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Effects of fertilizer application on summer usage of cereal fields by farmland birds in central Hungary

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Capsule Despite negative effects of inorganic fertilizer on weeds and invertebrates in cereal fields, impacts on bird usage were weak and non-linear.
Aim To assess the effects of inorganic fertilizer application to winter cereals on breeding-season usage by farmland birds.
Methods We measured bird usage of winter-sown cereal fields across a gradient of inorganic fertilizer inputs and tested for influences of management intensity and availability of semi-natural habitat on species richness and abundance of farmland birds.
Results Avian species richness and bird abundance were unrelated to fertilizer inputs, and declined at higher levels of total vegetation cover. Sky Lark abundance increased, while Yellow Wagtail counts declined with the extent of semi-natural habitat. Sky Lark abundance increased with vegetation cover and peaked at an intermediate level of weed species richness. Yellow Wagtail counts peaked at intermediate levels of fertilizer inputs.
Conclusions Compared with much of western Europe, cereal production in central Hungary is characterized by modest fertilizer inputs and large areas of semi-natural habitat. There was little evidence that increased applications of fertilizer are likely to have negative impacts on farmland birds, although increased application might reduce habitat suitability for Yellow Wagtails. Loss of semi-natural habitat is likely to have negative impacts on Sky Larks.

Negative impact of agricultural intensification on biodiversity is a global problem (Söderström *et al.* 2003, Semwal *et al.* 2004, Brennan & Kuvlesky 2005). It is especially important in Europe, where farmland accounts for 45% of the land area (Stoate *et al.* 2009). Approximately 60% of European farmland is devoted to arable cultivation. Intensive management practices encouraged by the Common Agricultural Policy (CAP) have had severe adverse effects on farmland biodiversity in the first 15 member states of the European Union (EU) (Donald *et al.* 2006). For example, the abundance of common farmland birds in the UK was reduced by 42% between 1970 and 2002 (Gregory *et al.* 2005) and similar declines have been reported from Spain, Italy and Portugal (Suárez *et al.* 1997, Laiolo 2005, Moreira *et al.* 2005). In central and eastern European (CEE) countries like Hungary, agricultural production declined following the collapse of the socialist political system in the early 1990s, resulting in more extensive agricultural management (Báldi & Faragó 2007, Stoate *et al.* 2009). The area of semi-natural habitats, such as extensively grazed grassland, remains relatively high in CEE countries (Donald *et al.* 2002) and biodiversity is consequently relatively abundant compared with western Europe. There is some evidence that previously declining species have experienced recent partial recoveries in Hungary (Szép & Nagy 2006, Báldi & Faragó 2007). However, there is also evidence of a decline in farmland bird populations since the political changes in some CEE countries (Reif *et al.* 2008, Sanderson *et al.* 2009). This period was characterized by localized management intensification (concentrated on the

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more agriculturally productive land), loss of semi-natural habitat and land abandonment (Donald *et al.* 2002, Herzon & O'Hara 2007).

In a country such as Hungary, where agriculture accounts for two-thirds of the land area and farmland supports nearly two-thirds of the protected species, preservation of biodiversity relies on sustainable and environmentally sensitive production systems. Several previous studies suggest extensive agricultural management has positive impacts on farmland birds in grasslands (Verhulst *et al.* 2004, Báldi *et al.* 2005, Batáry *et al.* 2007, Erdős *et al.* 2007). Conservation tillage-established crops were used by larger numbers of wintering birds (Field *et al.* 2007). In this study, we tested whether Hungarian farmland birds were sensitive to cereal management intensity, in particular to inputs of inorganic fertilizers. The nitrogen content of fertilizer is a widely used indicator of agricultural management intensity, mainly because of its impacts on vegetation structure and plant communities in cultivated fields (Kleijn *et al.* 2009). In the cereal fields considered in this study, fertilizer application enhanced crop growth and cereal cover which out-competed slower-growing weeds. Fertilizer application, therefore, had a negative impact on the abundance of nutrient-sensitive plants (especially native weed species); an application rate of 270 kg N/ha/year reduced weed species richness by 60% and total weed cover by 45% (Kovács-Hostyánszki, Batáry, Báldi & Harnos 2011). Higher fertilizer inputs were also associated with reduced invertebrate diversity (20% reduction of spider species) and abundance (65% reduction of bees) (Batáry *et al.* 2008, Kovács-Hostyánszki, Batáry & Báldi 2011). We hypothesize that the reduced weed and arthropod abundance, and/or the dense crop-dominated vegetation structure that is characteristic of highly fertilized cereal fields, would reduce the suitability of the most fertilized fields to foraging and nesting farmland birds.

