Ecology of Farmland Birds: What is the effect of spraying stubble fields on winter farmland bird diversity and abundance?

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Abstract

Across Europe and around the world, farmland bird numbers are in decline. Agricultural intensification is one of the main drivers of this decline seen across many species. Stubble fields are an excellent habitat for many farmland birds, providing a food source, nesting grounds, and cover from predators. Spraying stubble fields with herbicide can have a negative impact on biodiversity within these habitats. In this study, the effects of spraying stubble fields with glyphosate-based herbicide on farmland bird (1) diversity and (2) abundance was investigated. An additional investigation into the relationship between (3) field size, species richness and abundance was also conducted. This study took place in Northeast Cork, in association with the BRIDE Project (Biodiversity Regeneration In a Dairying Environment). A total of 12 fields across six farms were investigated, six of these sprayed (S) and six not-sprayed (NS). In order to gather the data needed for this investigation, point counts were carried out in each field. A list of target species was used to provide a baseline for the effects of herbicide application, however, all species observed were recorded. Questions 1 and 2 clearly showed that spraying stubble fields had a negative impact on species richness and abundance. Higher levels of species richness (mean difference of 4.22 species) and abundance (mean difference 33.33 individuals) occurred on not-sprayed fields than sprayed fields. For question 3 the results showed four positive correlations between field size, richness and abundance. Only one of these correlations proved statistically significant (species richness on not-sprayed fields). These results support the conclusions of previous research, in that spraying stubble fields with herbicide greatly reduces farmland bird diversity and abundance. (WC 272)

Introduction

As it accounts for over two thirds of the country's total land area, farmland plays a major role in the upkeep of biodiversity in Ireland. Hedgerows, fields, and treelines are some of the habitats provided by farmland for a wide range of species, including birds. Ireland covers a total area of 69,798km^2. Approximately 71% of this land is agricultural, and tillage farms encompass 3,500km^2 (9%) of the total agricultural land in Ireland (Teagasc, 2016). Proper management of this land is essential for the stability of biodiversity and protection of many species that are under threat. Unfortunately, farmland bird numbers across Europe and around the world are declining. Birds are good indicators of biodiversity levels of farmland, and their decline is of significant impact to the scientific community (Gregory *et al*., 2000). Direct habitat loss, habitat fragmentation, intensification of agriculture and reduced landscape quality are all contributing factors to these declining numbers in Western Europe (Tryjanowksi *et al*., 2011). The Countryside Bird Survey (1998-2016) shows that 26% of Ireland's common bird species are in decline. Yellowhammer, *Emberiza citrinella*, one of two of Ireland's remaining species of bunting, is shown to be stable. However, the Countryside Bird Survey only began in 1998, and yellowhammer populations crashed prior to this year, with the species now mainly found in the east and southeast of the country.

One factor thought to effect biodiversity and farmland bird populations is the spraying of stubble fields with herbicides such as 2,4-dichlorophenoxy acetic acid (2,4-D), 2-methyl-4-chlorophenoxy acetic acid (MCPA) and glyphosate. Glyphosate, the herbicide that is used on farms in this study, is an herbicide that targets 5-enolpyruvyl-3-shikimate phosphate synthase (EPSPS), an enzyme produced by plants and microorganisms. Once applied, glyphosate moves towards the carbon sinks of the plant and attacks meristematic tissues. Glyphosate is also harmful to some plant pathogens and is used to stop the spread of disease among genetically modified, glyphosate-resistant crops (GRCs) (Duke, 2017). When sprayed on stubble fields, herbicide kills weeds such as groundsel, thistle, and meadow grass, along with many other species that provide seed food for farmland birds. Herbicide use effects species diversity in the area where it is applied, if not beyond these limits if uncareful or imprecise application occurs (McLaughlin & Mineau, 1995). Newton (2004) stated that the use of herbicide for controlling weed growth, along with the early ploughing of winter stubble fields is one of the main causes for the decline in farmland bird populations in recent times.

Many studies have investigated the effects of herbicides, pesticides and fertilisers on farmland bird species. A study into the effect of pesticide and herbicide doses on birds in France showed that specialist feeding bird communities suffered more than generalist feeding communities, because the generalist feeding species did not rely on farmland as a main food source, and could forage in other habitats such as woodland (Chiron *et al.,* 2014). It is known that farmland specialists suffer to a greater extent than generalist species (Siriwardena *et al.,* 1998). Seed production of weed species is directly affected by herbicide therefore leading to a decline in food supply for granivorous species (Heard *et al.,* 2003). A study in the UK showed that population decline of turtle dove, *Steptopelia turtu,* and linnet, *Carduelis cannnabina* overlapped with the decline of weed species that were main sources of seeds for chicks, which resulted in linnet resorting to the seeds of dandelions and oilseed rape, which were unripe at that time of year (Moorcroft *et al.*, 2006).

