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The decline of the Starling *Sturnus vulgaris* in Denmark is related to changes in grassland extent and intensity of cattle grazing

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ABSTRACT

The Danish breeding Starling population declined at a mean annual rate of $-2.24\% \pm 0.39$ (95% CI) during 1976–2015 (a 60% decline overall). Starling density in the mid-1990s was positively correlated with dairy cattle abundance in 13 local areas. Regional declines in Starling abundance between 2001 and 2014 were positively correlated with loss of high intensity grazing pressure by dairy cattle, as more animal husbandry moved indoors. The long-term decline in national Starling abundance was positively correlated with the long term numbers of dairy cattle grazing outdoors. This study therefore confirms that not only does the extent of available grassland to breeding Starlings affect their relative abundance, but that the intensity of grazing of these grasslands is also of importance.

1. Introduction

Studies of farmland birds have tended to focus on species breeding and/or foraging on arable land (e.g. Robinson and Sutherland, 2002; Robinson et al., 2001). The annual cycle of tillage creates a series of temporary habitat states, with ploughing, for example, exposing invertebrates, seeds and plant storage organs, drilling providing seed, plant growth offering foraging habitat and harvest again providing food from spilled grain (e.g. Robinson and Sutherland, 1999). Not surprisingly, changes in cropping and agricultural practices have had a huge impact on some birds especially seed eating species (e.g. Chamberlain et al., 2000). This has been slightly to the neglect of those common species that are dependent on pastoral systems, a majority of which are more dependent on invertebrates and with seasonal patterns of food provision and availability that do not follow the same “boom and bust” cycle that occurs in arable agriculture (Vickery et al., 2001).

Denmark is predominantly an agricultural landscape (c. 60% of total land area is farmland; Levin and Normander, 2008) which has for centuries supported large numbers of dairy cattle. As the numerically dominant form of reared livestock, dairy cow abundance, nationally and regionally, is closely related to area of managed grassland. Although beef cattle contribute to grazing numbers, dairy cattle are numerically dominant: the ratio of dairy to beef cattle changed from 1:17 in 1982–1:6 in 2013. Dairy cattle require the best managed grassland, so dairy cattle are likely to constitute the key group of livestock that most drives relationships between cattle production, farmland practices, soil invertebrate fauna and their predators.

In this case study, we focus on the effects of regional changes in Danish agriculture on the changes in distribution and abundance of the Starling *Sturnus vulgaris*, a specialist grassland invertebrate feeder and a numerous and widespread species in Denmark as well as throughout Europe. Due to its abundance and association with human habitation it is a familiar and popular bird of societal interest. However, numbers of breeding Starlings in Denmark have declined during the last 40 years (Nyegaard et al., 2015). As a farmland species often associated with grazing cattle we hypothesized that radical changes in pastoral agriculture in the same period could have contributed to the Starling decline.

In this analysis, we first determine the degree to which the Danish Starling population has declined and if there were regional changes that correlate with the changes in the extent of grassland in these areas. Since the Starling depends on short grassland as foraging habitat for provisioning their nestlings

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(Feare, 1984; Devereux et al., 2004), we sought to establish a relationship between the extent of available grassland, the number of cattle and the density of Starlings.

The total area of grassland in Denmark has changed little since 1982, with recent large increases in rotational grassland balancing similar losses in set-aside land, due to the termination of set-aside schemes in 2007/2008 (Danmarks Statistik, 2016). In this context, set-aside land comprises agricultural land, which for a period was taken out of production, typically arable tillage in Denmark, with the aim to reduce agricultural production and which was mostly left as coarse uncultivated grassland. Numbers of dairy cows have declined by >40% from 1 million in 1982–2014 but have stabilized at c. 570,000 since 2004 (Danmarks Statistik, 2016).

Traditionally, dairy farms were small and evenly distributed over the country; milking herds were set out to graze on grassland every day during the warmest half of the year. Nowadays, economies of scale have concentrated dairy herds into larger units where grass is brought to cattle, which are increasingly kept indoors throughout the year (Seges, 2015; Danmarks Statistik, 2016). These changes have brought dramatic changes to the manuring of pastoral land as urine and faecal material is no longer applied “naturally” in a heterogeneous way in time and space by the animals themselves but applied as an intensive carpet of manure spread by the farmer a few times per year.

We investigate to see if regional changes, which comprise pronounced declines in the numbers of dairy farms and cattle in the eastern parts but far lesser declines in western Denmark, have affected the availability of grassland for Starlings, and hence their breeding status in these regions. Given a strong positive relationship between these measures, we reasoned that because dairy cows (and therefore traditionally managed grasslands) have declined most in the central and eastern regions of Denmark, the declines in breeding Starlings would be most severe in those parts of the country; by contrast because numbers of dairy cows and grassland area have changed least in the western part of the country, we would expect lower rates of declines in this area. We also investigated whether there has been a change in the numbers of cattle grazing outdoors to see if the degree to which this occurred could have any detectable effect on the regional Starling trends.

