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Contrasting population trends of Common Starlings (*Sturnus vulgaris*) across Europe

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The greatest loss of biodiversity in the EU has occurred on agricultural land. The Common Starling (*Sturnus vulgaris)* is one of the many numerous and widespread European farmland breeding bird species showing major population declines linked to European agricultural intensification. Here we present results based on monitoring data collected since 1975 in 24 countries to examine the influence of changing extent of grassland and cattle abundance (based on results of earlier studies showing the importance of lowland cattle grazed grassland for the species), wintering provenance and temperature on national breeding population trends of Starlings across Europe. Positive Starling population trends in Central-East Europe contrast with negative trends in North and West Europe. Based on this indicative approach, we found some support for the importance of cattle stock and no support for grassland, temperature or wintering provenance to explain Starling population trends in Europe. However, we acknowledge such a European-wide analysis may conceal regional differences in responses and suggest that currently accessible national land use data might be insufficient to describe the detailed current changes in animal husbandry and grassland management that may be responsible for changes in food availability and hence breeding Starling abundance and their differences across Europe. Reviewing results from local studies relating Starling population trends to local agricultural change offer contradictory results, suggesting complex interacting processes at work. We recommend combining national datasets on demography, land-use/agricultural practices and from autecological research to better explain the reasons for contrasting Starling trends across Europe, to enable us to predict how changing agriculture will affect Starlings and potentially suggest mitigation measures to restore local populations where possible.

1. Introduction

The greatest loss of biodiversity in the EU has reportedly occurred on agricultural land (Kleijn *et al.* 2011). Many farmland birds have exhibited severe (> 50%) population declines, at least since the 1980s (EBCC 2017a, Gamero *et al.* 2017). Individual species trends reflect specific changes in land use (e.g., Gillings *et al.* 2005), so meadow specialists have shown rapid declines in abundance in recent years (e.g., Bowler *et al.* 2018), especially species that feed on invertebrates associated with agricultural grasslands (Bowler *et al.* 2019). EU policies operating at large spatial scales appear to have helped attenuate declines of some farmland birds but not stopped them (Gamero *et al.* 2017), while the Common Agricultural Policy as a whole have had detrimental effects at the national level in at least one new EU Member state (Reif & Vermouzek 2018). The variation in land use and climate change across Europe may differentially affect a given species across its range, potentially resulting in contrasting regional impacts on its abundance and distribution. Since many bird species are migratory, such changes on the wintering areas may also be carried over to the breeding populations.

The Common Starling (*Sturnus vulgaris;* hereafter Starling) is a numerous and widespread European farmland bird, with highest breeding densities in Western, Central-Eastern and South-Eastern Europe of 7–9 breeding pairs per km^2 on average (Table 1, BirdLife International 2015). It is absent only from the extreme southern and northern areas of Europe (Hagemeijer & Blair 1997). Since the majority of the Starlings in the study area are short-distance migrants, conditions outside the breeding season may also have an impact on the populations. Starlings are predominantly grassland invertebrate feeders, often breeding in association with human habitation, making them familiar and popular birds of societal interest. Starlings are cavity breeders that forage within a few hundred metres from the nest site, emphasizing their specific habitat demands close to this (Tinbergen 1981, Smith & Bruun 2002, Bruun & Smith 2003, Heldbjerg *et al.* 2017). Grassland areas are also important foraging areas outside the nesting period, not least for the juvenile Starlings that gather in huge foraging flocks immediately after the breeding season.

Major declines in farmland Starling breeding abundance have been linked to the general intensification of European agriculture (Donald *et al.* 2001, 2006). Contrasting trends between regions within Denmark were related to differences in farming practices as declines in Starling abundance were positively correlated with the loss of high intensity grazing pressure by cattle (Heldbjerg *et al.* 2016).

Local Danish breeding Starling density was closely associated with foraging habitat structure and quality when feeding for provisioning young (Heldbjerg *et al.* 2017). The adult birds avoided high and closed crops and selected low/open crops especially short grass, particularly those grazed by horses and cattle, probably because such open grasslands provide the most available and accessible prey (Devereux *et al.* 2004).

However, it is less clear how these patterns are linked to Starling population trends in other countries, at regional and continental levels.

Here we analyse data from most of Europe to assess whether the patterns revealed, with regards to changes in Danish agriculture, are manifest throughout Europe. We here modelled the extent to which national Starling trends over the last four decades varied across Europe on a temporal and/or spatial (national/regional) scale. We investigated the degree to which changes in agricultural practices (as trends in grassland area and cattle numbers) based on experiences in Denmark, best explained variation in national population trends. We also simultaneously examined the effects of climatic changes (as the trend in annual mean spring temperature), which could benefit productivity through more second broods (Thellesen 2017, van Turnhout *et al.* 2016), but may also lead to drier conditions, which could adversely affect foraging and winter distribution (as the proportion of the Starlings that overwinter in major wintering areas).

2. Material and methods

2.1. Data

Most European countries have national common bird monitoring schemes, with volunteer ornithologists collecting data on relative species abundances, employing an array of various but standardized methods. Combined European population trends for Starling have been published under the Pan-European Common Bird Monitoring Scheme (PECBMS, www.pecbms.info), which collates all national/regional European bird-monitoring programmes at a European scale. National annual indices with standard errors are comparable between countries despite differences in field data collection methods (Gregory *et al*. 2005, EBCC 2017b) and are used to compute supranational species indices and trends.