As well as local field management, farmland bird density might also be influenced by habitats in the surrounding landscape (Benton *et al.* 2003, Herzon & O'Hara 2007). Mixed farming systems and non-cropped habitats are often associated with enhanced farmland bird species richness and abundance, although these effects are often species-specific (Fuller *et al.* 2004, Erdős *et al.* 2007, Batáry *et al.* 2010). Moreover, plant species richness in our study area was higher in cereal fields close to semi-natural habitats (Kovács-Hostyánszki, Batáry, Báldi & Harnos 2011).

Here we present an analysis of the effects of inorganic fertilizer application, weed species richness, vegetation and landscape structure on the abundance (and species richness) of birds using winter-sown cereal fields during the spring breeding season. We hypothesize that fertilizer application has a negative influence on field suitability for farmland birds as a consequence of its impacts on crop structure and prey density (both weed seeds and invertebrates). We also predict that the availability of nearby semi-natural habitats might increase the abundance or species richness of farmland birds using the adjacent cereal fields.

METHODS

Study area

Study sites were situated in the upper Kiskunság, central Hungary (46° 95′ N, 19° 17′ E; for a map see Batáry *et al.* (2008)). Eighteen study fields (15 wheat and three barley, all winter-sown) were selected based on farmer questionnaires of fertilizer and pesticide application rates. We defined seven levels of land-use intensity based on application rates of nitrogen fertilizer: 0, 34, 68, 92, 100, 113 and 270 kg N/ha/year. Three winter cereal fields were selected in each of these categories except the first (no fertilizer use) and sixth (113 kg N/ha/year) for which only one and two fields were available respectively. Herbicides were applied once to 17 of the 18 study fields, and this variable was, therefore, excluded from the analyses. All insecticide applications occurred after the final bird survey, so this factor was also excluded from the analyses. Mechanical aspects of management (e.g. harrowing, ploughing) were similar on all fields. The landscape was composed of a matrix of semi-natural grasslands and arable fields with scattered small woodlots and farms. The average arable field size was 57.1 ha (range: 9–172 ha) (for further management details see Kovács-Hostyánszki, Batáry, Báldi & Harnos (2011)).

Sampling methods

We used point count methods to survey breeding and foraging birds based on the Common Bird Census method in Hungary (Szép & Nagy 2002). Bird counting was performed twice (once in April and once in May) during 2005. A single point count comprised a 10-minute watch during which all birds were recorded by sight or sound within 100 m of the sampling point, omitting field boundaries. Censuses were only carried out under good weather conditions (no rain, little wind), from sunrise until 10 am. Birds were counted at a total of 84 points spread across the 18 study fields (an

Table 1. Coefficients of Spearman correlation between the fertilizer nitrogen (kg/ha/year) used in winter cereal fields and the listed vegetation parameters.

	Fertilizer nitrogen	Vegetation cover	Weed cover
Weed species richness	−0.448	0.151	0.715
Vegetation cover	0.127	1	0.316
Weed cover	−0.237	0.316	1

Vegetation cover is the sum of crop and weed cover.

average of 12 points per fertilizer application level). Most parts of the fields were covered by the census and points were not allowed to be close to field boundaries.

Vegetation was assessed along 95-m transects in each cereal field during the first week of June 2005. One transect was sampled in the interior of each cereal field (i.e. at least 50 m from the field edge) and these data were related to all bird census points within that field. Ten quadrats (1 m × 5 m) were sampled at 5-m intervals along each transect. Within each quadrat we scored the species richness of weeds, total vegetation cover at ground level (crop + weeds) and height (including cereal). Weed species richness was strongly correlated with weed cover ($r_s = 0.71$, $P < 0.001$) and negatively correlated with fertilizer application rate ($r_s = -0.45$, $P = 0.018$) (Table 1).

