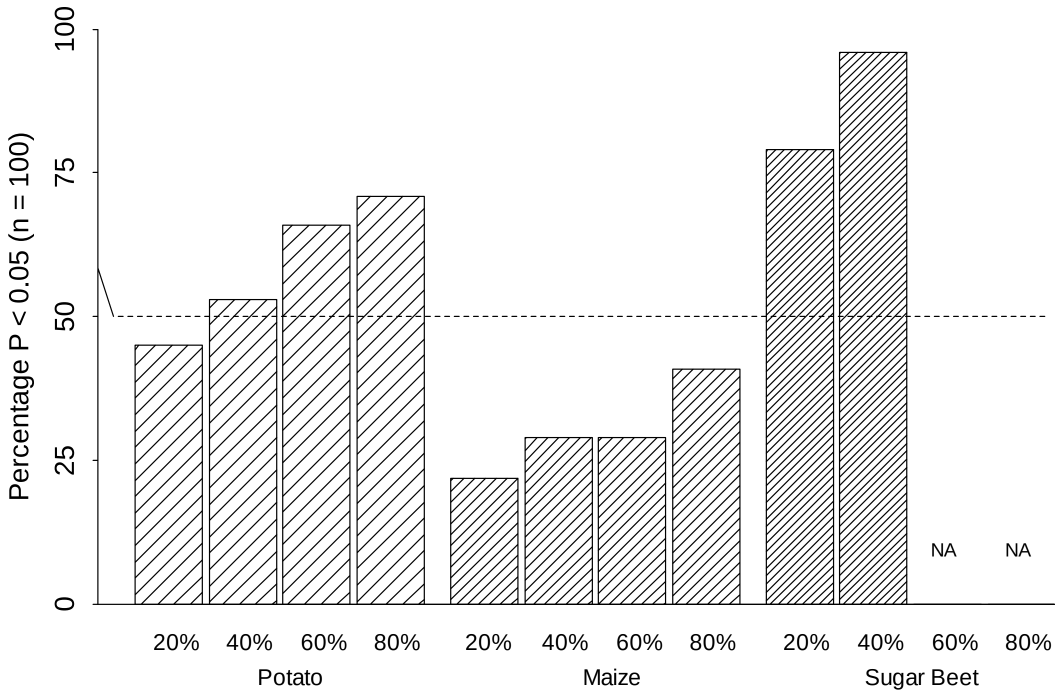
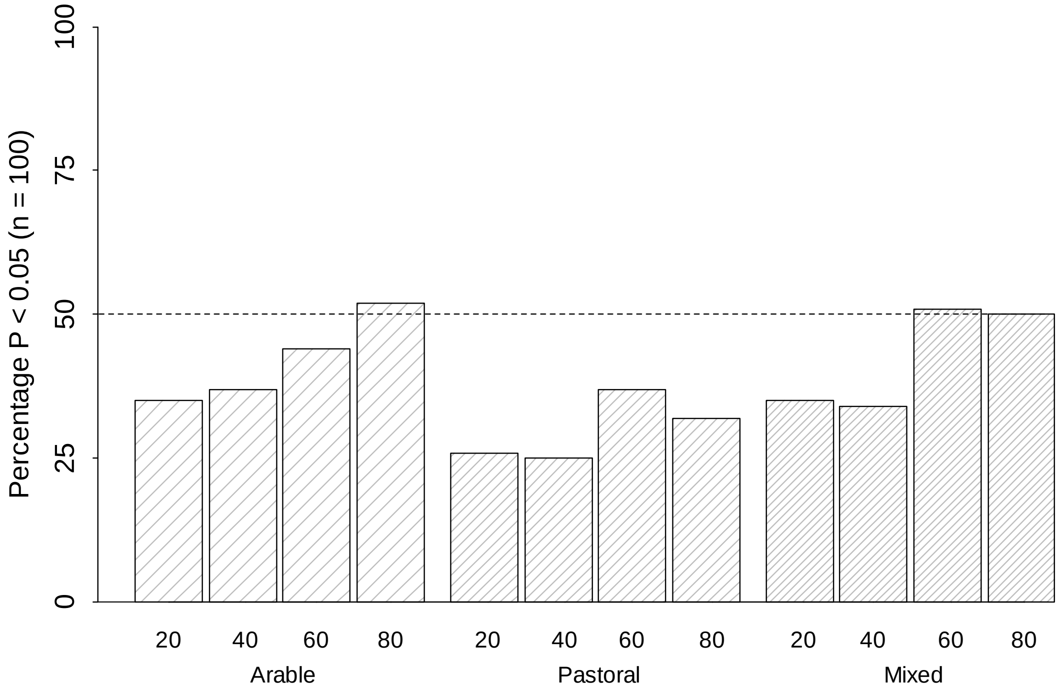
