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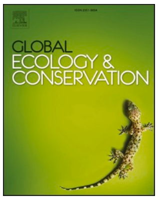

Winter agri-environment schemes and local landscape composition influence the distribution of wintering farmland birds

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ABSTRACT

Since 1992, the European Union puts in place agri-environment schemes (AES), such as unharvested set-aside fields with winter bird crops (WBC), to counteract farmland biodiversity declines that are associated with agricultural intensification since the second half of the 20th century. These measures aim at, among other things, improving habitat quality and food availability for farmland birds throughout the year. In this study in Dry Hesbaye, an agricultural region in eastern Flanders (Belgium), we use spatial generalized linear mixed models to investigate how species richness and the observation probability of ten bird species with different food diets are associated during winter (November - March) with WBC implementation in arable crop fields and the presence of landscape elements within 50 m of these fields. Our results show that species richness and the observation probabilities of nine out of ten wintering farmland bird species under study are increased at crop fields with WBC implementation. Species richness and observation probabilities are also associated with the presence of nearby landscape elements such as hedgerows, woodland, unpaved roads, or grass margins. We conclude that unharvested set-aside fields promote local diversity and observation probabilities of most of the species under study. In addition, AES measures should be implemented after considering the aforementioned natural or semi-natural nearby landscape elements, which also influence local diversity and species' observation probability.

1. Introduction

Over the last century, agricultural intensification, in addition to farmland abandonment, caused widespread declines in farmland biodiversity (Donald et al., 2001; Newton, 2004; Wretenberg et al., 2006; Butler et al., 2010; Kleijn et al., 2011). The most severe declines coincided with the post-War advent of industrialised agriculture (Benton et al., 2003; McHugh et al., 2017) which inflicted a

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considerable loss of semi-natural habitats and landscape heterogeneity through field enlargement and regional specialisation in agricultural practices, considerably more in Western Europe than Central and Eastern Europe (Fuller et al., 2005; Tryjanowski et al., 2011). It has been demonstrated that such intensifications, among things, negatively impact food availability and the presence of resting and breeding habitat for both insectivorous and granivorous bird species (Newton, 2004; Tscharntke et al., 2005).

As a response to farmland biodiversity declines, the European Union has put in place agri-environment schemes (AES, funded under Pillar 2 of the Union's Common Agricultural Policy) since 1992, through which farmers are financially compensated for loss of income due to measures taken to improve the environment (Pe'er et al., 2014; Rüdisser et al., 2015). Several AES measures exist to provide suitable habitats for ground-breeding bird species and to improve the availability of summer and winter food resources for farmland birds, including unharvested set-aside fields, floristically enhanced margins, and low-input spring cereal cultivation (MacDonald et al., 2012; Burgess et al., 2015). A wide range of studies have evaluated the ecological effectiveness of these AES on population densities and the availability of foraging and breeding resources (MacDonald et al., 2012; Burgess et al., 2015; McHugh et al., 2017; Redhead et al., 2018), highlighting species-specific responses to different forms of AES (Batáry et al., 2015).

The impact of AES on European farmland bird populations and the role of landscape heterogeneity herein has primarily been investigated during the breeding season (Geiger et al., 2010), while the effectiveness of winter-AES has been less widely assessed (but see for example Concepción and Díaz, 2019). The winter situation requires attention though, since farmland birds that feed on seeds in winter are affected more severely by agricultural intensification than other farmland birds (Chamberlain et al., 2000; Donald et al., 2001; Robinson and Sutherland, 2002; Gamero et al., 2017; PanEuropean Common Bird Monitoring Scheme, 2021). This trend is commonly associated with low food availability during winter due to the large-scale replacement of seed-rich habitats, such as ecologically important stubble fields, by autumn-sown cereal crops and more efficient harvesting (Butler et al., 2005; Wittingham et al., 2006).

Specific AES for wintering granivorous birds are designed to create seed-rich winter foraging habitats (Hole et al., 2002; Vickery et al., 2009). These measures often include set-aside policies by leaving stubble fields untouched during winter or by sowing seed-bearing crops that are not harvested, frequently termed *winter bird crops* (henceforth denoted as *WBC*; Henderson et al., 2004; Stoate et al., 2004; Perkins et al., 2007). In addition to providing winter food resources, there is growing evidence that a heterogeneous landscape can also be beneficial for wintering birds (Fuller et al., 2004; Geiger et al., 2010; McHugh et al., 2017; Redhead et al., 2018). For example, the presence of small natural or semi-natural elements in the landscape, such as hedgerows (Hinsley and Bellamy, 2000; Broughton et al., 2021), ponds (Lewis-Phillips et al., 2019), and unpaved roads (Dylewski and Tobolka, 2022) can act as food sources or hiding places, the importance of which differs between species (Tryjanowski, 1995).

Despite rigorous and costly conservation attempts (Harris et al., 2020), populations of most farmland birds continue to decline as a result of agricultural intensification (BirdLife International, 2022). We investigated the influence of AES as a conservation strategy on a wintering farmland bird community. We analysed monitoring data of the distribution of wintering farmland birds during eight winter seasons, i.e., 2009/2010 until 2016/2017, in Belgium, in a semi-rural and intensively cultivated area. We assessed whether bird species richness and species-specific observation probabilities were associated with particular WBC treatments and the presence of nearby surrounding landscape elements. We hypothesized that WBC treatments would improve the presence, and therefore the observation probabilities, of granivorous species, i.e., the main target species for these implementations that directly benefit from the measures via increased food resources. Secondly, we hypothesized as well that omnivorous, insectivorous, and carnivorous species were more likely to be present at these fields, as WBC implementation was expected to improve insect and small mammal densities, which act as important food resources for these species during winter (Perkins et al., 2008; Field et al., 2011; Aebischer et al., 2016). Furthermore, based on studies conducted during summer (e.g., Vickery et al., 2009; Tschumi et al., 2020), we expected that the presence of nearby (semi-)natural landscape elements, e.g., the hedgerows, grass margins or other small landscape elements, would positively affect the diversity of the farmland bird community and the observation probability of individual species. We interpret our results in a perspective relevant to conservationists and agricultural policy-makers within the EU and beyond.