Landscape structure was measured by mapping key habitat categories within a 500-m radius of each census point. Within these circles, six land-use categories were recognized: arable field; extensively grazed grassland; deciduous woodland; marshy habitat (usually reed *Phragmites australis* habitats); open water; and built-up area (for further details see Batáry *et al.* (2007)). Percentage semi-natural habitat was defined as the sum of grassland (ranges: 0–60%), woodland (0–46%) and marshy habitats (0–23%).

Statistical analysis

From the two bird census rounds, we used the higher count for each species at each point in the analyses (Bibby *et al.* 1992). We analysed bird species richness and total bird abundance. Sky Larks *Alauda arvensis* and Yellow Wagtails *Motacilla flava* were sufficiently numerous to be analysed separately. We used GLMMS to test for relationships between bird counts and the following potential explanatory variables: percentage of semi-natural habitat,; field area; nitrogen application rate; total vegetation cover; and weed species richness. Statistical models were built in three stages. First, we tested for linear and quadratic relationships involving percentage of semi-natural habitat and field area. Secondly, we tested for relationships involving nitrogen application rate (linear and quadratic) having allowed for any effects of semi-natural habitat or field area. Finally, we tested for any additional relationships involving total vegetation cover and weed species richness, having allowed for any effects of semi-natural habitat, field area or fertilizer inputs. At each stage, quadratic terms were dropped if they failed to achieve statistical significance ($P < 0.05$). Normal errors were specified for models analysing bird species richness and total bird abundance while Poisson errors with logit link function were used for Sky Lark and Yellow Wagtail counts. We allowed for the non-independence of census points located within the same field by including 'FIELD' as a random factor. All analyses were performed using the NLME and MASS packages of the R software (version 2.9.0; R Development Core Team 2009, Venables & Ripley 2002, Pinheiro *et al.* 2005).

RESULTS

A total of 682 individuals of 28 bird species were detected (22 species with 415 individuals in April and 18 species with 265 individuals in May) and the sum of maximum counts came to 536 individual birds for data analyses (Appendix). The only variable to influence species richness was total vegetation cover, with fewer species (and total individual birds) being recorded in fields with vegetation cover scores higher than approximately 85% (Table 2; Fig. 1). Total bird counts were also higher in larger fields. Sky Lark abundance increased with the extent of semi-natural habitat in the landscape (Fig. 2a), fell in fields larger than approximately 100 ha, increased with total vegetation cover, and peaked at a weed species richness of approximately 21 species (Table 2; Fig. 3). Yellow Wagtail abundance declined with the extent of semi-natural habitat (Fig. 2b), increased with field area and was lower at the highest fertilizer application rate (Table 2; Fig. 4).

DISCUSSION

This study investigated the effects of fertilizer application on the distribution of farmland birds in Hungarian winter cereal fields by taking into account factors such as vegetation and landscape structure. The application rate of inorganic fertilizer, a proxy for management intensity (Kleijn *et al.* 2009), had little impact on bird usage except in the case of Yellow Wagtails, where

Table 2. The results of the GLMMs investigating local- and landscape-scale effects in one model on the species richness and abundance of birds and on the two most abundant bird species in the Hungarian winter cereal fields.

	Species richness			Total abundance			Sky Lark			Yellow Wagtail		
	df	*F*	*P*	df	*F*	*P*	df	*F*	*P*	df	*F*	*P*
Semi-natural habitat (%)[a]	64	1.15	0.288	64	2.61	0.111	63	11.33	**0.001** +	64	36.51	<0.001 –
Quadratic (semi-natural habitat)												
Field area	64	1.60	0.211	64	8.70	**0.004** +	63	0.76	0.387	64	8.16	**0.006** +
Quadratic (field area)							63	19.36	**<0.001 –**			
Fertilizer nitrogen	13	0.06	0.805	13	0.52	0.482		0.05	0.820	13	0.87	0.369
Quadratic (fertilizer nitrogen)										13	10.56	**0.006 –**
Vegetation cover	13	0.00	0.957	13	0.17	0.689	13	9.58	**0.009** +	13	0.08	0.785
Quadratic (vegetation cover)	13	5.20	**0.040 –**	13	7.02	**0.020 –**						
Weed species richness	13	0.16	0.693	13	1.97	0.184	13	6.39	**0.025** +	13	0.25	0.629
Quadratic (weed species richness)							13	8.90	**0.011 –**			

Owing to the backward stepwise selection the final models retain only the main effects and the significant quadratic terms of the independent variables. The direction of the effects is indicated by " + " (positive) and "–" (negative) effect; [a]percentage of semi-natural habitats (sum of grassland, forest and marshy habitat) in 500-m radius circle around the bird census points; significant effects are in bold.