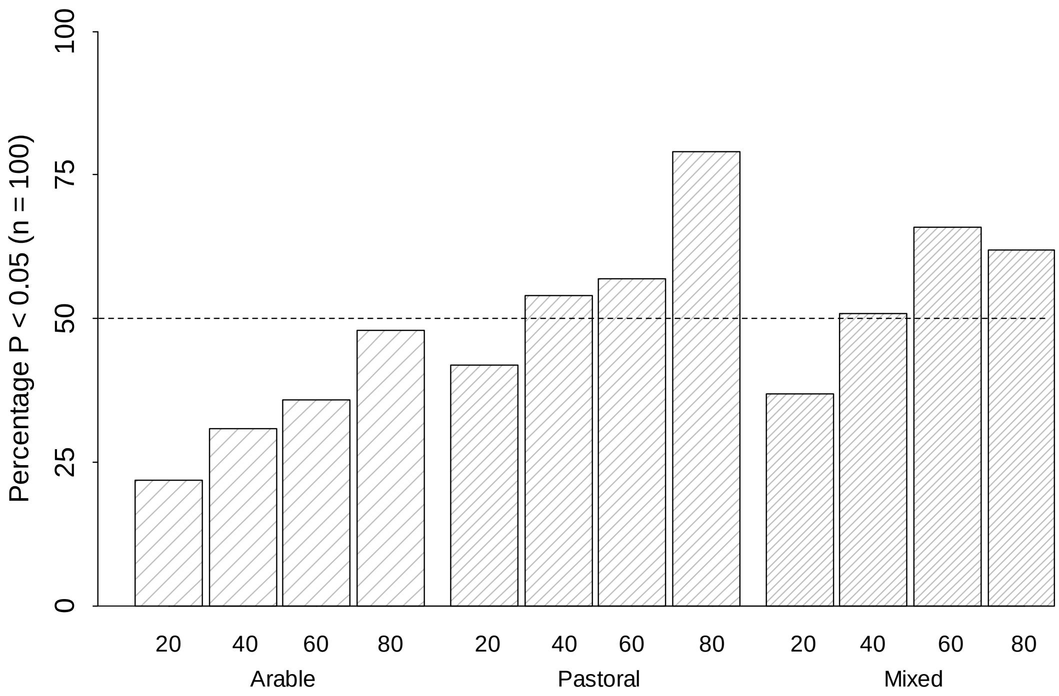