2. Methods

2.1. Agri-environment scheme implementation in Dry Hesbaye

This study was conducted in South-East Flanders (Belgium, province of Limburg, Dry Hesbaye), more particularly in the municipalities of Gingelom, St.-Truiden, Heers, Borgloon, Herstappe, Tongeren, Riemst, Bilzen, and Lanaken (Fig. 1). This fertile arable area is characterised by loess soils that overlie chalk sediments, such that groundwater sinks easily. The most prevalent primary crops were grains (covering 47% of the agricultural area), mainly winter wheat *Triticum hybernum* and barley *Hordeum vulgare*; industrial crops (22%) such as rapeseed *Brassica napus spec.*, flax *Linum usitatissimum*, chicory *Cichorium intybus*, and sugar beet *Beta vulgaris var.*; Corn *Zea mays* (18%); and other crops (13%), including fodder such as Alfalfa *Medicago sativa*.

AES have been introduced in this region under the Flemish Rural Development Program (PDPO; Programma voor Plattelandsontwikkeling). The first PDPO program (PDPO-I) took place between 2000 and 2006, the second (PDPO-II) between 2007 and 2013, and the third (PDPO-III) was running from 2014 until 2020. With regards to farmland bird conservation, AES had been implemented in legally established management areas since 2009. These AES were selected based on the presence of suitable habitat types, such as open farmland plateaus or semi-open agrarian areas which are also holding sufficiently large populations of key farmland bird species, such as Yellowhammer *Emberiza citrinella*, Corn Bunting *Emberiza calandra*, Skylark *Alauda arvensis,* or Partridge *Perdix perdix* (Vermeersch et al., 2000). The contractual agreements were concluded between the Flemish Land Agency (VLM) and individual farmers and were set for a period of five years, which could be renewed afterwards. The AES of interest in our study

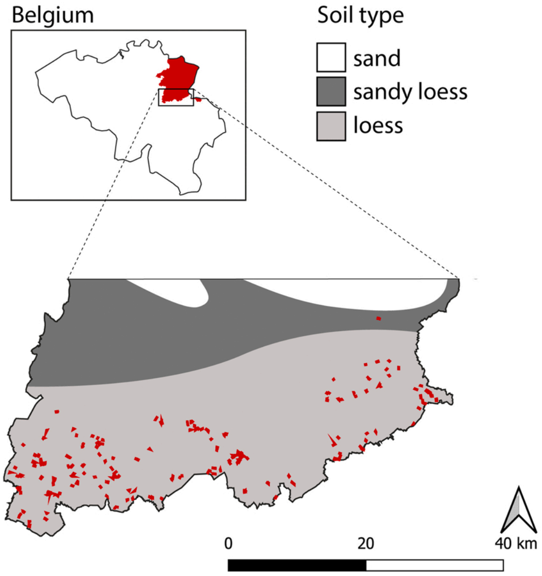

Fig. 1. The locations of the 174 investigated fields (colorized polygons), within the Dry Hesbaye region in the Southern part of the province of Limburg (Belgium). Background colors denote soil types.

Fig. 2. Pictures of AES fields that were examined in this study: (left) field with WBC implementation; (right) field with WBC implementation, with adjacent hedgerow and another field with WBC implementation within 50 m. The colorized area denotes the WBC implementation. Both pictures show fields with adjacent grass margins (the area between the colorized area and the colored outline).

comprised the cultivation of WBC, seed-rich crops: summer wheat and admixtures of fodder radish or flax with wheat or oats, which were not harvested in autumn, after which their crop residues were incorporated in early spring of the next year. The selection of these crops was made by VLM, based on expert-judgement. The primary goals were to provide winter food resources for granivorous target bird species: grain-preferring species such as Skylark or Corn Bunting were expected to benefit from oats, whereas Linnet *Linaria cannabina* was thought to prefer seed-rich crops such as fodder radish, and other species with a mixed seed-grain diet such as Reed Bunting *Emberiza schoeniclus*, were expected to benefit from multiple crop types (Orłowski and Czarnecka, 2007). Admixtures of grains and seeds were hypothesized to benefit diversity in general.

From 2009 until 2017, the period in which our data were collected, the total size of farmland area under AES for farmland bird management that implemented WBC had increased to 136 ha. In addition to WBC implementation for wintering birds, grass margins put in place as an AES to improve the breeding conditions of nesting birds, were present throughout the region. There had been no active creation or management of other landscape features, such as hedgerows or tree colonnades, within the AES context. These were however often naturally present in the direct surroundings of AES-managed farmland (Fig. 2).

2.2. Study design

During the winter seasons (November - March) of 2009/2010 – 2016/2017 (during PDPO-II and PDPO-III), farmland bird counts, henceforth defined as *sampling events*, were performed on farmland fields with or without WBC implementation, henceforth defined as *fields*.