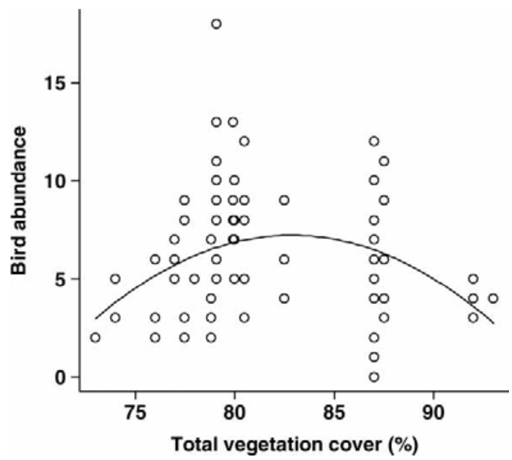

Figure 1. Bird abundance in relation to vegetation cover in winter cereal fields.
Note: The fitted line is derived from GLMM parameter estimates.

relatively few birds were counted in the most heavily fertilized fields. Nitrogen application rates in most of our study fields were typical for winter cereal fields in Hungary (e.g. 60–100 kg N/ha/year), compared with much heavier average application rates in the UK (250–300 kg N/ha/year), the Netherlands (150–200 kg N/ha/year) or elsewhere in western Europe (Chamberlain *et al.* 2002, Robinson & Sutherland 2002, Kleijn *et al.* 2006, Marshall *et al.* 2006). Our general failure to detect more negative impacts of fertilizer inputs on bird usage may in part be because of the relatively small number of fields in the study with high levels of fertilizer inputs (e.g. only three fields above 113 kg N/ ha/ year). However, previous studies on the same set of fields have detected marked impacts of fertilizer applications on weeds and invertebrate communities (e.g. applications of 270 kg N/ha/year were associated with reductions in species richness of nutrient-sensitive plants of 60% and their cover of 45%, reductions in spider diversity of 20%, and bee abundance of 65% (especially solitary bees); Batáry *et al.* 2008, Kovács-Hostyánszki, Batáry, Báldi & Harnos 2011, Kovács-Hostyánszki, Batáry & Báldi 2011). Maybe our failure to detect wider impacts of fertilizer application on total bird abundance was because of variable species-specific effects and/or a genuine lack of underlying association between breeding distributions and food resources in a few numerically dominant species, most notably Sky Larks (Appendix). The positive association between Sky Lark abundance and semi-natural habitat might allow Sky Larks to buffer any lack of food in highly fertilized cereal fields by exploiting prey resources in neighbouring semi-natural grassland.

Indirect effects of management intensity were evident for total bird species richness and abundance; both these measures of bird usage declined at higher levels of vegetation cover (Table 1). Low and intermediate fertilizer application rates (e.g. 60–100 kg N/ha/year) were associated with a relatively sparse and species-rich weed flora (Kovács-Hostyánszki, Batáry & Báldi 2011) while higher application rates often produced tall, dense crop structures (with high vegetation cover scores) that may have lacked bare ground for nesting