d) Linnet - Sugar beet cropping pattern by land-use

Figure 1. The percentage of significant ($P < 0.05$) correlations obtained from log linear regression models of BBS counts (linnet) and GM crop conversion scenario for three crops (potato, maize and sugar beet). Each bar on the graph represents the results of regression analysis on 100 simulated datasets. Graph a) shows the results for all BBS squares combined and for all three crops with the scenarios of 20, 40, 60 and 80% of crop converted to GM. Graphs b (potato), c (maize) and d (sugar beet) show the analysis broken down into land-use (arable, pastoral and mixed) with each figure showing the scenarios of 20, 40, 60 and 80% of crop converted to GM. ‘NA’ signifies that the datasets could not be generated due to the large area of cropping required to simulate the conversion scenario (greater than the maximum it was possible to simulate given the actual areas of stubble available).

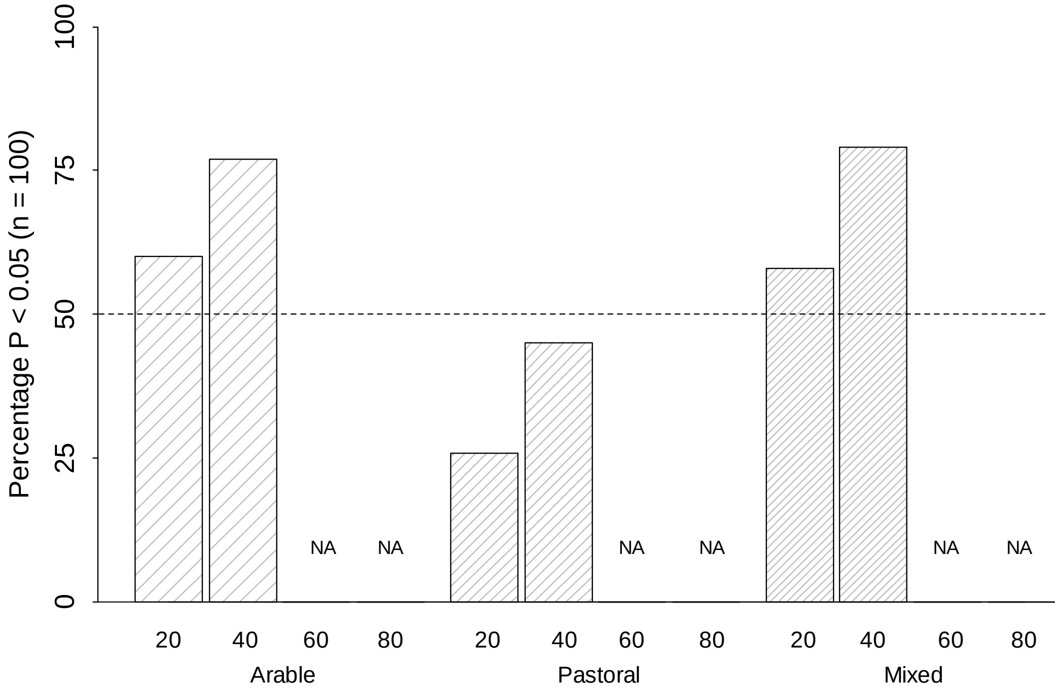
Figure 2


a) Skylark - All BSS squares (lowland England farmland)