Throughout the course of the study, 813 sampling events were undertaken, on 174 fields. The number of sampling events varied per field and per winter season. For 128 fields, more than one sampling event was undertaken. Although the selection of the monitored fields was not performed randomly, it was primarily driven by the objective to cover a large geographical range that holds the managed fields. Practical considerations, e.g., accessibility or optimal time management, played a limited role as well. These considerations led

Table 1
Overview of explanatory variables with accompanying summary statistics. Frequency denotes the proportion of sampling events out of the total 681 field visits for which the environmental feature or the WBC category was present. Mean observed species richness (with standard deviation) is provided for every category of the binary/categorical variables.

categorical variable

	explanation	frequency (percentage)	mean species richness (sd)
treatment	type 1: no WBC	87 (12.78%)	1.356 (1.397)
	type 2: oats/fodder radish	58 (8.52%)	3.569 (2.348)
	type 3: wheat	224 (32.89%)	3.491 (2.335)
	type 4: wheat/fodder radish	70 (10.28%)	3.886 (2.210)
	type 5: wheat/flax	242 (35.54%)	3.583 (2.619)

continuous variables

	explanation	mean (sd)	min	max
field size	field size in km^2	0.635 (0.641)	0.08	5.76
temperature	temperature in °C during sampling event	4.078 (4.760)	-11	14

binary variables

			mean species richness (sd)	
	explanation	frequency (percentage)	variable = yes	variable = no
grass margin	bordering AES grass margin	379 (55.65%)	3.400 (2.330)	3.172 (2.585)
unpaved road	bordering unpaved road	125 (18.36%)	3.616 (2.630)	3.227 (2.401)
woodland	woodland within 50 m of border	101 (14.83%)	3.911 (3.060)	3.191 (2.311)
hedgerow	at least one hedgerow or tree colonnade within 50 m of border	300 (44.05%)	4.087 (2.755)	2.677 (1.966)
fruit plantation	fruit plantation within 50 m of border	260 (38.18%)	3.112 (2.524)	3.413 (2.395)
other WBC	at least one other field with WBC within 50 m of border	246 (36.12%)	3.699 (2.482)	3.071 (2.401)

to the fact that some fields were not revisited, while others were revisited more than 10 times; Fig. S1 and Table S1 in the supplementary material provide additional details.

Each field received WBC implementation, i.e., either (i) a mix of oats and fodder radish; (ii) wheat; (iii) a mix of wheat and fodder radish; or (iv) a mix of wheat and flax (Table 1). WBC implementation was applied to the total size of each field. Field sizes were not set by design and varied. The type of WBC implementation and field sizes remained unchanged throughout the five-year contract. A selection of 65 out of these 174 fields was also monitored, at least once and maximally five times, before the WBC implementation, when they were subject to intensive agriculture that consisted of yearly crop rotations of winter grains, sugar beet, and maize. This yielded 94 (out of the 813) sampling events that were used as controls.

2.3. Monitoring protocol

All sampling events were done by a team of two ornithologists employed by VLM. The ornithologists would jointly arrive at a field and use binoculars to detect individuals of different species, after which they would continue searching for birds while crossing the field, each person following one of two straight transect lines. These lines would lie in parallel to each other, at distances that allowed optimal visual coverage of the field. When having crossed the field, the ornithologists would return to the starting point along the field borders, after which the sampling event would end.

The ornithologists counted the observed number of individuals for each species detected during the monitoring event. When the sampling event had ended, both ornithologists jointly assessed their species counts and after correcting for double counts, these would be merged into one data record containing abundances of each detected species. When large flocks of birds were observed, the estimated number of individuals counted by each of the two ornithologists was averaged. Birds were recorded when they were observed sitting in or flying up from the monitored field, or through their calls. Birds observed in surrounding fields were not added to the count.

2.4. Data processing

All data were digitally stored using GIS and were spatially aggregated at field level. The species abundance counts were transformed to binary species presence/absence data, as abundance data were sometimes approximate. Note that visual monitoring of birds, particularly in winter, may be subject to detectability problems for specific species, e.g., Skylark (Atkinson et al., 2006). We therefore use “observation/no observation”, instead of “presence/absence”, to acknowledge that individuals of a species might have been present, but unobserved, during a sampling event.

We defined species richness and observation/no observation per species separately for each field at every sampling event. Species richness was defined as the number of different species observed at a sampling event. To avoid extreme cases of zero-inflation, we have only analysed observation/no observation for species typically related to farmland ecosystems that were observed in at least 50 sampling events. These conditions were met for Skylark, Reed Bunting, Yellowhammer, Linnet, Corn Bunting, Pheasant *Phasianus* *colchicus*, Kestrel *Falco tinnunculus*, Buzzard *Buteo buteo*, Grey Heron *Ardea cinerea* and Hen Harrier *Circus cyaneus*.

Table 1 provides summary statistics of all variables, based on the subset of records taken up in the analysis (consult Section 2.5 for more details). We defined a set of explanatory variables for each field visit: based on the AES implementation contract and local landscape features that were documented by one of the ornithologists at the start of the AES implementation, we defined a categorical *treatment* variable with five categories (no WBC [control, i.e., intensive agriculture], a mix of oats and fodder radish, wheat, a mix of wheat and fodder radish, and a mix of wheat and flax). Field sizes, i.e., the size of the colourized areas in Fig. 2., were obtained from detailed GIS maps of the AES fields. Nearby landscape element variables included the presence of one or more summer AES *grass margins* (to correct for the possible effect of summer AES implemented throughout the study region), or at least one *unpaved road* directly adjacent to the field, and the presence of other *WBC* fields, *woodlands*, *hedgerows*, or *fruit plantations* in close proximity (0–50 m) of the field's border. The presence of at least one *unpaved road* showed a large negative correlation with the presence of at least one road with ongoing traffic ($r = -0.945$). We have not included the latter as an explanatory variable in our analyses due to multicollinearity concerns, but we note that the effect of the presence of an *unpaved road* will partly reflect the effect of the absence of ongoing traffic. Landscape elements remained virtually unchanged throughout the study period, so the respective variables were kept constant throughout the study. For each sampling event, we additionally used *temperature* (°C) as an explanatory variable to correct for weather-related heterogeneity in activity.