We used Starling abundance indices from 24 national monitoring schemes within PECBMS. We applied a modelling approach to explain national changes in abundance by incorporating six explanatory variables (described in more detail below): (i) breeding region, (ii) time period, (iii) the percentage of a country's Starling population wintering in the Atlantic region, (iv) mean annual change in national number of cattle, (v) mean annual change in grassland area (land under permanent meadows and pastures, which Starlings are highly selective for and therefore is considered a more sensitive variable to explain changes in Starling abundance than the total area of farmland) and (vi) mean annual change in spring temperature (the trend in variables iv – vi is within each time period).

(i) Breeding Regions
We followed the PECBMS definition of five breeding regions, representing different climate and landscape zones of Europe, which affects agricultural practice. These were: "Central-East" (CE: Czechia, Estonia, Hungary, Latvia, Poland, Slovakia, Slovenia), "North" (N: Finland, Norway, Sweden), "South" (S: France, Italy, Spain), "South-East" (SE: Bulgaria, Greece, Romania) and "West" (W: Austria, Belgium, Denmark, Germany, Ireland, The Netherlands, Switzerland, UK), (EBCC 2017a). However, in contrast to PECBMS, we were constrained to group East Germany with Germany in the West region due to the availability of national land use information and grouped Slovenia with CE to avoid a single-country-region (see Appendix Section 1).

(ii) Time Periods
We chose three time periods with at least seven years of data (A: 1975–1990, B: 1990–2004 and C: 2004–2014), to calculate the slope of the regression for each combination of country and period (Table 1). We used two breakpoints; 1990 because of political changes in CE starting to influence agriculture at that time (Donald *et al.* 2001) and 2004 when most of the new EU Member States entered EU, which is known to affect patterns of agricultural land-use (Reif & Vermouzek 2018) due to the EU Common Agricultural Policy (CAP) (after EBCC 2017a, Table 1).

(iii) Wintering areas (AW)
Starlings generally migrate west or southwest to winter in coastal countries (Fliege 1984), so we crudely assigned migration either to the Atlantic or Mediterranean regions. Breeding Starlings from Lithuania, Poland and Germany all partly winter in countries in both coastal regions, but the vast majority of Starlings from further north and west winter in the Atlantic region, whereas those to the south and east winter in the Mediterranean (Fliege 1984). We calculated the ratio (AW) of Starlings wintering in the Atlantic region relative to the Mediterranean region, based on EURING breeding bird recovery data from each country for which data were available (HH, unpublished results). The AW value was entered into the model as a probability for each country from 0 (none of the breeding birds wintered in the Atlantic region (e.g., Italy)) to 1 (almost all wintering there (e.g., the Netherlands)). Spain and France were scored as 0.5 AW, since they are situated in both Atlantic and Mediterranean regions.

(iv)–(vi) Habitat availability and temperature
To test whether national population trends of Star-

Table 1. Overview of countries and their assignment to regions (W = West, N = North, CE = Central-East, S = South and SE = Southeast), first year of Common Bird Monitoring, Starling trends in three periods (A = 1975–1990, B: 1990–2004, C: 2004–2014), first year included in the model, Atlantic Winter Range ratio and region of Europe used in the current analysis and the national population sizes (Birdlife International 2015).

Country	CBM First year	Starling trend Period A	Starling trend Period B	Starling trend Period C	Model First year	Atlantic Winter Range (%)	PECBMS region	Population size 2011 (×1,000)
United Kingdom	1966	–0.014	–0.023	–0.025	1975	100	W	1,700–2,200
Finland	1975	–0.050	–0.004	0.003	1975	100	N	52–67
Sweden	1975	–0.016	–0.011	–0.019	1975	100	N	306–714
Denmark	1976	–0.008	–0.010	–0.018	1976	100	W	270
Czechia[1]	1982	0.016	0.009	0.001	1993	5	CE	1,080–2,160
Estonia[2]	1983	0.027	–0.004	–0.001	1992	99	CE	150–250
Netherlands	1984	–0.012	–0.028	–0.010	1984	100	W	396–713
France	1989		–0.006	–0.007	1990	50	S	2,600–5,200
Germany[3]	1989		–0.004	–0.009	1990	53	W	2,800–4,500
Belgium[4]	1990		–0.008	–0.014	1990	99	W	150–200
Latvia	1995		–0.005	0.0208	1995	100	CE	447–626
Norway	1996		–0.002	0	1996	100	N	55–220
Austria	1998		0.001	–0.017	1998	0	W	140–240
Ireland	1998		0	–0.006	1998	100	W	737–1,915
Spain	1998		0.006	–0.000	1998	50	S	400–1,200
Hungary	1999			0	2004	0	CE	710–990
Switzerland	1999			–0.005	2004	0	W	150–220
Italy	2000			–0.000	2004	0	S	800–2,000
Poland	2000			0.003	2004	61	CE	2,000–2,500
Bulgaria	2005			–0.018	2005	0	SE	800–2,000
Slovakia	2005			0.0111	2005	0	CE	400–800
Greece	2007			0.0306	2007	0	SE	200–390
Romania	2007			–0.014	2007	0	SE	1,500–3,000
Slovenia	2007			0.003	2007	0	CE	180–350

1) Land use data prior to 1993 referred to Czechoslovakia are omitted in this study
2) Land use statistics available from Estonia only since 1992
3) Former East and West Germany are included together in the West region for convenience
4) Land use data for Belgium and Luxembourg were combined until 1999; The values from Belgium are corrected for the share from Luxembourg

lings were related to trends in habitat availability, we included (iv) the national trends in number of head of cattle (ΔCattle) and (v) the area of permanent meadows and pastures (ΔGrass) in each country (derived from www.faostat.com). Finally (vi) we included the change in mean spring (April–June) temperature (ΔTemp) in each country (derived from Climate Change Knowledge Portal (2019)) to see whether such a climatic parameter affected the Starling populations, based on two studies which found a strong effect of climate change on Starling abundance (Chylarecki 2013, Thellesen 2017). All trends were based on linear regression of log-transformed values from a minimum of seven consecutive years within each time period. We found no strong collinearity between the six explanatory variables outlined above ($0.01 < |r| < 0.51$).