b) Skylark - Potato cropping pattern by land-use



c) Skylark - Maize cropping pattern by land-use

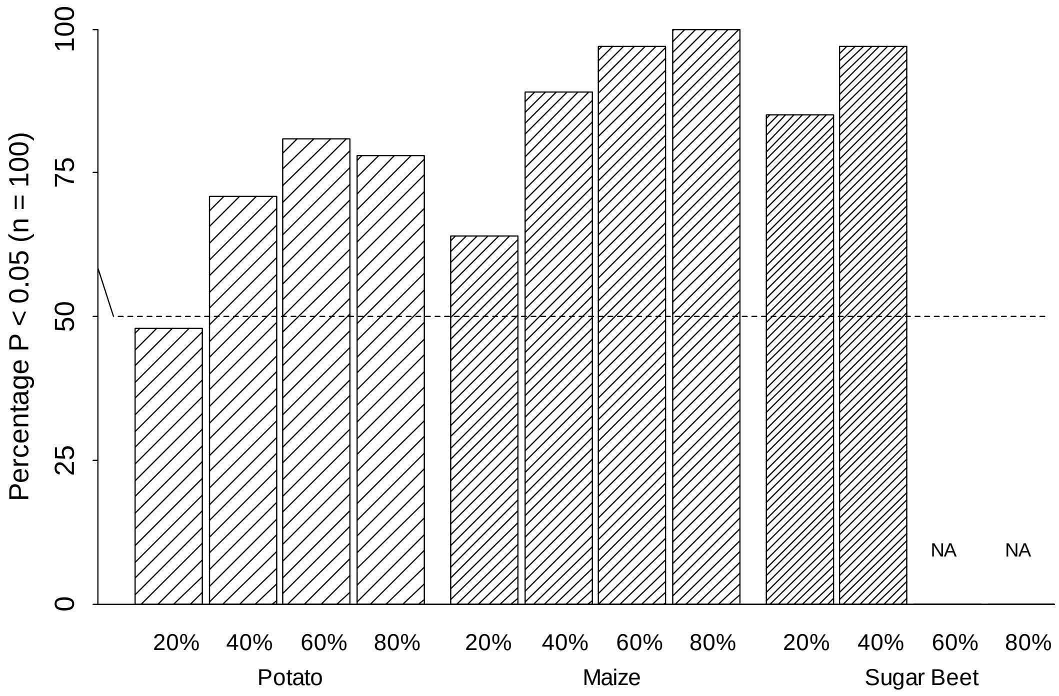


d) Skylark - Sugar beet cropping pattern by land-use

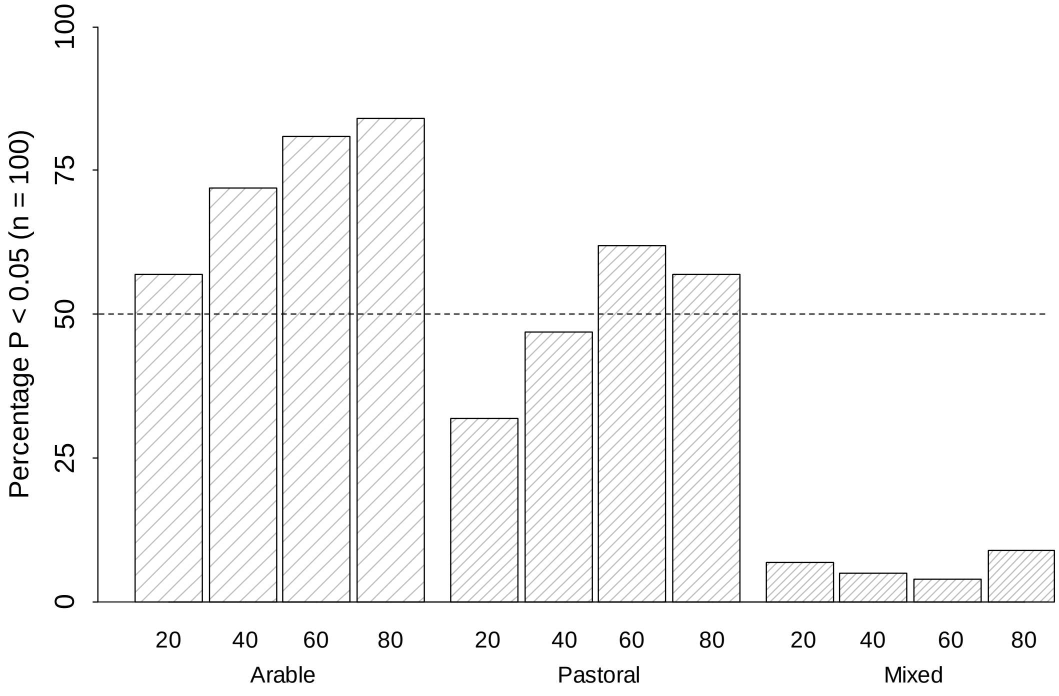
Figure 2. The percentage of significant ($P < 0.05$) correlations obtained from log linear regression models of BBS counts (skylark) and GM crop conversion scenario for three crops (potato, maize and sugar beet). Each bar on the graph represents the results of regression analysis on 100 simulated datasets. Graph a) shows the results for all BBS squares combined and for all three crops with the scenarios of 20, 40, 60 and 80% of crop converted to GM. Graphs b (potato), c (maize) and d (sugar beet) show the analysis broken down into land-use (arable, pastoral and mixed) with each figure showing the scenarios of 20, 40, 60 and 80% of crop converted to GM. 'NA' signifies that the datasets could not be generated due to the large area of cropping required to simulate the conversion scenario (greater than the maximum it was possible to simulate given the actual areas of stubble available).