Note that missingness among explanatory variables was limited, i.e., explanatory variable data were available for most sampling events, yielding 681 sampling events with complete data. Only temperature data showed moderate missingness, i.e., for 87 out of the 813 sampling events.

2.5. Statistical analysis

We modelled species richness with the spatial Besag-York-Mollié 2 (BYM2) negative binomial model (Riebler et al., 2016; Simpson et al., 2017), a generalised linear mixed model (GLMM) accounting for spatial correlation, within-field correlation through time and/or zero-inflation, by introducing two random effects. These random effects captured spatially structured and spatially unstructured extra-variability at the field level, while the negative binomial overdispersion parameter accommodated extra-variability at the level of the sampling event. The spatially unstructured extra-variability at the field level could have originated from repeated measurements through time, while unobserved natural phenomena that are specific to a field visit, i.e., weather conditions affecting visibility, may have led to extra-variability at the level of the sampling event. For each species separately, a binary outcome indicating observation/no observation was modelled with a spatial binomial BYM2 GLMM with a logit link, the linear predictor of which again contained field-specific spatially structured and unstructured random effects terms. In all models, the spatial random effects structure required constructing a neighborhood matrix. We defined neighbors as fields with their closest centroid-to-centroid distance being smaller than 500 m, based on previous studies (Siriwardena et al., 2006; Hinsley et al., 2010; Siriwardena, 2010) and home range data of farmland birds within a similar habitat context (own unpublished data). A sensitivity analysis where a threshold of 1000 m was used instead of 500 m yielded very similar model results.

In order to flexibly fit models accounting for spatial correlation, a Bayesian estimation approach was used, more particularly via integrated nested Laplace approximation (INLA; Rue et al., 2009), a computationally fast Bayesian estimation method that computes approximations of posterior marginal distributions for latent Gaussian models. All analyses were performed in R 4.0.3 (R Core Team, 2020), through the R-INLA package (version 21.02.23). Detailed model formulations, R code, and specifications of prior distributions have been provided as supplementary material.

For each outcome, we applied forward stepwise model selection using all explanatory variables introduced in Section 2.3, based on 95% credible intervals (and Bayesian p-values), yielding multivariable models. Multicollinearity assessments did not detect problematic associations between the explanatory variables. Field size was considered to be an important confounder and was therefore included in each model, at each stage of the model selection process, regardless of the significance of its effect. Note that temperature was added as an explanatory variable that could explain true temperature-related ecological trends, but it could correct for sampling bias caused by weather conditions as well. We adopted an analysis using sampling events for which all explanatory variables were available, yielding a dataset consisting of 681 sampling observations in 167 fields. This approach was valid under the assumption of complete random missingness, which was justifiable based on interviews with one of the data collectors.

3. Results

The mean observed species richness per visit was equal to 3.30 and ranged between 0 and 14. Species richness was positively associated with the implementation of WBC (Table 2, Fig. 3). All WBC types were associated with higher species richness as compared to no WBC implementation. Species richness was additionally positively associated with field size and with the presences of woodland or at least one hedgerow in the close proximity of the survey field.

The observation probability of Skylark was positively associated with wheat/fodder radish admixtures (Table 2, Fig. 3). This probability was negatively associated with the presence of a number of landscape elements, such as hedgerows, woodland and fruit plantations, while there was a positive association with field size.

All WBC types were associated with higher probabilities to observe Reed Bunting when compared to fields without WBC implementation (Table 2, Fig. 3). This association was particularly strong for fields with solely wheat, which were also linked with larger observation probabilities than fields with wheat/flax admixtures. These probabilities were also significantly larger for larger fields and for fields without fruit plantations in their close proximity.

Table 2

Summary and model results for the analysis of the observed species richness (BYM2 negative binomial GLMM) and the observation probabilities of Skylark, Reed Bunting, Yellowhammer, Corn Bunting, Yellowhammer, and Linnet (BYM2 binomial GLMM). We show parameter estimates (posterior means) and their 95% credible intervals, to which a Bonferroni correction is applied for pairwise comparisons of the effects of categories of the treatment variable. Empty cells refer to variables that, due to insignificance at the global 5% significance level, were not included in the final model after forward model selection, except the “field size” effect which was included in each model, at each stage of the selection process, regardless of its significance. The observation frequency denotes the number of sampling events during which a species was observed (in percentages between brackets). The supplementary material provides more information on model parametrization and the motivation behind using specific techniques, such as Bonferroni corrections, in addition to R code to fit the models in INLA.