Starling population trends

Our response variable was the national periodic population trend estimate (46 in total since each country was divided by up to 3 time periods, i.e., a combination of (i) Breeding Regions and (ii) Time Periods), of which 44 had information on all parameters, Table 1), defined as the mean annual log-transformed population change (hereafter ΔStarling).

Table 2. AICc-information of candidate models to explain variation in population trends of Starlings in European countries. Period (P): 1975–1990 vs. 1990–2004 vs. 2004–2014. ΔGrass (G): annual change in grass cover, ΔCattle (C): annual change in cattle numbers, ΔTemp (T): annual change in temperature, Atlantic Winter range (AW): Percent of the country's breeding population wintering in the Atlantic region, Region (R): see Table 1. wi: Akaike's weights. ER: the evidence ratio of the weight of the model with most support divided by the wi of the model in question.

Model	AICc	dAICc	*wi*	ER
C + R	–265.48	0.00	0.24	1.0
Region (R)	–263.08	2.4	0.07	3.3
Atlantic Winter range (AW)	–262.79	2.69	0.06	3.8
C + AW	–262.54	2.94	0.06	4.3
Period (P)	–262.29	3.19	0.05	4.9
P + R	–262.19	3.29	0.05	5.2
(null model)	–261.98	3.49	0.04	5.7
P + AW	–261.96	3.52	0.04	5.8
AW + R	–261.95	3.53	0.04	5.9
G * C + R	–261.80	3.67	0.04	6.3
ΔCattle (C)	–261.51	3.97	0.03	7.3
G + R	–261.41	4.07	0.03	7.6
P + C	–261.33	4.15	0.03	8.0
G + AW	–261.26	4.22	0.03	8.2
P + T	–261.17	4.31	0.03	8.6
T + R	–261.08	4.39	0.03	9.0
P + G	–260.81	4.67	0.02	10
ΔGrass (G)	–260.59	4.89	0.02	12
P * R	–260.41	5.07	0.02	13
C + G	–260.06	5.42	0.02	15
C * R	–260.00	5.48	0.02	15
ΔTemp (T)	–259.98	5.49	0.02	16
C + T	–259.51	5.97	0.01	20
G + T	–258.59	6.89	0.01	31
C * G	–258.18	7.30	0.01	38
G * R	–256.13	9.34	0.00	107

2.2. Population modelling

We explained ΔStarling using combinations of the six predictor variables as main effects in a linear mixed-effects model with Country as random effect to control for non-independence of observations belonging to the same population. Predictor variables were: period (P: A, B or C), region (R: CE, N, S, SE and W), proportion of the national population wintering in the Atlantic region (AW), ΔCattle, ΔGrass and ΔTemp. To give the most precise estimates of ΔStarling the highest weight, the individual trends were weighted by the inverse value of the ΔStarling standard errors. Models without weights gave similar results and are not included here. We only selected 26 models (including a model with no fixed effects, the base model) with parameters that we considered biologically meaningful, which included interactions between some of the variables: (i) period × ΔGrass and (ii) period × ΔCattle, to account for temporal changes in land use, (iii) period × region, to account for spatio-temporal differences in population dynamics and (iv) ΔCattle × ΔGrass, to account for any interaction between these land use factors (Table 2). All the analyses were conducted using program R version 3.5.1 R Core Team 2018). We used R-package lme4 (Bates *et al.* 2015) and lmerTest (Kuznetsova *et al.* 2017) to run the linear mixed effect models.

We used an information criteria based model selection approach to identify the most parsimonious statistical models to explain variation in the trends. These were identified on the basis of AICc-values and derived Akaike's weights (*wi*) (Burnham *et al.* 2011) from maximum likelihood

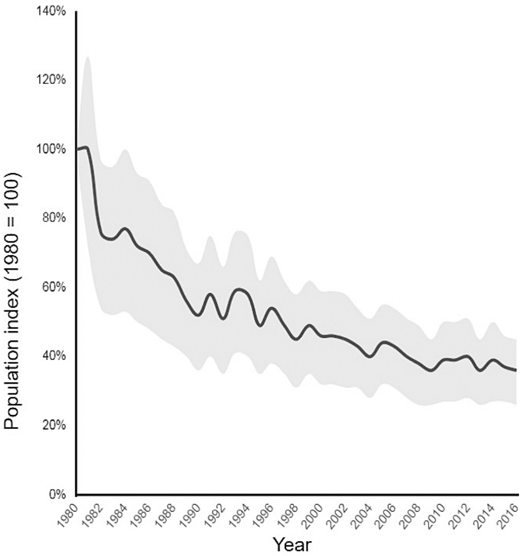

Fig. 1. Pan-European indices for Starling (*Sturnus vulgaris*) 1980–2016 (Index 100 = 1980) with 95% confidence limits based on data from PECBMS (Pan-European Common Bird Monitoring Scheme, data source: EBCC/BirdLife/RSPB/CSO).

optimization. We evaluated a total of 25 candidate models comprising main effects from 1–2 predictor variables (N = 20) and 5 models comprising the main effects and the interaction terms of two predictors. The parsimony of these models was contrasted with the "base model" (no fixed effects), which only comprised the intercept measured as the evidence ratios (*ER*s) of the model's Akaike's weights (Burnham *et al.* 2011).