Winter stubble fields are essential for biodiversity and sustaining the balance of food webs associated with farmland habitats, as they provide an important source of food not just for granivorous bird species, but also for invertebrates and smaller mammals (Evans *et al.*, 2011). Studies show that granivorous birds display a strong preference for stubble fields, often to the point where birds will exclude other field types (Wilson *et al.,* 1996). It can be assumed that spraying stubble fields with glyphosate can result in deterioration of food webs, reducing the amount of granivorous, insectivorous and ultimately carnivorous species found in these habitats. Across Western Europe, there has been a major change in sowing times of crops in the last 50 years. Ploughing and replanting seed in autumn has resulted in stubble fields that were once available to birds throughout winter becoming unavailable during a period where food sources are already low (McKenzie *et al.,* 2011). Foraging for farmland birds comes with a trade-off. Birds are at risk of predation when foraging for seed, and are therefore likely to select fields where the risk of being caught by a predator is low (Butler *et al.,* 2005). These foraging areas with a low risk of predation would be fields with relatively high stubble and an abundance of natural vegetation cover, as a result of not spraying. According to studies conducted into the predatory behaviour of birds of prey, the sparrowhawk, *Accipiter nisus,* was shown to hunt mainly according to vulnerability of their prey (Quinn & Cresswell, 2004). Studies on the kestrel, *Falco tinnunculus*, showed more predatory success over areas with less dense vegetation cover (Toland, 1987). Lack of natural vegetation cover due to spraying has been influential on the already declining bird populations due to reduced food supply for energy gain, and is doubled by the possibility of over-predation as a result of lack of cover.

It is widely thought that agri-environment schemes (AES) are the most obvious, economical solutions for managing the application of herbicides to stubble fields, thus halting or mitigating declines in bird populations (Gillings *et al.,* 2005). First introduced by the European Union in 1985 (EU regulation 797/85), AES are one of the main sources of biodiversity and wildlife conservation, while also being the highest in terms of conservation expenses (Batáry *et al.,* 2015). Intensification of agriculture is usually thought to be a major driver of biodiversity loss around the world in terrestrial habitats, however in Europe it is also considered to be a major solution to many of the problems it has caused (Foley *et al.,* 2011). Species richness has been enhanced in AES that focus mainly on areas not directly farmed, such as field margins and hedgerows, rather than areas that are directly farmed, such as crop fields and grassland (Batáry *et al.*, 2015). In more recent AES, focus is on ecosystem services such as pollination (Ekroos *et al.*, 2014). Kleijn & Sutherland (2003) conducted a study into the effectiveness of AES, and stated that trying to collect data from schemes across all countries involved can give unclear and often negative results. Therefore, it was suggested that ecological evaluations should become part of each individual AES, for a more accurate representation of their effectiveness on biodiversity. This suggestion was supported by the fact that positive effects of AES are closely tied to the landscape structure and complexity, which can vary from country to country (Batáry *et al.,* 2015). One such AES is the BRIDE Project, in Northeast Cork. The BRIDE Project is funded by the EU and also the Department of Agriculture, Food, and the Marine. Farmers that take part in the project are asked to implement various measures to improve the range of habitats in the area. Using a scoring system, farmers are rewarded using a results-based payment scheme (BRIDE Project, 2021).

This study aims to investigate the effect of spraying winter stubble fields with glyphosate herbicide on farmland bird diversity (species richness) and abundance. Donal Sheehan, BRIDE Project manager, provided six farmers, four involved in the BRIDE Project and two not involved. 12 fields were identified between all farms, six fields sprayed with herbicide and six fields not-sprayed. All species observed were recorded. A list of 13 target species was compiled to provide a baseline for the effects of sprayed versus not-sprayed fields, and also to investigate the effectiveness of a target species list. An analysis of target species will be followed by an analysis of all species. The main questions of interest in this investigation are: 1. Does spraying winter stubble with herbicide effect farmland bird diversity? 2. Does spraying winter stubble with herbicide effect farmland bird abundance? 3. For both sprayed and not-sprayed stubble fields, is there a correlation between field size and species abundance and richness? For questions 1 and 2, it is predicted that the sprayed winter stubble fields will present negative effects on diversity and abundance of farmland birds. For question 3, a positive correlation between field size and species richness and abundance is expected to be found. (WC 1,418)

Methods

Study site

The field research was carried out across nine days, ranging from the 4th of November 2020 to the 3rd of December 2020. The study took place on arable land, located within the River Bride catchment in Northeast Cork. 12 fields containing winter stubble were required, six of these fields sprayed with glyphosate, and six fields not sprayed. Donal Sheehan (BRIDE Project manager) provided names and locations of six farmers who owned fields meeting these requirements. These farms were numbered 1-6. Farms 1,2,4 and 6 were participants of the BRIDE Project, farms 3 and 5 were not. The fields to be studied were visited and identified on the 22nd of October 2020, after arrangements were made to meet each farmer. Sprayed and not-sprayed fields were then numbered 1-6 each, for example S1 and NS1. Farm 1 contained three fields (NS1, NS2, S1), farm 2 contained one field (NS3), farm 3 contained two fields (S2, S3), farm 4 contained three fields (S4, S5, S6), farm 5 contained one field (NS4) and farm 6 contained two fields (NS5, NS6). To lower the chances of double counting where possible, fields on the same farm were preferably chosen if they were not adjacent to each other. Adjacent fields occurred and could not be avoided in two situations, fields NS1 and NS2, and S4 and S5. Using Google Earth Pro, a map was created of all the fields.