	species richness		Skylark		Reed Bunting		Yellowhammer		Corn Bunting		Linnet	
observation frequency			144 (21.2%)		198 (29.1%)		312 (45.8%)		51 (7.5%)		129 (18.9%)	
explanatory variable effect	estimate	95% CI	estimate	95% CI	estimate	95% CI	estimate	95% CI	estimate	95% CI	estimate	95% CI
intercept	-0.051	[−0.268;0.160]	-1.491	[−2.321;−0.744]	-2.901	[−3.875;−2.058]	-2.514	[−3.313;−1.773]	-4.534	[−5.860;−3.515]	-5.254	[−7.539;−3.522]
oats/radish vs. no WBC	0.969	[0.619;1.327]	0.311	[−1.188;1.803]	1.618	[0.210;3.208]	0.460	[−0.807;1.716]			5.010	[2.675;8.503]
wheat vs. no WBC	0.937	[0.649;1.241]	0.838	[−0.231;2.071]	2.301	[1.163;3.706]	1.523	[0.625;2.499]			2.680	[0.404;6.117]
wheat/radish vs. no WBC	1.057	[0.721;1.403]	1.571	[0.350;2.926]	1.885	[0.549;3.441]	0.430	[−0.769;1.631]			4.276	[1.964;7.746]
wheat/flax vs. no WBC	0.870	[0.587;1.172]	0.435	[−0.652;1.683]	1.484	[0.349;2.878]	1.978	[1.083;2.956]			2.608	[0.335;6.042]
wheat vs. oats/radish	-0.032	[−0.279;0.220]	0.529	[−0.545;1.762]	0.692	[−0.263;1.738]	1.065	[0.027;2.186]			-2.303	[−3.286;−1.380]
wheat/radish vs. oats/radish	0.088	[−0.204;0.382]	1.260	[0.041;2.612]	0.269	[−0.908;1.488]	-0.030	[−1.328;1.273]			-0.721	[−1.780;0.299]
wheat/flax vs. oats/radish	-0.099	[−0.343;0.152]	0.127	[−0.980;1.385]	-0.126	[−1.102;0.925]	1.521	[0.488;2.641]			-2.375	[−3.361;−1.449]
wheat/radish vs. wheat	0.120	[−0.114;0.350]	0.726	[−0.167;1.616]	-0.423	[−1.344;0.451]	-1.094	[−2.152;−0.119]			1.582	[0.703;2.477]
wheat/flax vs. wheat	-0.066	[−0.224;0.092]	-0.402	[−1.109;0.293]	-0.816	[−1.441;−0.216]	0.455	[−0.170;1.087]			-0.071	[−0.852;0.706]
wheat/flax vs. wheat/radish	-0.186	[−0.416;0.047]	-1.129	[−2.050;−0.212]	-0.394	[−1.303;0.538]	1.549	[0.570;2.613]			-1.653	[−2.554;−0.773]
grass margin							-0.511	[−1.004;−0.031]			0.695	[0.235;1.168]
unpaved road							1.022	[0.430;1.643]				
woodland	0.230	[0.061;0.398]	-1.010	[−1.838;−0.266]								
hedgerow	0.337	[0.201;0.472]	-1.044	[−1.579;−0.546]			1.616	[1.124;2.130]				
fruit plantation			-1.123	[−1.716;−0.598]	-0.637	[−1.106;−0.181]			-2.156	[−3.867;−0.753]		
other WBC												
field size	0.224	[0.128;0.322]	0.401	[0.022;0.775]	0.672	[0.349;1.025]	0.157	[−0.224;0.559]	1.270	[0.596;2.045]	0.416	[0.108;0.713]
temperature							0.061	[0.022;0.101]				
neg. bin. overdispersion	0.023	[0.004;0.057]										
conv. marg. var.	0.076	[0.044;0.122]	0.405	[0.099;0.981]	0.480	[0.165;1.012]	0.805	[0.336;1.550]	3.349	[1.527;6.406]	0.041	[0.000;0.199]
scaling parameter	0.102	[0.007;0.360]	0.182	[0.009;0.633]	0.246	[0.010;0.789]	0.193	[0.012;0.632]	0.088	[0.007;0.299]	0.463	[0.057;0.946]

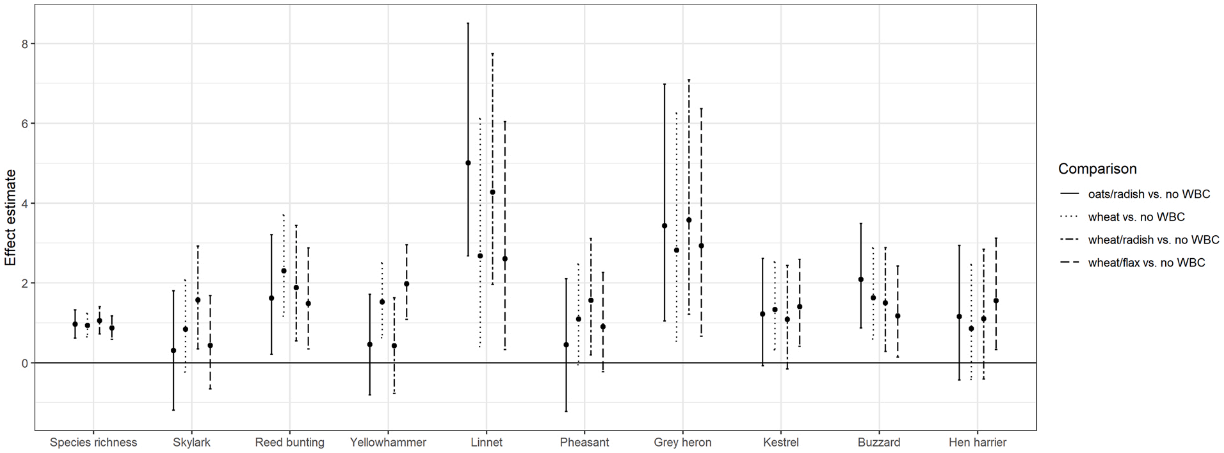

Fig. 3. Model-based estimates of effects of different WBC implementations vs. no WBC, along with 95% credible intervals that were Bonferroni-corrected in line with Tables 2 and 3. Effects are estimated within models obtained through model selection. Effect estimates should not be compared between outcomes, as their model parameterizations differ. Effect estimates for Corn bunting lack, as WBC implementation was not taken up in the selected model.