3. Results

There was a general and continuous moderate decline in the overall European population of Starlings in 1980–2015, corresponding to 68% decline throughout (EBCC 2017b, Fig. 1), but with considerable variation between individual countries (Fig. 2) and with major and often contrasting differences between breeding regions over the study period (Fig. 3).

The top-ranked model consisted of ΔCattle + Breeding region as the only explanatory variables (Table 2). This model had 5.7 times more support than the base model without covariates (Table 2). No other models had reasonable support within 2 ΔAICc units. We found that long-term changes in

Table 3. Coefficients, their 95% confidence intervals and P-values of the variables in the top ranked model. Variables included were trend in number of cattle (ΔCattle) and breeding regions (R) and the different regions: R-N: North, R-CE: Central-East, R-S: South and R-SE: Southeast.

Variable	Coefficients [95% CI]	P-value
Intercept	–0.0129 [–0.0184 to –0.0074]	< 0.001
Cattle	0.0047 [0.0009 to 0.0085]	0.02
R-N	0.0002 [–0.0096 to 0.0100]	0.97
R-CE	0.0201 [0.0109 to 0.0294]	< 0.001
R-S	0.0087 [–0.0031 to 0.0204]	0.16
R-SE	0.0209 [0.0060 to 0.0359]	0.009

ΔCattle numbers, in combination with region were positively associated with changes in Starling population (P = 0.02; Table 3). However, there was also a large variation in the positive correlation between ΔCattle and ΔStarlings, so despite the proven importance in combination with region, the contribution of ΔCattle in itself was relatively little, which is also apparent from Table 2.

As breeding region turned out to be important as a predictor of long-term changes in Starling numbers, we estimated the mean annual change in Starling numbers by region for each time period as a post hoc operation (Fig. 3). The regional differences for the whole period) revealed statistically significant population decreases [95% CI] of c. 2.62% [2.29–2.95] per year in N Europe (1975–2016), c. 3.43% [2.67–4.19] per year in W Europe (1966–2016), c. 2.44% [0.34–4.54] per year in SE Europe (2005–2016) and c. 1.20% [0.22–2.18] per year in S Europe (1989–2016) contrasting to a significant positive annual trend of about 1.48% [0.65–2.31] in CE Europe (1982–2016) (data from https://pecbms.info/methods/pecbms-methods/, accessed 1. April 2019.

4. Discussion

4.1. Differences in Starling trends in European regions

PECBMS shows an overall decline in Starling abundance across Europe since 1980 (EBCC 2017b). Our analysis indicates that within this overall pattern of decline, there were contrasting