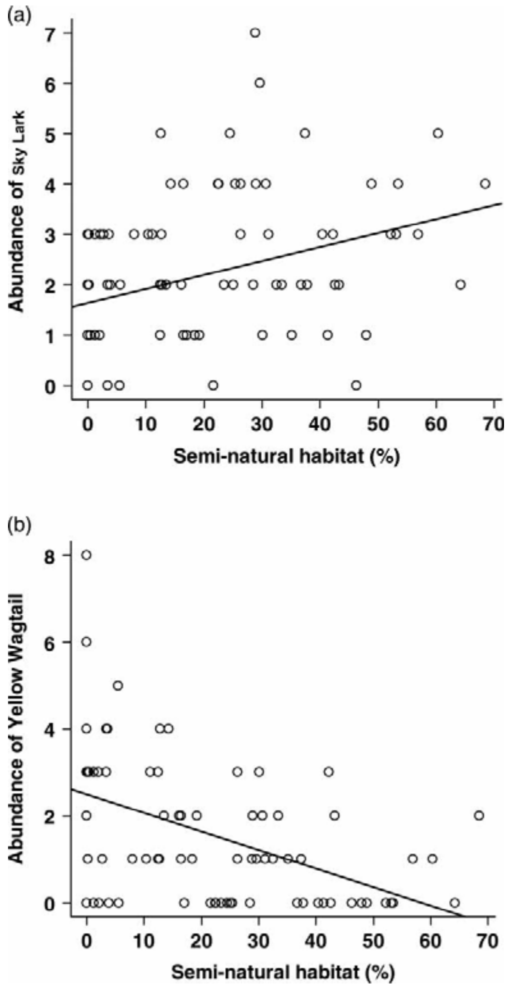

Figure 2. Abundance of (a) Sky Lark and (b) Yellow Wagtail in relation to the proportion of semi-natural habitats in a 500-m radius around the bird census point. The fitted line is derived from GLMM parameter estimates.

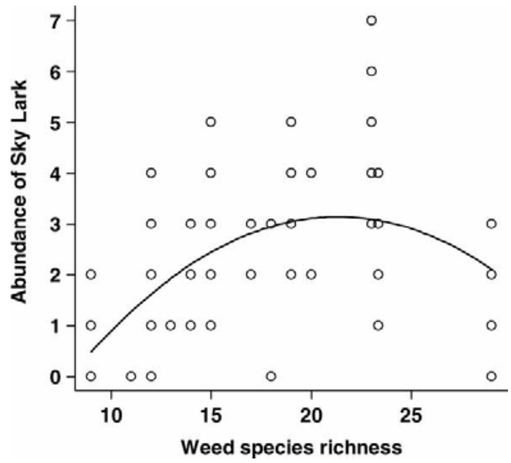

Figure 3. Sky Lark abundance in relation to weed species richness. The fitted line is derived from GLMM parameter estimates.

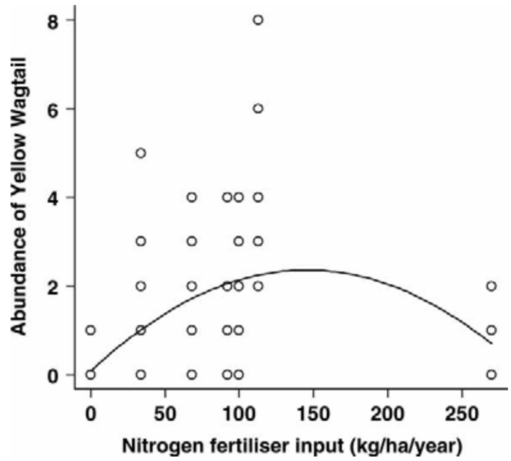

Figure 4. Yellow Wagtail abundance in relation to nitrogen fertilizer application (kgN/ha/year). The fitted line is derived from GLMM parameter estimates.

or inhibited access for birds to prey (Moorcroft *et al.* 2002, Schaub *et al.* 2010). The positive influence of field area on total bird abundance probably reflects a tendency for species like Yellow Wagtails and Quail to prefer larger fields.

The two most abundant species, Sky Larks and Yellow Wagtails, were affected by management and landscape, but in different ways. Sky Larks preferred localities providing a relatively high proportion of semi-natural habitat (especially extensively grazed grassland, which is a preferred nesting and foraging habitat in Hungary (Erdős *et al.* 2009)), and avoided the largest cereal fields. The generally positive influence of weed species richness on Sky Lark abundance (Fig. 3) probably reflects the enhanced abundance and diversity of seed and invertebrate prey in those fields (Poulsen *et al.* 1998, Mason & Macdonald 2000, Batáry *et al.* 2007). All four relatively low Sky Lark counts at high weed species richness (Fig. 3) were observed in the largest cereal field, which might reflect a negative influence of field area.