Yellowhammer was the most frequently observed species, as it was observed during 45.8% of all field visits (Table 2). The probability to observe Yellowhammer was largest in fields with admixtures of wheat and flax or fields with solely wheat (Table 2, Fig. 3). In addition, we found significantly positive associations with the presence of at least one hedgerow or an adjacent unpaved road, and temperature, and a significant negative association with the presence of an adjacent grass margin.

The Corn Bunting analysis could not detect an effect of any WBC type, but it was likely underpowered due to infrequent observations of the species (observed in 7.5% of all field visits; Table 2). The analyses pinpointed that their observed presence was associated positively with field sizes and negatively with the presence of fruit cultivation in the field's close proximity.

The probability to observe Linnet was larger in fields with any type of WBC type as compared to no WBC (Table 2, Fig. 3). They were observed particularly more in fields with admixtures containing fodder radish. In addition, these observation probabilities were positively associated with adjacent grass margins and field size.

For the observation probability of Pheasant, there was a positive effect of fields with wheat/fodder radish admixtures as compared to no WBC implementation (Table 3, Fig. 3). The analysis pointed as well towards positive associations with adjacent unpaved roads and fields with hedgerows in their close proximities.

The observation probability of Grey Heron was higher in fields with any type of WBC than fields without WBC (Table 3, Fig. 3). The analyses pointed towards increasing observations at locations without nearby woodland and during sampling events with lower temperatures.

When compared to fields without WBC, Kestrel was observed more in fields with 100% wheat or wheat/flax admixtures (Table 3, Fig. 3). Positive effects were reported for the presence of at least one other field with WBC within 50 m of a field's boundaries, at least one nearby hedgerow, and field size.

For Buzzard, every WBC type was linked to higher observation probabilities as compared to fields without WBC. They were also observed more in large fields and fields with nearby woodland (Table 3, Fig. 3).

Hen Harrier was more frequently observed in fields with wheat/flax admixtures than those without WBC (Table 3, Fig. 3). Fields that had at least one other WBC field in their vicinity (50 m) were associated with a larger observation probability, while adjacent hedges had a slightly significant negative effect.

4. Discussion

In the intensively cultivated landscape of our study, fields in which WBC were implemented were associated with increased species richness and increased observation probabilities of nine out of the ten studied wintering farmland bird species. In addition, the presence of nearby landscape elements was often significantly associated with general species richness and/or observed species occupancy, suggesting that the implementation of WBC into the surrounding landscape has to be taken into consideration.

As expected, WBC in our study supported wintering farmland bird communities, therefore fulfilling their role as food resources for granivorous species during the winter (Hancock and Wilson, 2003). Additionally, our study results suggest that omnivorous and insectivorous species also benefited from higher food availability within WBC (Perkins et al., 2008; Field et al., 2011; Aebischer et al., 2016). Corn Bunting was the only species for which no association with WBC implementation could be shown, and this might be due to limited statistical power. The increased presence of small mammals (Broughton et al., 2014) and wintering farmland birds in WBC, probably explained the high observation probability of predatory species in our study, including Grey Heron.

We also demonstrated species-specific responses to WBC-categories. For predatory species such as Buzzard and Grey Heron, WBC implementation was associated with increased observation probabilities regardless of the WBC type. Reed bunting and Linnet

Table 3

Summary and model results for the analysis of the observation probabilities of Pheasant, Grey Heron, Kestrel, Buzzard, and Hen Harrier (BYM2 binomial GLMM). We show parameter estimates (posterior means) and their 95% credible intervals, to which a Bonferroni correction is applied for pairwise comparisons of the effects of categories of the treatment variable. Empty cells refer to variables that, due to insignificance at the global 5% significance level, were not included in the final model after forward model selection, except the "field size" effect which was included in each model, at each stage of the selection process, regardless of its significance. The observation frequency denotes the number of sampling events during which a species was observed (in percentages between brackets). The supplementary material provides more information on model parametrization and the motivation behind using specific techniques, such as Bonferroni corrections, in addition to R code to fit the models in INLA.