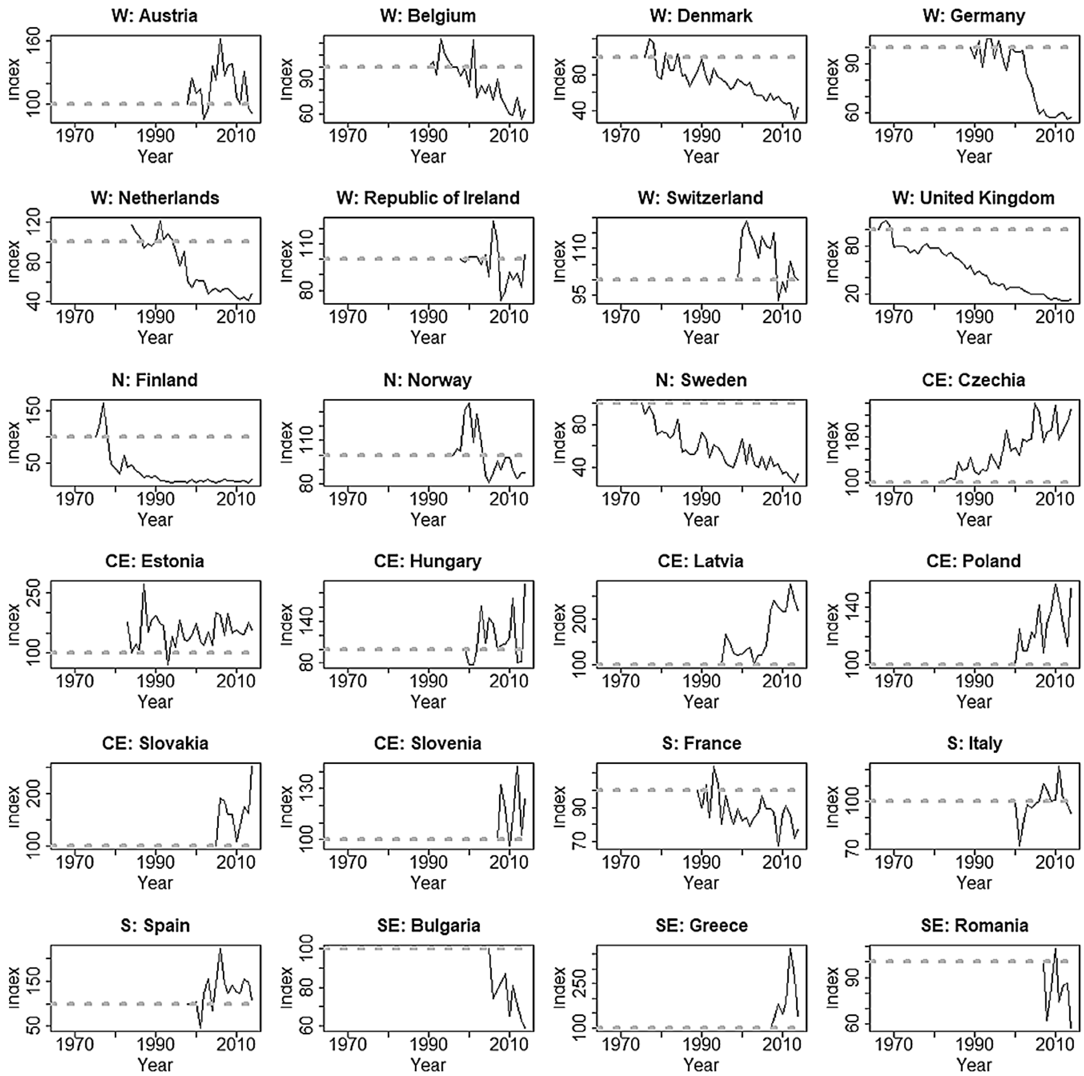

Fig. 2. National indices for Starling (*Sturnus vulgaris*) with indication of European region. The dashed grey lines indicate index = 100. Data provided by PECBMS.

trends at regional and national scales, with significant declines in North and West of Europe, a significant increase in Central-East and no significant trend in South Europe.

4.2. Effect of changes in the land use

As expected, we found support for declines in Starling numbers to be associated with decreases in cattle numbers (dependent upon region). Increasingly, husbandry occurs indoors, with grass cut and transported to cows in stables, a trend likely to have adverse effects on Starling foraging opportunities compared to situations where cattle graze outdoors (Heldbjerg *et al.* 2016). The generally weak support may be because increasing indoor husbandry does not affect national cattle statistics, but the effect is adverse to Starling foraging habitats. To fully investigate this relationship requires knowledge of the changes in numbers of cattle grazing outside, but national statistics for cattle kept indoors versus outdoors are rarely available.

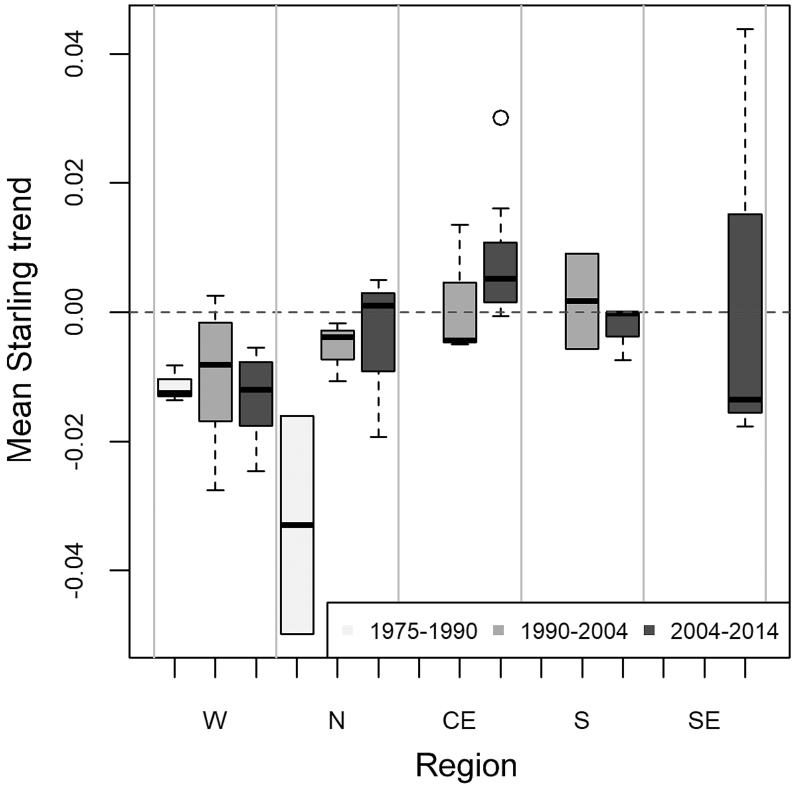

Fig. 3. Boxplot showing regional means of national annual changes derived from least square regression models of Starling abundance. 1975–1990 (in light grey), 1990–2004 (in medium grey) and 2004–2014 (in dark grey). Regional analyses are based on national data aggregated according to breeding regions.

We found no support for any relationships between changes in Starling numbers and changes in area of permanent meadows and pastures. This may be because changes in grassland area indeed have no effect on Starling abundance or more likely that the information on grassland statistics was not detailed enough for this purpose. FAOSTAT data on changes in grassland area may reflect changes in absolute extent, but may mask changes in soil moisture and sward height, grass species composition (reseeded or permanent), grazing use and intensity, mowing frequency, fertilizers and pesticides. All of these factors could also be important measures of habitat quality for Starlings (e.g., Olsson *et al*. 2002).

4.3. Differential patterns of cattle grazing across Europe

Starlings rely largely on agriculture, specifically on cattle and other grazing animals, which maintain short grass swards and in a condition suitable for adult Starlings to successfully provision their young. There are several national examples of how changes in husbandry and grassland management affects Starlings. These case studies are discussed in Appendix Section 2 and suggest that the importance of grazing cattle varies between and within countries, depending on local factors limiting their populations.