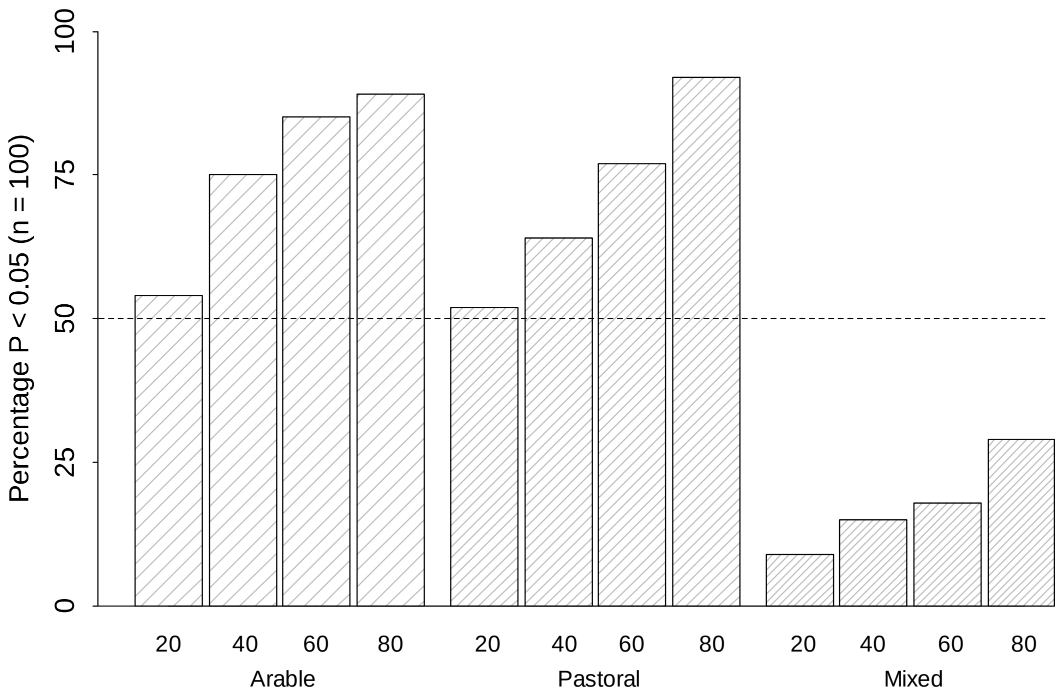
Figure 3

a) Yellowhammer - All BSS squares (lowland England farmland)