	Pheasant		Grey Heron		Kestrel		Buzzard		Hen Harrier	
observation frequency	117 (17.2%)		105 (15.4%)		199 (29.2%)		179 (26.3%)		102 (15.0%)	
explanatory variable effect	estimate	95% CI	estimate	95% CI	estimate	95% CI	estimate	95% CI	estimate	95% CI
intercept	3.190	[−4.188;−2.318]	-4.459	[−6.726;−2.744]	-3.238	[−4.098;−2.477]	-2.656	[−3.486;−1.931]	-3.224	[−4.278;−2.328]
oats/radish vs. no WBC	0.449	[−1.216;2.104]	3.436	[1.044;6.981]	1.220	[−0.075;2.610]	2.090	[0.869;3.485]	1.155	[−0.434;2.941]
wheat vs. no WBC	1.092	[−0.050;2.468]	2.818	[0.541;6.257]	1.334	[0.324;2.524]	1.627	[0.595;2.878]	0.860	[−0.419;2.459]
wheat/radish vs. no WBC	1.563	[0.199;3.113]	3.574	[1.214;7.091]	1.090	[−0.150;2.439]	1.503	[0.281;2.887]	1.100	[−0.408;2.841]
wheat/flax vs. no WBC	0.903	[−0.227;2.267]	2.935	[0.665;6.368]	1.407	[0.408;2.588]	1.173	[0.138;2.423]	1.559	[0.331;3.123]
wheat vs. oats/radish	0.646	[−0.542;2066]	-0.599	[−1.643;0.521]	0.120	[−0.829;1.140]	-0.454	[−1.307;0.417]	-0.289	[−1.416;0.989]
wheat/radish vs. oats/radish	1.115	[−0.275;2.694]	0.142	[−1.074;1.403]	-0.129	[−1.315;1.063]	-0.585	[−1.664;0.468]	-0.055	[−1.442;1.373]
wheat/flax vs. oats/radish	0.458	[−0.733;1.878]	-0.480	[−1.509;0.634]	0.193	[−0.747;1.207]	-0.908	[−1.778;−0.026]	0.410	[−0.660;1.656]
wheat/radish vs. wheat	0.465	[−0.572;1.471]	0.741	[−0.279;1.735]	-0.248	[−1.207;0.641]	-0.129	[−1.016;0.699]	0.235	[−0.938;1.289]
wheat/flax vs. wheat	-0.188	[−0.918;0.540]	0.118	[−0.621;0.866]	0.073	[−0.531;0.678]	-0.453	[−1.057;0.140]	0.698	[−0.035;1.470]
wheat/flax vs. wheat/radish	-0.651	[−1.666;0.387]	-0.622	[−1.594;0.383]	0.322	[−0.563;1.273]	-0.325	[−1.171;0.570]	0.465	[−0.531;1.601]
grass margin										
unpaved road	0.760	[0.145;1.392]								
woodland			-1.177	[−2.155;−0.331]			0.528	[0.034;1.015]		
hedgerow	0.563	[0.042;1.101]			0.587	[0.180;1.009]			-0.507	[−0.993;−0.035]
fruit plantation										
other WBC					0.699	[0.293;1.113]			0.999	[0.543;1.460]
field size	0.118	[−0.283;0.502]	0.275	[−0.073;0.607]	0.838	[0.438;1.314]	0.275	[0.015;0.533]	0.169	[−0.157;0.471]
temperature			-0.072	[−0.117;−0.028]						
conv. marg. var.	0.703	[0.288;1.539]	0.372	[0.061;1.018]	0.299	[0.065;0.740]	0.068	[0.001;0.322]	0.057	[0.000;0.254]
scaling parameter	0.225	[0.012;0.709]	0.213	[0.011;0.709]	0.195	[0.012;0.633]	0.394	[0.038;0.897]	0.466	[0.024;0.972]

observations were positively associated with the implementation of any WBC-type, but showed preferences that aligned with prior expectations, i.e., buntings feeding extensively on cereal grain and Linnet readily taking smaller seeds (Wilson et al., 1999). Other species, such as Skylark, were closely associated with specific WBC-categories (i.e., wheat/fodder radish admixtures for Skylark). This aligns with findings showing that different admixtures likely are important in determining the value for specific species (Henderson et al., 2004). It has been suggested that sowing fields containing seeds (e.g. *Brassicaceae*, such as fodder radish and oilseed; Cassida et al., 1995) in combinations with other fields containing various cereal types (e.g. wheat and flax) will support the greatest variety of species (Redhead et al., 2018). Although we did not explicitly account for internal field structure, vegetation composition and structure could differ between WBC fields in addition to their WBC-category, which likely affected their suitability for different species (Henderson et al., 2004; Perkins et al., 2008).

The degrees to which species richness and species-specific observation probabilities were associated with the presence of nearby landscape elements, varied considerably. Only a small number of positive associations between the presence of grass margins or unpaved roads near WBC fields and species' observation probabilities were detected, while their presence was not associated with overall species richness. Nevertheless, grass margins and unpaved roads can provide sources of overwintering invertebrates (e.g., Woodcock et al., 2007; Smith et al., 2008), high densities of small mammals (e.g., Askew et al., 2007), and natural seeds in later winter when sown seeds become depleted (Wilson, 1992; Moorcroft et al., 2002). The value of grass margins, which form among the most popular AES in our study area, has been rigorously investigated (Vickery et al., 2009), demonstrating its significant importance as food and nesting resource during the breeding season for various species, such as Yellowhammer, Corn Bunting, and Skylark. However, their value for most species, both during summer and winter, relies on the vegetation structure and composition and the implementation in the local landscape. In our study, most grass margins consisted of dense, grass-only margins, which provided the least food resources, and access for foraging birds was likely restricted (Vickery et al., 2001, 2002; Wilson et al., 2005). Optimal margin management should therefore focus on promoting multi-species margins containing a mosaic of short and long vegetation (Douglas et al., 2009).

The presence of hedgerows near WBC fields was positively associated with overall species richness and the observation probability of a number of farmland birds in these WBC fields. Consistent with previous studies (Geiger et al., 2014; Tschumi et al., 2020), our study results suggest that the presence of hedgerows comes at the expense of open-habitat species, such as Skylark and Hen Harrier, but benefits overall bird species (diversity) and abundance, providing opportunities for resting, perching, feeding or predator avoidance throughout winter (Hinsley and Bellamy, 2000; Broughton et al., 2021). It is surprising that observation probabilities of Reed Bunting, Corn Bunting, Linnet and Buzzard were not significantly associated with the presence of hedgerows. In this perspective, variation in hedge size and structure, the density and spatial arrangement of hedgerows in the local landscape may have obscured our findings (Hinsley and Bellamy, 2000). Note that in the case of Corn Bunting, this was likely related to limited analysis power.