Declines in Starling population and in juvenile Starling survival have also been reported to coincide with changes in pastoral farming practice in Finland (Solonen *et al*. 1991), Netherlands (Versluijs *et al*. 2016), United Kingdom (Robinson *et al*. 2005, Freeman *et al*. 2007) and Sweden (Smith *et al*. 2012). In addition, while the number of farms is decreasing across Europe, the sizes of individual farms are increasing (https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Farm_structure_statistics). Due to the limited range of Starling provisioning flights, more farms with cows likely support more Starlings nationally than fewer farms with more cows (Rintala & Tiainen 2007). There is a clear difference in trends of breeding Starlings between Ireland and Britain, where Starlings are showing a serious decline in Britain but are stable/increasing in Ireland (Balmer *et al.* 2013). Could this difference between neighbouring countries be explained by better foraging conditions for the Starlings in Ireland due to much smaller farm sizes and less intensification of keeping cattle indoors? The average size of agricultural holdings has increased everywhere in EU (except Czechia with massive collectivisation after the WWII and subsequent restart of small farming after 1990). Average farm size is generally much higher in West Europe than in Central-East Europe (https://ec.europa.eu/ eurostat/statistics-explained/index.php?title=Farm_structure_statistics), which might contribute to explaining the general population decline across Europe and the contrasting regional trends.

4.4. Variation in the breeding habitat across Europe

The major conclusion from this work is that Central (increasing) and Southern (stable) European Starling populations contrast declining trends in other parts of Europe. The 12 Central and Eastern European countries that joined the EU in 2004 or 2007 generally support higher farmland bird densities than the original 15 member states (Sanderson *et al.* 2013). This may be because of the historical, economic and technological differences in Central-Eastern European agriculture compared to Western Europe where declines have been most dramatic. However, following accession, these countries have also seen declines in specialist farmland birds (Tryjanowski *et al.* 2011, Spasov *et al.* 2017, Reif & Vermouzek 2018).

Farmland landscapes and habitats are much more diverse in Central-Eastern Europe than in Western Europe (Tryjanowski *et al.* 2011). Western European farmland has little (and declining) semi-natural vegetation cover, fixed landscape elements, sharp transitions between managed patches, higher levels of chemical and fertilizer application and generally greater production per unit area (Tryjanowski *et al.* 2011). Consequently, Central-Eastern European farmland bird populations tend to be denser and more stable (Báldi & Batáry 2011, Tryjanowski *et al.* 2011). Noticeable increases in grassland and grassland birds in Czechia (Reif & Hanzelka 2016) as a result of transformation of less productive arable fields to meadows and pastures in the sub-montane areas (see Appendix Section 2) may be similar in neighbouring countries and could potentially contribute to the development of Starling populations in these areas. However, agricultural intensification in Western Europe caused widespread declines among farmland birds in the late 20th century (Donald *et al.* 2006) and comparable changes in Central-Eastern Europe are either predicted in the near future (Tryjanowski *et al.* 2011, Szép *et al.* 2012, Sanderson *et al.* 2013) or are ongoing (Reif & Vermouzek 2018). Intensification can be illustrated by the use of fertilizers; between 2002 and 2014, the application of nitrogen fertiliser per ha cropland increased by 20–40% in the CE and SE regions to the same level as in N and S regions, where levels remained stable in the same period. The level in the W region is higher but now declining (–18%; Data from Faostat http://www.fao.org/faostat/en/#data/EF, approached 13 July 2017).

4.5. Variation in demographic parameters

As we have not been able to clearly assign the differential trends to breeding habitat variables, we should instead try to describe variation in demographic parameters and focus on factors affecting specific traits. Several studies found no corresponding decline in brood size per breeding pair to declining populations (Freeman *et al.* 2007; Versluijs *et al*. 2016; Thellesen 2017), indeed in the UK, production of fledglings per breeding attempt actually increased during 1966–2000 (Freeman *et al.* 2007) and in The Netherlands this parameter showed no significant change over the period 1995–2012 (Versluijs *et al*. 2016). Svensson (2004) suggested that fewer pairs start breeding in declining populations due to habitat deterioration and that this non-breeding, floating part of the population plays a key role in the total dynamics. Some demographic studies have shown that first winter juvenile survival contributed most to Starling population trends in the United Kingdom and the Netherlands (Freeman *et al.* 2007, Versluijs *et al.* 2016). Polish Starlings showed much higher first-year survival (0.45, Kania & Chylarecki, unpublished) than in the Netherlands (c. 0.20, Versluijs *et al.* 2016) and such differences may be of a great importance to understanding contrasting trends between Starlings in West Europe and Central-East Europe. Hence, perhaps we should be looking more at what affects changes in first year survival from specific breeding areas rather than just conditions on breeding areas.

4.6. Alternative explanations for population changes

A potential explanation for differential regional population trends could be geographical variation in the availability of alternative Starling food items due to variation in the chemical control of food resources. The Starling was among the species for which Hallmann *et al.* (2014) found negative correlations between local trends and neonicotinoid concentrations in the Netherlands. Antihelmintics, commonly administered orally to cattle and sheep to expel parasitic worms in the west, are excreted largely unaltered in the dung and retain their insecticidal activity and are known to have negative effects on pasture invertebrate diversity (Jacobs & Scholz 2015) including dung beetles (*Coleoptera: Scarabaeoidea*) known as food items for Starling nestlings (Feare 1984).

Pesticides in general have been shown to have detrimental effects on UK farmland bird populations (Vickery *et al.* 2001) but may only be one of more factors, since specialised farmland birds in Sweden declined despite reductions in pesticides (Wretenberg *et al.* 2006). There may also be natural differences in food resources between regions. Second broods, which are much more abundant in central Europe than further north, where they are mostly absent, are fed a more diverse diet than earlier broods, supplemented by aquatic, arboreal and flying insects and more plant material (Gromadzki 1969), particularly berries (Havlín & Folk 1965).