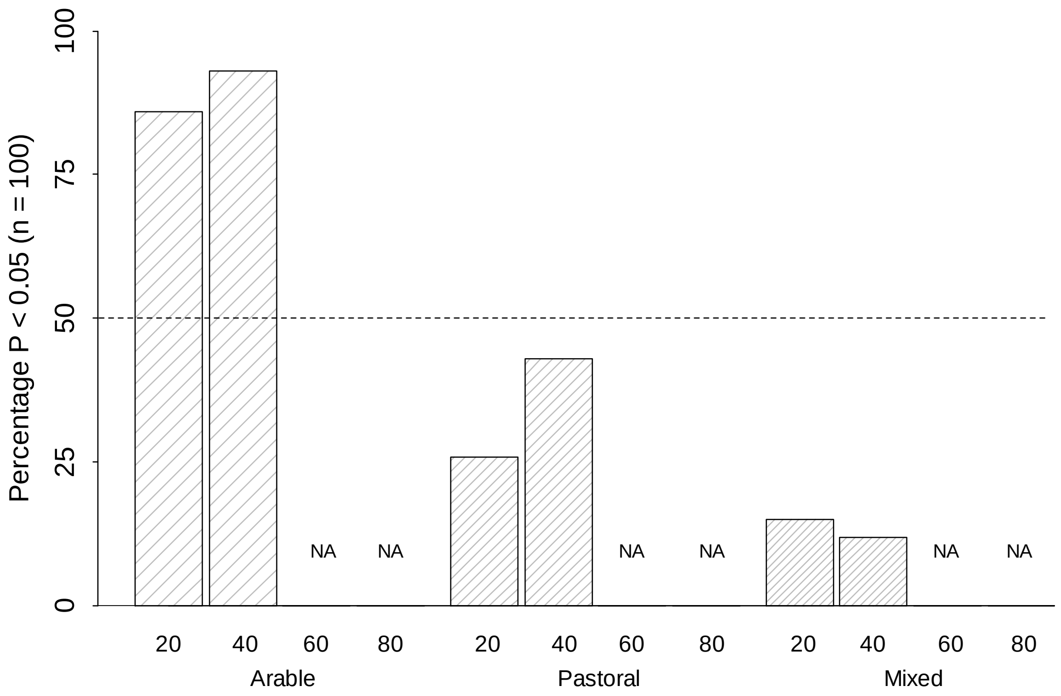


b) Yellowhammer - Potato cropping pattern by land-use





c) Yellowhammer - Maize cropping pattern by land-use



d) Yellowhammer - Sugar beet cropping pattern by land-use

Figure 3. The percentage of significant ($P < 0.05$) correlations obtained from log linear regression models of BBS counts (yellowhammer) and GM crop conversion scenario for three crops (potato, maize and sugar beet). Each bar on the graph represents the results of regression analysis on 100 simulated datasets. Graph a) shows the results for all BBS squares combined and for all three crops with the scenarios of 20, 40, 60 and 80% of crop converted to GM. Graphs b (potato), c (maize) and d (sugar beet) show the analysis broken down into land-use (arable, pastoral and mixed) with each figure showing the scenarios of 20, 40, 60 and 80% of crop converted to GM. ‘NA’ signifies that the datasets could not be generated due to the large area of cropping required to simulate the conversion scenario (greater than the maximum it was possible to simulate given the actual areas of stubble available).

Appendix

Table A1.

Crop	Scenario	Species	% P < 0.05	% P > 0.05	% estimates (+)	% estimates (-)	% P < 0.05 & Estimates (+)	% P < 0.05 & Estimates (-)
Maize	20	LI	58	42	91	9	54	4
Maize	40	LI	71	29	91	9	69	2
Maize	60	LI	73	27	93	7	73	0
Maize	80	LI	81	19	97	3	81	0
Maize	20	S	22	78	50	50	14	8
Maize	40	S	29	71	33	67	8	21
Maize	60	S	29	71	35	65	9	20
Maize	80	S	41	59	29	71	4	37
Maize	20	Y	64	36	99	1	64	0
Maize	40	Y	89	11	100	0	89	0
Maize	60	Y	97	3	100	0	97	0
Maize	80	Y	100	0	100	0	100	0
Potato	20	LI	84	16	98	2	84	0
Potato	40	LI	93	7	100	0	93	0
Potato	60	LI	100	0	100	0	100	0
Potato	80	LI	99	1	100	0	99	0
Potato	20	S	45	55	82	18	43	2
Potato	40	S	53	47	90	10	52	1
Potato	60	S	66	34	93	7	66	0
Potato	80	S	71	29	94	6	71	0
Potato	20	Y	48	52	90	10	48	0
Potato	40	Y	71	29	99	1	71	0
Potato	60	Y	81	19	100	0	81	0
Potato	80	Y	78	22	99	1	78	0
SugarBeet	20	LI	94	6	100	0	94	0
SugarBeet	40	LI	100	0	100	0	100	0
SugarBeet	60	LI	0	0	0	0	0	0
SugarBeet	80	LI	0	0	0	0	0	0
SugarBeet	20	S	79	21	100	0	79	0
SugarBeet	40	S	96	4	100	0	96	0
SugarBeet	60	S	0	0	0	0	0	0
SugarBeet	80	S	0	0	0	0	0	0
SugarBeet	20	Y	85	15	100	0	85	0
SugarBeet	40	Y	97	3	100	0	97	0
SugarBeet	60	Y	0	0	0	0	0	0
SugarBeet	80	Y	0	0	0	0	0	0

Table A1. Summary of the regression model results for each combination of crop, species and scenario, showing the percentage of $P < 0.05$ and $P > 0.05$ results, percentage of positive and negative parameter estimates and percentage of the latter that were significant at $P < 0.05$.