Figure 1. Map of study site, including sprayed (white) and not-sprayed (green) fields, and the river Bride running from east to west.

This allowed the coordinates of each field to be recorded, along with the area of each field which was used for establishing point counts and also to test for a correlation between field size and species richness and abundance. The coordinates can be seen in Table 1. It was decided that three counts of each field would provide enough data for the study.

Target species

Using the BRIDE Project target species list and BirdWatch Ireland's Birds of Conservation Concern, a list of target species was compiled for the project. The list includes a combination of red listed species, amber listed species and common species not of conservation concern, and will provide a baseline for the effects of sprayed versus not-sprayed fields. The target species are yellowhammer *Emberiza citrinella,* skylark *Alauda arvensis*, stonechat *Saxicola rubicola*, robin *Erithacus rubecula,* greenfinch *Chloris chloris*, goldfinch *Carduelis carduelis,* linnet *Linaria cannabina*, chaffinch *Fringilla coelebs*, blackbird *Turdus merula*, song thrush *Turdus philomelos*, buzzard *Buteo buteo*, fieldfare *Turdus pilaris* and redwing *Turdus iliacus*.

Point counts

The method of data collection in this study was the use of point counts. Point counts were selected over transects as to reduce the amount of walking done in each field, thus reducing possible disturbance to birds foraging within the fields. Point counts are a widely used and effective way of collecting data in relation to various aspects of avian research, such as habitat studies, diversity estimation and abundance patterns (Simons *et al.*, 2007). Using Google Earth Pro, the area of each field was recorded. Once the area of each field was noted, the method for carrying out the point counts had to be established. The method of keeping the radius of the point counts constant and altering number of point counts per field was chosen. A radius of 60 metres was set for each point count and point count duration was set at eight minutes.

Google Earth Pro was used to map 60 metre radius point counts in each field. Mapping the plots in advance allowed for the preparation of cardinal points for individual count plots. The minimum number of point counts conducted per field was one, for smaller fields, and the maximum was seven for the largest field. Upon arrival at each field, the centre of each point count plot was marked using a one metre wooden pole (for fields containing more than one point count plot). The point counts were then carried out in succession. An eight-minute timer was set. Species were only identified by sight, not sound (as this allowed for too much misidentification). Celestron Up-close G2 10x-30x 50mm Zoom Binoculars were used. Species were recorded using recording sheets. These recording sheets contained columns of target species and also a column marked 'other', and rows that indicated number of visits. As species were observed they were recorded using tally marks. All species not on the target list were recorded in the 'other' column, and the species type was also recorded. To reduce bias, each point count of eight minutes was divided into four two-minute sub-counts. North was observed for two minutes, then east, followed by west, and finally south. Upon completion of each point count, the next count location was assumed and conducted. This was repeated until all counts in a given field were complete.

Table 1. Field type, coordinates, area (m^2), number of point counts per field and dates of each visit (ordered from first visit to last visit).

Field	Field Type	Latitude	Longitude	Area m^2	No. of point counts	Dates of Visits (1^{st}, 2^{nd}, 3^{rd})
S1	Sprayed	52.082440°	-8.214917°	44,854	3	4/11/2020 23/11/2020 30/11/2020
S2	Sprayed	52.138050°	-8.241607°	40,586	2	18/11/2020 26/11/2020 3/12/2020
S3	Sprayed	52.124500°	-8.156400°	77,357	4	18/11/2020 26/11/2020 3/12/2020
S4	Sprayed	52.104667°	-8.151324°	58,244	3	17/11/2020 25/11/2020 1/12/2020
S5	Sprayed	52.107248°	-8.150562°	34,368	2	17/11/2020 25/11/2020 1/12/2020
S6	Sprayed	52.102600°	-8.155700°	34,667	2	17/11/2020 25/11/2020 1/12/2020
NS1	Not-sprayed	52.078400°	-8.210800°	132,371	7	4/11/2020 23/11/2020 30/11/2020
NS2	Not-sprayed	52.078914°	-8.205268°	26,026	1	4/11/2020 23/11/2020 30/11/2020
NS3	Not-sprayed	52.089559°	-8.256907°	98,519	6	4/11/2020 23/11/2020 30/11/2020
NS4	Not-sprayed	52.101000°	-8.128800°	39,389	2	17/11/2020 25/11/2020 1/12/2020
NS5	Not-sprayed	52.069435°	-8.021337°	103,156	6	18/11/2020 26/11/2020 3/12/2020
NS6	Not-sprayed	52.071000°	-8.025780°	59,587	3	18/11/2020 26/11/2020 3/12/2020