In contrast, Yellow Wagtails were more abundant in larger fields in localities with less semi-natural habitat. A strong preference for nesting in cereal fields during the early part of the breeding season has also been described in the UK, followed by a shift to more open crops for second nesting attempts (Gilroy *et al.* 2010). We cannot be sure that Yellow Wagtails continued using cereal fields for second nesting attempts in our study area. The preference of Yellow Wagtails for large arable fields in the landscape seems to be a general characteristic of the species (in England, Mason & Macdonald (2000); in Germany, Stiebel (1997)). Yellow Wagtail abundance was the highest at intermediate fertilizer application rates (60–100 kg N/ha/year), possibly reflecting a trade-off between their preference to nest in relatively dense vegetation (Bradbury & Bradter 2004), which in this region may require fertilization (Smit *et al.* 2008), and their need for abundant invertebrates (which is hindered by fertilizer application; Kovács-Hostyánszki, Batáry, Báldi & Harnos 2011, Kovács-Hostyánszki, Batáry & Báldi 2011). Alternatively, high rates of inorganic fertilizer application might be associated with compacted soils and/or lower soil organic matter and hence reduce the suitability of those fields for Yellow Wagtails, probably as a consequence of reduced invertebrate prey availability (Gilroy *et al.* 2008).

We acknowledge that the relatively low number of fields in this study will have limited our power to detect underlying relationships between agricultural intensification and abundance or species richness of farmland birds. However, we suggest that the conservation of farmland bird diversity in cereal-dominated areas of Hungary depends on the maintenance of extensive farming practices and associated semi-natural habitats (particularly grassland). In this study we showed that further intensification of cereal management and loss of semi-natural grassland is likely to have negative impacts on the most abundant farmland bird species. Previous studies have highlighted the importance of extensively and traditionally managed arable fields and semi-natural grasslands for several taxa in Hungary (Batáry *et al.* 2007, 2008, Kovács-Hostyánszki, Batáry, Báldi & Harnos 2011, Kovács-Hostyánszki, Batáry & Báldi 2011, Verhulst *et al.* 2004). Therefore, agri-environment measures in central Hungary should support a landscape with extensive cereal production (<100 kg N/ha/year), and with a high proportion of semi-natural grasslands to promote a variety of bird species. In contrast with western European countries, where habitat heterogeneity is suggested as one important factor limiting farmland biodiversity (Benton *et al.* 2003), the maintenance of extensive, open, semi-natural habitats may be more important in central Europe (Batáry *et al.* 2011, Sanderson *et al.* 2009). Hence some characteristic and abundant farmland bird species in these regions are associated with open habitats and avoid woodland edges, for example (Sanderson *et al.* 2009). Given the large-scale and pervasive changes in agricultural practices in the new member states of the EU since accession and those expected in the future, further studies of the effects of expected land management changes (including intensification of crop management, loss of semi-natural habitats and land abandonment) are urgently needed.

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APPENDIX

Bird species observed in winter cereal fields in central Hungary (2005) during the two occasions of the bird census.

Species		No. individuals observed	
		April	May
Sedge Warbler	*Acrocephalus schoenobaenus*	0	1
Sky Lark	*Alauda arvensis*	176	97
Swift	*Apus apus*	10	4
Goldfinch	*Carduelis carduelis*	7	2
Greenfinch	*Carduelis chloris*	1	0
Marsh Harrier	*Circus aeruginosus*	5	4
Montagu's Harrier	*Circus pygargus*	1	0
Wood Pigeon	*Columba palumbus*	7	0
Hooded Crow	*Corvus corone cornix*	0	2
Rook	*Corvus frugilegus*	5	5
Quail	*Coturnix coturnix*	32	25
Cuckoo	*Cuculus canorus*	1	2
House Martin	*Delichon urbica*	1	0
Corn Bunting	*Emberiza calandra*	2	2
Kestrel	*Falco tinnunculus*	7	2
Red-footed Falcon	*Falco vespertinus*	0	6
Chaffinch	*Fringilla coelebs*	1	0
Swallow	*Hirundo rustica*	37	22
Bee-eater	*Merops apiaster*	0	1
Yellow Wagtail	*Motacilla flava*	112	85
Golden Oriole	*Oriolus oriolus*	1	0
Tree Sparrow	*Passer montanus*	0	2
Pheasant	*Phasianus colchicus*	1	2
Chiffchaff	*Phylloscopus collybita*	1	0
Stonechat	*Saxicola torquata*	2	0
Whinchat	*Saxicola rubetra*	0	1
Starling	*Sturnus vulgaris*	4	0
Lapwing	*Vanellus vanellus*	1	0

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