Table A2.

Crop	Scenario	Land-use	Species	% P < 0.05	% P > 0.05	% estimates (+)	% estimates (-)	% P < 0.05 & Estimates (+)	% P < 0.05 & Estimates (-)
Maize	20	Arable	LI	45	55	79	21	42	3
Maize	20	Mixed	LI	36	64	68	32	34	2
Maize	20	Pastoral	LI	48	52	30	70	21	27
Maize	20	Arable	S	22	78	42	58	6	16
Maize	20	Mixed	S	37	63	80	20	36	1
Maize	20	Pastoral	S	42	58	21	79	3	39
Maize	20	Arable	Y	54	46	98	2	54	0
Maize	20	Mixed	Y	9	91	70	30	9	0
Maize	20	Pastoral	Y	52	48	91	9	51	1
Maize	40	Arable	LI	57	43	87	13	55	2
Maize	40	Mixed	LI	53	47	72	28	48	5
Maize	40	Pastoral	LI	38	62	41	59	11	27
Maize	40	Arable	S	31	69	22	78	5	26
Maize	40	Mixed	S	51	49	85	15	50	1
Maize	40	Pastoral	S	54	46	13	87	0	54
Maize	40	Arable	Y	75	25	98	2	75	0
Maize	40	Mixed	Y	15	85	81	19	14	1
Maize	40	Pastoral	Y	64	36	96	4	63	1
Maize	60	Arable	LI	51	49	87	13	51	0
Maize	60	Mixed	LI	50	50	78	22	48	2
Maize	60	Pastoral	LI	44	56	47	53	15	29
Maize	60	Arable	S	36	64	20	80	2	34
Maize	60	Mixed	S	66	34	88	12	65	1
Maize	60	Pastoral	S	57	43	6	94	0	57
Maize	60	Arable	Y	85	15	99	1	85	0
Maize	60	Mixed	Y	18	82	92	8	18	0
Maize	60	Pastoral	Y	77	23	97	3	76	1
Maize	80	Arable	LI	62	38	93	7	62	0
Maize	80	Mixed	LI	58	42	83	17	58	0
Maize	80	Pastoral	LI	46	54	55	45	27	19
Maize	80	Arable	S	48	52	17	83	2	46
Maize	80	Mixed	S	62	38	94	6	62	0
Maize	80	Pastoral	S	79	21	0	100	0	79
Maize	80	Arable	Y	89	11	100	0	89	0
Maize	80	Mixed	Y	29	71	93	7	29	0
Maize	80	Pastoral	Y	92	8	99	1	92	0
Potato	20	Arable	LI	79	21	96	4	79	0
Potato	20	Mixed	LI	15	85	74	26	12	3
Potato	20	Pastoral	LI	43	57	43	57	33	10
Potato	20	Arable	S	35	65	66	34	32	3
Potato	20	Mixed	S	35	65	73	27	33	2
Potato	20	Pastoral	S	26	74	60	40	15	11
Potato	20	Arable	Y	57	43	92	8	57	0
Potato	20	Mixed	Y	7	93	49	51	4	3
Potato	20	Pastoral	Y	32	68	62	38	25	7
Potato	40	Arable	LI	87	13	100	0	87	0