Analysis

An independent samples *t*-test (two-tailed) assuming equal variances with a critical *P*-value of 0.05 was used to analyse the effects of spraying stubble fields with herbicide on the species richness of the target species. This analysis was then followed by another independent samples *t*-test with a critical *P*-value of 0.05 to analyse the effects of spraying stubble fields with herbicide on species richness across all species recorded. Similarly, an independent samples *t*-test (two-tailed) assuming equal variances was used to analyse the effects of spraying winter stubble fields with herbicide on species abundance for target species, and across all species. This test also had a critical *P*-value of 0.05. These tests were conducted on target species as an indicator of the effects on the larger scale, and also to investigate if the use of a target species list is effective. As data was normally distributed, four Pearson's Correlation Coefficient tests (one-tailed) were conducted to establish if there was an effect of field size on species richness and abundance on both sprayed and not-sprayed fields. Each test had a critical *P*-value of 0.05. The tests carried out are as follows: field size and abundance on sprayed fields, field size and richness on sprayed fields, field size and abundance on not-sprayed fields, and field size and richness on not-sprayed fields. (WC 1,171)

Results

The results of the independent samples *t*-tests (two-tailed) and Pearson's Correlation Coefficient are presented below.

Species richness

For the 13 target species, the mean total species richness for not-sprayed fields was higher than the mean for sprayed fields (Table 2, Fig. 2; t = -3.65, df = 34, P = 0.001). There was a statistically significant difference between the means of not-sprayed and sprayed fields. Mean species richness for target species on not-sprayed fields was 6.89, with a range of 4-9 species. Mean species richness for target species on sprayed fields was 5.17, with a range of 3-8 species. For all species recorded, the mean total species richness for not-sprayed fields was higher than that of sprayed fields (Table 2, Fig. 2, t = -5.23, df = 34, P < 0.001). There was a statistically significant difference in species richness between not-sprayed fields and sprayed fields. The mean species richness for not-sprayed fields was 12.22, and 8.00 for sprayed fields (Fig. 2). The results of the tests for both target species and all species state that herbicide application has a negative effect on the species richness of farmland birds. For not-sprayed fields, 56.38% of species found were target species. For sprayed fields, 64.63% of species found were target species.

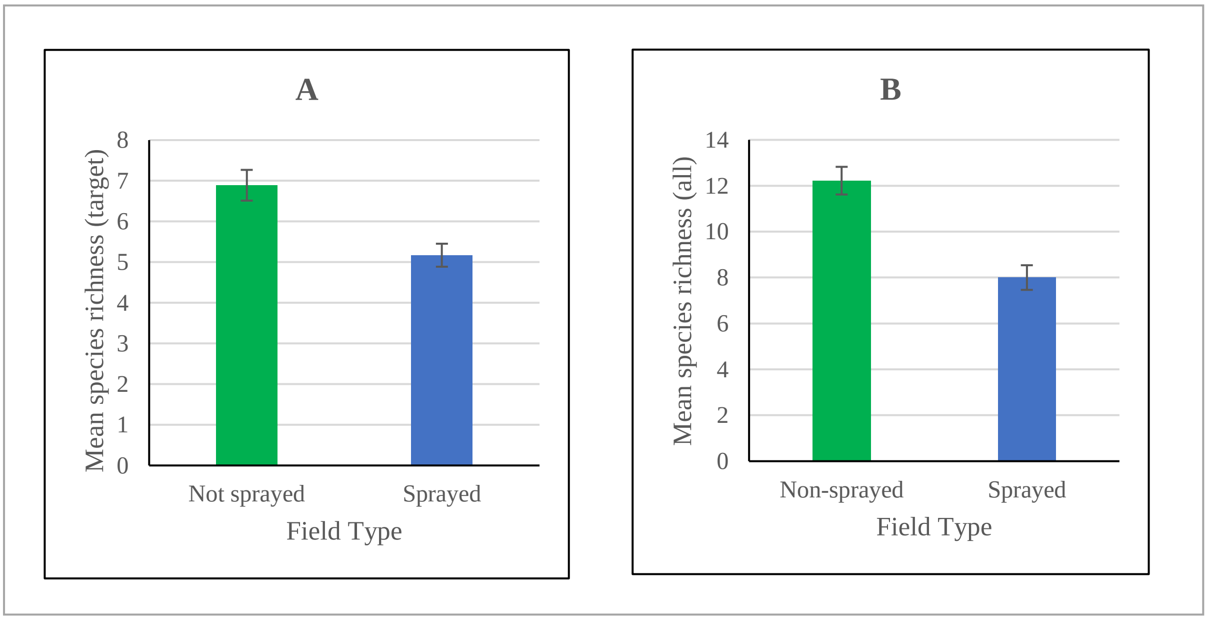

Figure 2. Mean species richness for target species (A) and all species (B) for not-sprayed vs. sprayed fields. Field type is shown on the X-axis, mean richness is shown on the Y-axis. Error bars represent standard error.