Interestingly, we observed negative observation probabilities for several species (i.e. Skylark, Reed Bunting, and Corn Bunting) at WBC fields close to fruit plantations, which we currently cannot explain. Further research should investigate whether fruit plantations may, for example, due to their intensive management, negatively affect these species through reduced food resources, or act as structural obstacles for species that prefer open land, such as Skylark.

Previous studies have shown that many farmland birds move between resources less than 1 km apart (Siriwardena et al., 2006; Siriwardena, 2010). A more diverse local landscape that provides multiple food resources, might therefore improve wintering conditions of bird communities. However, these communities do not only respond to local habitat resources, but may also require complementary resources at a larger landscape scale (Vickery and Arlettaz, 2012). Larger-scale landscape diversity has also been shown important for farmland raptors moving at larger distances (Jankowiak et al., 2015). In this perspective, our study design was somehow biased towards investigating local effects, demonstrating that the implementation of different WBC-categories in addition to nearby landscape elements can directly affect wintering farmland birds of different functional groups. How this subsequently affected local farmland bird communities during the breeding season was not the purpose of our study.

Considering the limitations of our study, none of the investigated fields were specifically designed to use as controls. We instead used surveys conducted before WBC implementation as control measures, when intensive agriculture took place at these fields. It was therefore difficult to disentangle differences between control and "treatment" measurements from temporal effects in our models. However, densities of farmland birds have been declining throughout the last two decades (PanEuropean Common Bird Monitoring Scheme, 2021; BirdLife International, 2022). We would therefore expect negative trends through time, which does not tally with our results, pinpointing increases in observation probability when changing from no WBC to WBC. We argue that this consistency in results strongly suggests the beneficial effects of WBC implementation. Note as well that we explicitly modelled the observation probability, which does not necessarily represent the presence probability, due to limited, possibly species-specific, detectability (Tryjanowski et al., 2015). However, the random effects used in our models could accommodate several sources of heterogeneity, including extra-variability caused by zero-inflation (Neyens et al., 2017), which is often encountered due to limited detectability. The partly opportunistic nature of data collection led to unbalance in the number of field visits, which was in part based on practical considerations. Often the ornithologists would visit fields that were located en route. It was difficult to evaluate the possible effects of this sampling approach on the analysis, although model estimation was not affected by it and the BYM2 model structure could, as discussed before, deal well with extra-variability caused by these latent processes.

Although our study results demonstrate that WBC implementation promoted local species richness and observation probabilities of most of the commonly encountered farmland bird species in the Dry Hesbaye region, we did not evaluate the cost-effectiveness of these measures. Future economic assessments of WBC implementation in our study region will be important, especially since studies show that current farmland conservation measures are cost-effectively below par. For the United Kingdom, Collas et al. (2023) show increased economic benefits of land-sparing, in contrast to land-sharing practices, while yielding the same biodiversity targets.

Tscharntke et al. (2021) recommend promoting large-scale heterogeneity of the crop mosaic in intensively cultivated farmland, while allocating enough patches, i.e., at least 20% of the total area, for semi-natural habitat. While we did not investigate the effects of large-scale farmland configuration, our results align with recommendations that investments in semi-natural landscape elements can be effective measures to promote local farmland bird diversity.

5. Conclusion

Our study shows that the implementation of different types of winter bird crops in an intensively-cultivated landscape s positively associated with local species richness and the observation probability of nine out of ten investigated wintering farmland birds, including non-target species of higher trophic levels. Observations of most considered species, either associated with open habitats (i.e., Skylark), or with semi-open habitats (i.e., Yellowhammer, Linnet, and Reed Bunting), predator species (i.e., Grey Heron, Hen Harrier, Buzzard and Kestrel), and opportunistic species (i.e., Pheasant), displayed positive correlations with the presence of some form of WBC. The presence of nearby landscape elements, such as hedgerows, was also positively linked with overall species richness and the observation probability of several farmland birds, but for instance not of Skylark. Even though the presence of adjacent grass margins was not correlated with community diversity during winter, weed-rich and diverse grass margins may be an important food resource when WBC are largely depleted of seeds by late winter.

Although our study suggests that winter AES implementation has positive local effects on farmland birds, it is unknown how this may affect ongoing population declines at larger scales (Princé et al., 2012). In this perspective, previous studies have demonstrated that implementing more and different AES improves habitat suitability for the majority of farmland birds (Redhead et al., 2018; Staggenborg and Anthes, 2022; Roilo et al., 2023). Whether such implementations have to be applied widely across the agricultural landscape (e.g., through land-sharing) or can be grouped/clustered more cost-effectively (e.g., through land-sparing) remains to be investigated. In any case, farmland birds are mobile, and in correspondence with our results, this stresses the importance of considering the implementation of AES on a wider scale, reinforcing the general conception that creating diverse, heterogeneous landscapes will provide suitable winter resources for a diverse community of wintering farmland birds. By offering complementary resources, such as hedges (for cover) and semi-natural grassland (summer resources), in combination with WBC (winter food resource), it is expected that negative effects of intensive agriculture on farmland bird communities can, at least partly, be mitigated.

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Declaration of Competing Interest

The authors declare no competing interests.

Data Availability

The data used in this study are confidential and the property of the Flemish Land Agency. They are not publicly available, but can be requested to be made available for research purposes.

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Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.gecco.2023.e02533.

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