Potato	40	Mixed	LI	19	81	66	34	19	0
Potato	40	Pastoral	LI	55	45	62	38	53	2
Potato	40	Arable	S	37	63	81	19	35	2
Potato	40	Mixed	S	34	66	82	18	33	1
Potato	40	Pastoral	S	25	75	61	39	16	9
Potato	40	Arable	Y	72	28	98	2	72	0
Potato	40	Mixed	Y	5	95	56	44	1	4
Potato	40	Pastoral	Y	47	53	78	22	38	9
Potato	60	Arable	LI	92	8	100	0	92	0
Potato	60	Mixed	LI	27	73	77	23	27	0
Potato	60	Pastoral	LI	71	29	81	19	69	2
Potato	60	Arable	S	44	56	82	18	44	0
Potato	60	Mixed	S	51	49	88	12	50	1
Potato	60	Pastoral	S	37	63	73	27	29	8
Potato	60	Arable	Y	81	19	100	0	81	0
Potato	60	Mixed	Y	4	96	48	52	1	3
Potato	60	Pastoral	Y	62	38	88	12	59	3
Potato	80	Arable	LI	94	6	100	0	94	0
Potato	80	Mixed	LI	32	68	86	14	31	1
Potato	80	Pastoral	LI	74	26	87	13	68	6
Potato	80	Arable	S	52	48	85	15	50	2
Potato	80	Mixed	S	50	50	92	8	50	0
Potato	80	Pastoral	S	32	68	77	23	26	6
Potato	80	Arable	Y	84	16	100	0	84	0
Potato	80	Mixed	Y	9	91	47	53	0	9
Potato	80	Pastoral	Y	57	43	94	6	55	2
SugarBeet	20	Arable	LI	80	20	99	1	80	0
SugarBeet	20	Mixed	LI	26	74	85	15	26	0
SugarBeet	20	Pastoral	LI	53	47	62	38	49	4
SugarBeet	20	Arable	S	60	40	95	5	59	1
SugarBeet	20	Mixed	S	58	42	91	9	58	0
SugarBeet	20	Pastoral	S	26	74	70	30	18	8
SugarBeet	20	Arable	Y	86	14	100	0	86	0
SugarBeet	20	Mixed	Y	15	85	67	33	14	1
SugarBeet	20	Pastoral	Y	26	74	59	41	20	6
SugarBeet	40	Arable	LI	95	5	100	0	95	0
SugarBeet	40	Mixed	LI	47	53	95	5	47	0
SugarBeet	40	Pastoral	LI	73	27	75	25	71	2
SugarBeet	40	Arable	S	77	23	99	1	77	0
SugarBeet	40	Mixed	S	79	21	97	3	79	0
SugarBeet	40	Pastoral	S	45	55	79	21	37	8
SugarBeet	40	Arable	Y	93	7	100	0	93	0
SugarBeet	40	Mixed	Y	12	88	72	28	11	1
SugarBeet	40	Pastoral	Y	43	57	80	20	34	9
SugarBeet	60	Arable	LI	0	0	0	0	0	0
SugarBeet	60	Mixed	LI	0	0	0	0	0	0
SugarBeet	60	Pastoral	LI	0	0	0	0	0	0
SugarBeet	60	Arable	S	0	0	0	0	0	0
SugarBeet	60	Mixed	S	0	0	0	0	0	0
SugarBeet	60	Pastoral	S	0	0	0	0	0	0

SugarBeet	60	Arable	Y	0	0	0	0	0	0
SugarBeet	60	Mixed	Y	0	0	0	0	0	0
SugarBeet	60	Pastoral	Y	0	0	0	0	0	0
SugarBeet	80	Arable	LI	0	0	0	0	0	0
SugarBeet	80	Mixed	LI	0	0	0	0	0	0
SugarBeet	80	Pastoral	LI	0	0	0	0	0	0
SugarBeet	80	Arable	S	0	0	0	0	0	0
SugarBeet	80	Mixed	S	0	0	0	0	0	0
SugarBeet	80	Pastoral	S	0	0	0	0	0	0
SugarBeet	80	Arable	Y	0	0	0	0	0	0
SugarBeet	80	Mixed	Y	0	0	0	0	0	0
SugarBeet	80	Pastoral	Y	0	0	0	0	0	0

Table A2. The summary of the regression model results for each combination of crop, species, conversion scenario and landscape type, showing the percentage of $P < 0.05$ and $P > 0.05$ results, percentage of positive and negative parameter estimates and percentage of the latter that were significant at $P < 0.05$.