Table 2. Values obtained from independent samples *t*-tests on target species and all species, for species richness. Shown are *t*-value, degrees of freedom (*df*) and *P*-value.

	***t*-value**	***df***	***P*-value**
Target species	-3.65	34	0.001
All species	-5.23	34	0.000

Species abundance

Not-sprayed fields showed a higher mean abundance of individuals per field than sprayed fields for the target species (Table 3, Fig. 3; t = -3.39, df = 34, P = 0.002). A statistically significant difference existed between the means of not-sprayed fields and sprayed fields. Mean abundance for target species in not-sprayed fields was 59.28 individuals. Mean abundance for target species in sprayed fields was 35.44 individuals. For all species recorded, the mean abundance of individuals in not-sprayed fields was greater than the abundance of individuals in sprayed fields (Table 3, Fig. 3; t = -3.77, df = 34, P = 0.001). The difference that existed between the means of not-sprayed and sprayed fields was statistically significant. The mean abundance of individuals in not-sprayed fields was 83.44, and the mean abundance of individuals in sprayed fields was 50.11.

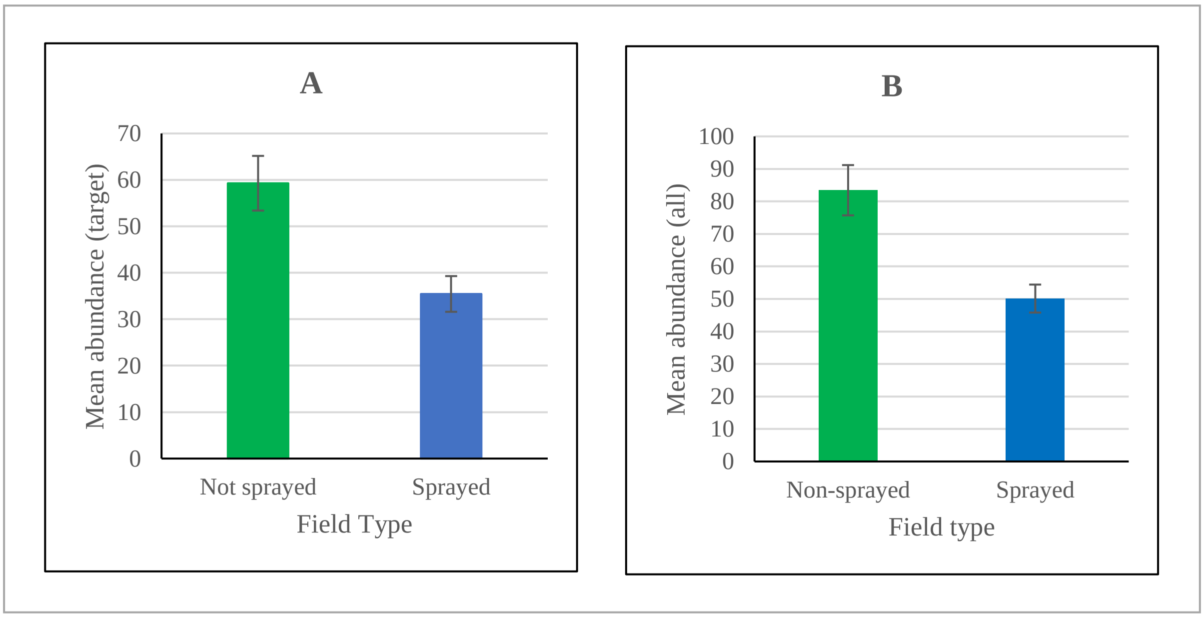

Figure 3. Mean species abundance for target species (A) and all species (B) of not-sprayed vs. sprayed fields. Field type is shown on the X-axis, mean abundance is shown on the Y-axis. Error bars represent standard error.

Table 3. Values obtained from independent samples t-tests on target species and all species, for species richness. Shown are *t*-value, degrees of freedom (*df*) and *P*-value.

	***t*-value**	***df***	***P*-value**
Target species	-3.389	34	0.002
All species	-3.767	34	0.001

Table 4 gives the full list of the 30 species recorded across all fields, along with the mean abundance of each species per field type.

Table 4. Mean abundance of each species recorded per field type for not-sprayed and sprayed fields.