Starling populations are locally considered pests due to their consumption of cherries, germinating cereals and cattle food and has been controlled by shooting, capture and by destroying roosts using explosives, poisons and detergents, although it is doubtful whether these methods effectively reduced local abundance (Feare 1984). Despite an estimated annual hunting bag of c. 650,000 Starlings in 2014/2015, with the majority of the Starlings shot in France and Spain (Hirschfeld & Attard 2017), such actions at winter roosts seem rarer since the 1970s and hunting is only permissible under the Birds Directive Appendix IIB (Official Journal of the European Union 2010) in Southeast and Southwest Europe. The impact of hunting on different breeding populations remains unstudied, but the present population declines do not coincide with those regions where the greatest hunting is occurring, for example, Polish Starlings (showing higher survival rates) winter in areas subject to Starling hunting whereas Dutch and British Starlings (with a lower survival rate) do not.

Climate change could potentially be a contributory factor to explain regional differences, but model selection could not detect any significant effect of spring temperature at this scale of resolution, for explaining changes in Starling abundance. The mean monthly temperatures in the breeding period (April–June, Climate Change Knowledge Portal 2019) showed a uniform pattern of temperature increase across Europe in 1991–2015 (range 0.016 – 0.074 Celsius per year). Such a temperature increase was shown to be beneficial for the Northern populations of European birds in contrast to Southern populations (Jiguet *et al*. 2010).

Since this is the opposite to the pattern found in this study, we contend that at present this aspect of climate change contributes little to observed changes in abundance across Europe. Starlings have adapted to local conditions to breed from northernmost Scandinavia to the Mediterranean, i.e. birds are subject to large variations in their ambient temperatures. Despite no obvious overall direct effect of variations in temperature changes, there may be indirect effects on Starling populations via regional differences in temperature change-induced effects on their foraging microhabitats, e.g. through prey accessibility. Moreover, precipitation or drought durations may also impact differentially upon populations.

4.7. Importance of monitoring-based research for conservation

Despite the fact that PECBMS provides population indices for 170 common birds in Europe

(EBCC 2017b) and supports various multi-species studies (e.g., Gregory & van Strien 2010, Gamero *et al.* 2017), this study represents the first pan-European collaborative analysis of a single abundant species, illustrating the potential for using this material in relation to species conservation. Even within a given biogeographical region, contrasting agricultural management can result in large variations in other farmland species' density in relation to field size, crop composition and sward height (Koleček *et al.* 2015) and the regional differences in trends offers an opportunity to test specific hypotheses at different scales. Thus, coordinated, comparative research based on information from monitoring programmes across the entire breeding range provides the potential to formulate research questions in the case of contrasting trends and thereby be vital to understand the consequences of land-use change on common birds (Báldi & Batáry 2011).

Reviewing results from local studies relating Starling population trends to local agricultural change offer contradictory results, suggesting complex interacting processes at work. We need to base management recommendations on multiple studies and study sites to understand and resolve the conservation problems of a species across its entire range (Whittingham *et al.* 2007, Mikulić *et al.* 2014). This highlights that conservation measures to counteract the negative effects of farming must consider all geographical scales and landscape structures (Wretenberg *et al.* 2007). For the Starling and probably most other species, it is likely that we need more detailed data on important environmental variables than those we used here to capture the variance between the different areas.

This study focuses on Starlings and farmland. However, woodland and urban areas are also important for breeding Starlings (Robinson *et al.* 2002) and changes in these habitats may also influence overall population abundance. Demographic data, detailed data on land-use and agricultural practices combined with data from autecological research are essential to understand the contrasting Starling trends in Europe and enable us to predict how differential trends in agriculture will affect productivity and survival for Starlings and how we may propagate positive changes for Starlings under the given conditions.

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Kottaraisten kantojen kehitys vaihtelee eri puolilla Eurooppaa

Maatalousympristön monimuotoisuus on vähentynyt voimakkaasti EU:n alueella. Kottarainen (*Sturnus vulgaris*) on yksi runsaista ja laajalle levinneistä Euroopan maatalousympäristön lajeista, jonka kantojen taantumisen on esitetty johtuvan maatalouden tehostumisesta. Tässä työssä selvitimme miten kansalliset kottaraiskantojen vaihtelut ovat yhteydessä laidunalueiden ja karjan määrään, pesimä- ja talvehtimisalueen sijaintiin sekä lämpötilaan käyttäen vuodesta 1975 alkaen kerättyä aineistoa 24 maasta. Kottaraiskannat runsastuivat Keski-Euroopan itäosissa, mutta taantuivat Pohjois- ja Länsi-Euroopassa. Karjan määrän muutokset olivat positiivisesti yhteydessä kottaraismääriin, mutta laidunalueiden määrällä, talvehtimisalueiden sijainnilla tai lämpötilalla ei ollut merkitsevää vaikutusta.

Koska analyysimme on Euroopan-laajuinen ja käytetyt muuttujat maakohtaisia kokoomatietoja, voivat analyysit jättää huomioimatta erilaisia paikallisia vaikutuksia. Tällä hetkellä käytössä olleet kansalliset keskiarvotiedot voivat olla liian epätarkkoja erottamaan eläintilojen ja niittyjen hoidon vaikutusta kottaraisten ruokailumahdollisuuksiin, jolla on puolestaan merkitys lajin runsauteen ja pesimämenestykseen eri puolilla Eurooppaa. Paikalliset kottaraistutkimukset antoivat ristiriitaisen kuvan kannankehityksien ja alueellisten maatalouden muutosten yhteydestä, mikä viittaa erilaisiin alueellisiin vuorovaikutussuhteisiin.