Species	**Mean abundance across NS fields**	**Mean abundance across S fields**
Greenfinch *Chloris chloris*	3.4	1.2
Linnet *Linaria cannabina*	1.5	0.3
Goldfinch *Carduelis carduelis*	6.9	3.6
Chaffinch *Fringilla coelebs*	13.6	10.0
Robin *Erithacus rubecula*	2.9	3.4
Stonechat *Saxicola rubicola*	0.4	0.1
Yellowhammer *Emberiza citrinella*	0.8	0.2
Blackbird *Turdus merula*	3.2	2.6
Redwing *Turdus iliacus*	1.7	2.6
Song thrush *Turdus philomelos*	3.8	1.2
Fieldfare *Turdus pilaris*	0.6	0.4
Skylark *Alauda arvensis*	20.2	10.0
Buzzard *Buteo buteo*	0.1	0.1
Grey wagtail *Motacilla cinerea*	0.3	0.2
Wren *Troglodytes troglodytes*	1.4	0.5
Rook *Corvus frugilegus*	10.5	8.1
Starling *Sturnus vulgaris*	2.0	0.2
Magpie *Pica pica*	1.5	0.8
Dunnock *Prunella modularis*	0.6	0.0
Reed bunting *Emberiza schoeniclus*	0.8	0.0
Pied wagtail *Motacilla alba yarrellii*	0.4	0.2
House sparrow *Passer domesticus*	2.2	0.4
Bullfinch *Pyrrhula pyrrhula*	1.2	0.4
Great tit *Parus major*	0.1	0.2
Mistle thrush *Turdus viscivorus*	0.2	0.0
Snipe *Gallinago gallinago*	1.9	2.3
Blue tit *Cyanistes caeruleus*	0.3	0.3
Woodpigeon *Columba palumbus*	0.1	0.3
Jackdaw *Corvus monedula*	0.8	0.8
Pheasant *Phasianus colchicus*	0.1	0.0

Field size, species richness and abundance

Fields were analysed in terms of species richness in relation to field size for all species, and abundance in relation to field size for all species.

Table 5. Results from Pearson's Correlation Coefficient. The association between richness and abundance of both field types in relation to field size.

	Pearson's correlation	P-value
Richness S	0.608	0.100
Richness NS	0.762	0.039
Abundance S	0.289	0.289
Abundance NS	0.623	0.093

For both not-sprayed and sprayed fields, a strong positive correlation was found between species richness and field size. The relationship between field size and species richness for not-sprayed fields was statistically significant. Sprayed fields did not prove statistically significant. For not-sprayed fields, a strong positive correlation was found between abundance and field size. For sprayed fields, a low positive correlation was found between abundance and field size. For both field types, neither correlation proved to be statistically significant (Table 5, Fig. 4). (WC 920)

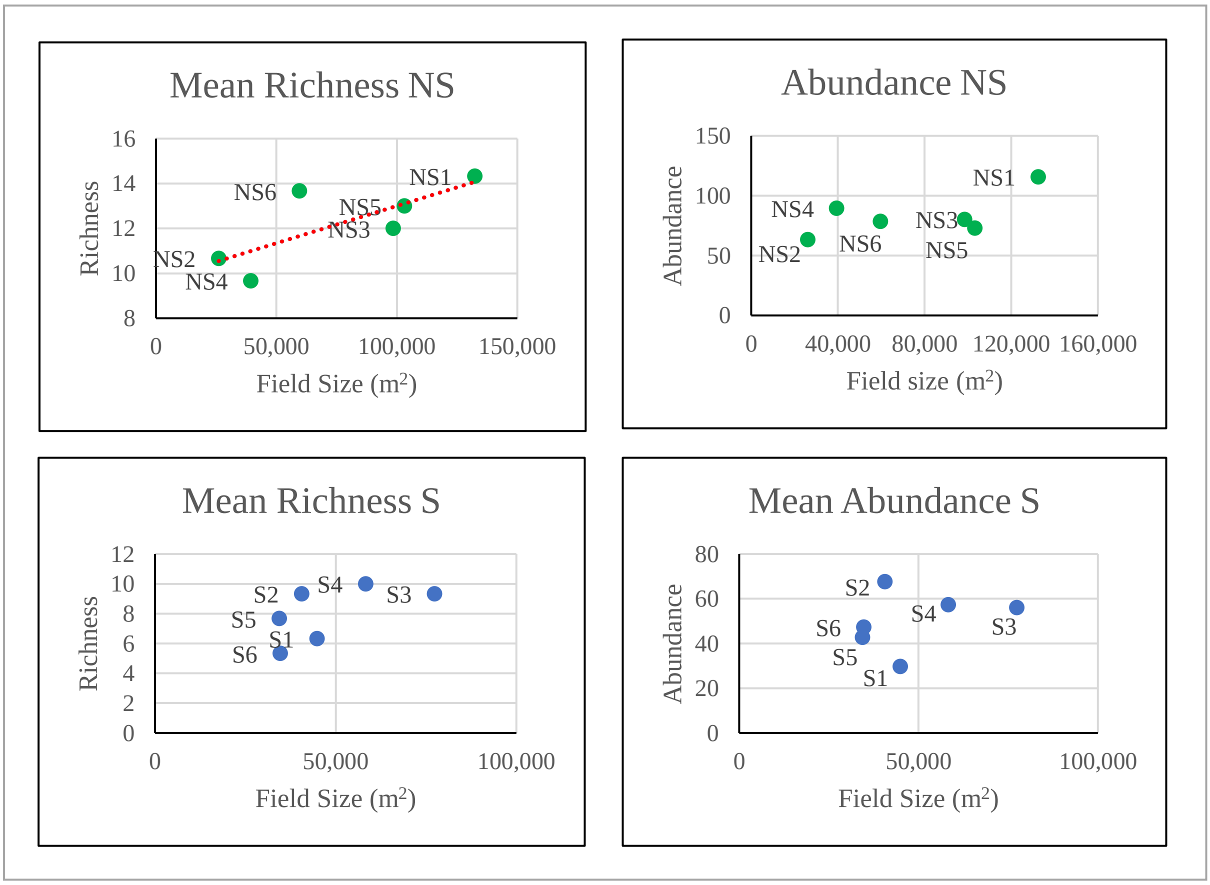

Figure 4. Scatter plots displaying relationship between abundance, richness and field size for all species for both not-sprayed and sprayed fields. Each point represents the mean of three counts carried out on that field. Field size is shown on the X-axis, while abundance and richness for all species is shown on the Y-axis.

Discussion

For both sprayed and not-sprayed fields, a total of 2,404 individual birds were recorded across a range of 30 different bird species. Upon carrying out the research, there was a noticeable difference (visibly and audibly) in bird activity on not-sprayed fields compared to sprayed fields. For questions 1 and 2 of this investigation, the application of herbicide had a negative effect on farmland bird diversity and abundance. For question 3, positive correlations were found between field size, species richness and abundance. In terms of fields themselves, not-sprayed fields were clearly greener than sprayed fields, which showed little greening (Fig. 5). As time went on, not-sprayed fields became greener. In the same time period, sprayed fields also became slightly greener, however the level of green cover was fractional in comparison to the green cover present in not-sprayed fields. Because of this, it was expected that levels of

Figure 5. The image on the left is the not-sprayed field NS5, showing an abundance of green cover (taken 26/11/2020). The image on the right is the sprayed field S4, showing little to no green cover (taken 25/11/2020).

abundance and richness would increase with each visit. However, this was not the case. Weather played an influential role in relation to abundance and richness levels, with drier days (66% of days in the field) generally showing higher levels of abundance and richness than wetter days (33% of days in the field). This behaviour of sheltering from rainfall is widely acknowledged in the field of ornithology. In a review by Kennedy (1970), it was stated that it is important for birds in temperate regions to take shelter when faced with rainfall, especially in cold winter conditions when food is scarce. Across all days in the field, the temperature ranged from 4-11°C, with an average temperature of 6.6°C.

Species richness

For species richness it was predicted that sprayed fields would have a lower species richness than not-sprayed fields. The results for question 1 of this investigation concur with the predictions stated in the introduction. This study presents evidence that shows there is a higher species richness on not-sprayed fields compared to sprayed fields. On average, not-sprayed fields contained 4.22 more species than sprayed fields. The quantity of food available to birds, from plant seeds to insects was noticeably higher in not-sprayed fields. Species richness increased in both sprayed and not-sprayed fields where the presence of another biodiversity regeneration measure existed. Other measures implemented by farmers in the BRIDE Project include field margins, installation of bird boxes and the creation of ponds. For NS1 and NS2, a pond was located between the two fields, which acted as an additional attraction for bird species. NS2 showed relatively high levels of richness even though it was one of the smallest fields in the study. This is likely due to the presence of a field margin, and also the pond located on the south side of the field. NS3 contained an owl box, however as the three owl species found in Ireland are mainly nocturnal, no owls were observed during the study as point counts were conducted during the day. Nevertheless, the presence of owl boxes and the potential increase of owls could possibly be a biological solution for pest control in farmland habitats for rodent species (Roulin & Willenegger, 2020).

Despite the clear lack of green cover, some sprayed fields showed high levels of species richness, with levels matching that of not-sprayed fields. S2 and S6 showed higher levels of species richness than other sprayed fields. A small woodland was located along the northern edge of S2. In this field, the majority of species recorded were foraging on the ground close to the woodland side. It was on S2 where a flock of 27 redwing was recorded on the second visit. Redwing are a migratory bird with a northern breeding distribution that encompasses Scandinavia, Iceland and Russia. During the winter, redwing migrate south to European countries including Ireland for food sources, and to avoid the harsh winter conditions (Redfern *et al.*, 2000; Rivalan *et al*., 2007). S6 showed high levels of species richness, which was likely caused by the existence of a pond located near the northeast corner of the field. Upon closer inspection of the pond, there was a myriad of birds. These birds were not included in the point count but their presence was noteworthy.