Suosittelemme yhdistämään kansalliset aikasarjat demografisiin ja yksilöekologisiin aineistoihin, jotta voisimme paremmin ymmärtää kottaraisten erisuuntaisia kannankehityksiä Euroopassa. Tämä mahdollistaisi myös ennustamaan miten maatalouden muutokset voivat vaikuttaa kottaraiskantoihin tulevaisuudessa ja millä hoitokeinoilla taantuneita kantoja voitaisiin elvyttää.

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Appendix

Section 1. Administrative borders

Changes in national administrative borders create challenges to such analyses. Germany consisted of two countries with very different land-use policies until 1990. The German data show large differences in regional Starling trends (2005–2016), with numbers increasing in the southwest in stark contrast to declines in the northwest and east (Trautmann, S., unpublished). Starlings from eastern Germany winter in the Mediterranean, while West German populations winter in the Atlantic. Despite these variations, we were constrained to treat Germany as one unit here, because land use information is only available for the entire country. Czechoslovakia split into Czechia and Slovakia in 1993, so land use statistics from before 1993 were excluded. Similarly, Belgium and Luxembourg were grouped for land use statistics until 1999.

Section 2. National case studies

In Denmark, proportions of dairy cattle grazing outside on grassland declined from 74% in 2003 to 25% in 2013 (Heldbjerg *et al.* 2016). Despite the modest 2.3% decline in dairy cattle numbers, this period thus witnessed a major change in grassland management, which had consequences for Starlings that are dependent on grazed grassland, especially for provisioning young (Heldbjerg *et al.* 2016, 2017) but also outside the breeding season (Versluijs *et al.* 2016). Similarly, the percentage of dairy cows kept permanently indoors increased from 8 to 35% in The Netherlands between 1997 and 2015 (Versluijs *et al.* 2016, CBS 2019) during which period the Dutch Starling population roughly halved.

However, there is no simple relation between national numbers of outdoor cattle and starling trends. For instance, the steepest declines in Starling abundance in the Netherlands have occurred in areas that retain most grazing cattle (van Turnhout, C., unpublished). Furthermore, the Swedish Starling population has still declined (Green et al. 2018) despite Swedish legislation since 1988, that requires that all cattle should be outside for six hours per day, 60–120 days per year (Jordbruksverket 2019). Similar legislation exists in Norway since 2004, that requires all cattle to be outside for 12–16 weeks per year, which have resulted in a 5–10% increase in the number of grazing cattle in 2006–2016, corresponding to a period with an increase in the Starling population (Kålås, J.A., unpublished).

Grassland area and quality are undoubtedly very important, but not always caught by agricultural statistics.

In the former Czechoslovakia, in the 1980s, there were the biggest collective farms in Europe with virtually no small private farmers. Two opposite trends arose in Czechia after 1990; a trend of merging large areas and another trend of private farmers who got their land back and started to farm by themselves. In Czechia, numbers of grazing cattle increased after the end of the communist period (1989) despite much fewer cattle overall now. This was a result of transforming less productive arable fields to meadows and pastures in the sub-montane areas, which moreover are now often run as organic dairy farms. Consequently, despite less cattle now compared to 1982–1989, there is much more suitable habitat for foraging Starlings (Vermouzek, Z., unpublished). Slovakia shared the same history in Czechoslovakia. The average holding is large and the number of cattle declining. However, during 2005–2012 the number of sheep increased by c. 25% in the mountainous central and eastern Slovakia. For the foraging Starlings, the high number of sheep (c. 400,000) may have a similar positive effect on the pastures as cattle (Ridzoň, J. unpublished).

In Italy, where the Starling is declining in the largely intensively farmed lowlands (but is otherwise stable or increasing), there was a 24% loss of grasslands and pastures between 1982 and 2010 (Italian Statistical Institute, www.istat.it) whereas the change in abundance of grazing cattle was negligible. There was a significant correlation between grassland loss (2006 and 2014) and Starling decline (2000–2017) in all 11 regions of the country where Starling trends contributed to the estimation of Farmland Bird Index (Calvi, G., unpublished). In the former communist countries, the general pattern after the regimes fell around 1990, was that large areas of cropland and grassland were abandoned in the late 1990s and early 2000s (Sutcliffe *et al.* 2015). In Latvia for instance, the area of meadows and pastures declined by 28% in the 1990s and the number of cattle decreased by 75% until 2001 when the numbers increased again (Aunins, A., unpublished). The farm structure in the new EU member states is now polarised with few very large and industrialised farms and a large number of very small farms (Sutcliffe *et al.* 2015). The increase of grassland areas and number of cattle after c. 2001 have undoubtedly been beneficial for Starlings.

In addition to changes in cattle abundance, the number of cattle farms can also make a difference. For instance, numbers of Finnish dairy farms have declined drastically (Rintala & Tiainen 2007) and the number of farms of all agricultural types there have halved during 1995–2015 (http://statdb.luke.fi/). In Denmark, there are 95% fewer dairy farms in 2017 than in 1975, whereas the number of cattle per farm has increased 11.5 times (http://www.statistikbanken.dk). One large cattle farm probably supports fewer Starling territories than several smaller cattle farms with the same number of animals (Rintala & Tiainen 2007).