Species abundance

Question 2 addressed the abundance of individuals in fields. Like species richness, it was predicted that abundance on not-sprayed fields would be higher than that of sprayed fields. The results obtained from this part of the study agree with the predictions made. Not-sprayed fields contained 33.33 more individuals than sprayed fields on average. Like species richness, abundance was influenced by food availability. Another factor that influenced high species abundance was the amount of ground cover present in not-sprayed fields. This cover provides protection for some bird species against predators, however there can be a trade-off, with increased ground cover reducing the vigilance of some birds (Wilson *et al.,* 2005). An investigation into chaffinch feeding behaviour showed that in stubble fields with more cover, there was a 13% increase in alertness and a 13% decrease in peck rate (Whittingham *et al.,* 2004). The most abundant species across all fields was skylark with approximately 544 individuals recorded. Skylark are an amber listed species in Ireland (Lynas *et al.*, 2007). Almost 70% of skylark recorded were on not-sprayed fields. It was suggested in the 1960's that skylark was in decline in Ireland (Ruttledge, 1966). The decline in skylark in Ireland has been of particular concern, with numbers declining mainly due to agricultural intensification (Crowe *et al.,* 2010). With skylark being the most numerous species in this study, the effectiveness of not-spraying fields is evidently beneficial for the skylark population.

It was not exactly clear from this investigation as to what caused the negative effects on abundance and richness. It is known that because herbicide application causes a reduction in green cover, this results in a lack of food supply. This impacts directly on seed availability, and also on insect abundance due to the lack of weeds to support insect populations (Newton, 1995). Herbicide application can directly affect some insects but the majority of negative impacts occur indirectly (Fryer & Chancellor, 1970; Freemark & Boutin, 1995). One such insect is honey bee *Apis melifera* (Gill *et al.,* 2018). A study into the effects of glyphosate exposure resulted in a cascade of toxicological impacts (Burlew, 2010). Some herbicides, in certain cases, can have direct impacts on birds. Toxic herbicides such as Dinoseb and Paraquat can potentially kill birds (Cox, 1991). However, these herbicides have been banned in the EU. An investigation into the effects of Roundup (a glyphosate-based herbicide) on the reproductive organs of mallard *Anas platyrhynchos* showed that when exposed to Roundup, the mallard experienced changes in testicle structure. Exposure also altered hormone levels (Oliveira *et al.,* 2007). Although the occurrence of fatalities due to herbicide application is infrequent, there is a plethora of evidence showing that herbicide application negatively impacts on bird species.

Field size, species richness and abundance

Despite producing three strong positive correlations and one weak positive correlation, only the relationship between field size and species richness of not-sprayed fields proved statistically significant. This means that a higher level of species richness was recorded in larger fields, but the abundance per field was not significantly related to field size. There is little evidence to suggest that abundance and richness increase with field size. It could possibly be down to the species; birds that gather in large flocks such as skylark may prefer larger fields with a greater supply of food, whilst other species may prefer small fields that allow them to easily break for the cover of hedgerows. A study in France showed a positive correlation between field size and the density of harriers *Circus*, which resulted in low densities of grey partridge *Perdix perdix* due to high levels of predation (Bro *et al.*, 2001). The purpose of this analysis was to get a better understanding of preference in relation to field size. If a significant correlation was to be found, it would allow farmers to effectively select fields to spray, or not to spray. Additional investigations would be required to get a more accurate set of results.

Implications of results

The results of this investigation definitively state that spraying stubble fields with herbicide has a negative effect on both the species richness and abundance of farmland birds. Not-sprayed fields seemed like a completely different habitat in comparison to sprayed fields, in relation to green cover, bird activity, insect activity and food supply. In cases where sprayed fields were within close proximity to another available habitat such as a pond or woodland, individuals were seen to favour the alternate habitat (S2 and S6). In areas where not-sprayed fields were coupled with another biodiversity regeneration measure, richness and abundance increased. This was the case for NS1 (located beside a pond) and NS2 (presence of field margin and pond).

This study design allowed for data in relation to all questions of interest to be collected at once. The design consisted of clear and concise methods that produced results in accordance with previous results from other studies conducted in Ireland and further afield. If this study was to be repeated for the BRIDE Project or otherwise, it would be favourable to establish more fields to investigate, with more visits per field. The results provide information with field-specific data that can be used to tailor certain aspects of the BRIDE Project, depending on the status of individual fields/farms. This study demonstrates the effectiveness and simplicity of the biodiversity regeneration measures implemented by this particular agri-environment project, which sets an example for conservation standards in Ireland. (WC 1,629)

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