2. Materials and methods

2.1. Data collection

The Danish Common Bird Monitoring (CBM) programme uses point count census data to generate population indices and trends for more than 100 common breeding bird species. The annual sampling now involves circa 370 routes across the country (mean $\pm$ CI: 282 $\pm$ 32; median 321.5 routes per year during the time series 1976–2015), monitored in the period 1. May–15. June (Nyegaard et al., 2015). Most routes consist of 20 (but always $\geq$10) marked ‘points’ at which all birds seen and heard were recorded in a 5-min observation period (Heldbjerg 2005). All routes and points were counted in at least two successive years by the same observer, at the same time of year ($\pm$7 days), same time of day ($\pm$30 min) and under good weather conditions. Altogether, observations of 225,719 Starlings are included in this study.

The habitats surrounding each point are ascribed in quarters to one or more of nine predefined basic habitat types (Coniferous, Deciduous, Arable, Grassland, Heath, Dunes/Shore, Bog/Marsh, Lake and Urban). In total 29.0% and 8.1% of all habitat registrations were from arable habitat and grassland, respectively (Heldbjerg, 2005; Larsen et al., 2011). The majority of the surveyed plots were from ‘mixed’ habitats.

2.2. Estimating changes in annual abundance

Indices and trends were calculated by fitting a log linear regression model to point count data with Poisson error terms using the software TRends and Indices for Monitoring data (TRIM; Pannekoek and van Strien, 2004), where the count at a given site in a given year is assumed to be the result of a site and a year effect. The programme also estimates the dispersion factor, correcting for overdispersion where this occurs, and takes account of serial correlation between counts at the same site in different years. Standard errors for the indices are generated based on the assumption that the variance is proportional to the mean, and a pattern of serial correlation, which declines exponentially with time between counts (Pannekoek and van Strien, 2004). The TRIM assessment of rate of change was used in this study to generate species trends, taking the standard errors into account.

The population changes are described by indices (the proportional percentage change in the size of the Starling population in relation to the starting value) and we are therefore only interested in the relative changes (not the absolute number) during the study period, using the additive slope provided by TRIM. Based on the 95% confidence intervals generated about these estimates, we determined which of these datasets showed trends that significantly differed from zero.

In order to compare Starling trends in different regions of the country we analysed the trends for these. The number of counted points per year was reduced when limited to regions, so relatively poor coverage in earlier years constrained us to consider only the period 1990–2015 in the regional analyses.

2.3. Regional starling breeding densities

We used Starling breeding density assessments from the Danish Bird Atlas from 1993 to 1996 (2nd Atlas; Grell 1998). We only included data collected during 10–30 May, the typical nestling period in Denmark, to avoid data from periods including post-breeding flocking behaviour. The density data were derived from Atlas point count censuses consisting of 5-min registrations mostly from 10 points, systematically dispersed within each 5 $\times$ 5 km grid square. We included all birds counted in the selected period; 4258 points on 452 routes/squares out of a total of 1602 squares (28.2%).

Since the data on the Starling density were too sparse to use based on the 98 Danish Municipalities as a unit, we amalgamated the density data into the 13 local count areas (which closely corresponded to the former Danish counties) as sampling units. We used the centre coordinate of each atlas square to aggregate all squares within local count areas.

2.4. Regional analysis

For the regional analysis, we divided the country into four regions, three almost equally large parts, West, Central and East, together with the island of Bornholm, which is geographically relatively small and distant from the others (Supplementary material Fig. 3; Table 1). Starling trends were analysed for each of these to compare the rates of decline for support for the hypothesis that the decline was more pronounced in areas with the largest decline in dairy cattle.

2.5. Agricultural statistics

We used area data on the extent of key tillage crops, grassland management types and annual cattle statistics in Denmark obtained from StatBank Denmark, the online repository for Danish agricultural statistics published annually (Danmarks Statistik, 2016). While the data for the whole of the country is provided

Table 1
The regions of Denmark used in the analysis, the total size of the regions, mean annual number of monitored point count routes (1990–2015), the population trend (mean annual percentage change (±95% CI)) of Starlings (1990–2015), the number of observed Starlings, the percentage change in numbers of dairy cows (1989–2010), the density of dairy cows (2010) and the density of high grazing pressure area (2014).

Region	Area (km^2)	N Point counts	Starling trend (%/year)	N Starlings	Cows/km^2	Cow trends (%)	HGP/km^2
West	15,585	114	−1.71 ± 0.61	65,880	21.2	−24.2	0.352
Central	17,555	99	−3.87 ± 0.82	47,338	11.8	−34.0	0.089
East	9193	102	−4.55 ± 0.73	47,472	2.7	−41.1	0.017
Bornholm	588	13	1.49 ± 1.02	10,701	10.0	−13.2	0.352

annually, data from the 98 different municipalities are only registered in selected years. We therefore used the mean of data gathered in the years 1989 and 1999 to describe the cattle and grass statistics per Municipality as close as possible to describe conditions at the time of the 1993–1996 Atlas period and the data from 2010 as reflecting the most recent situation.

We examined agricultural statistics from the 98 Municipalities, to see if there was a change in the regional extent of grassland between 1982 and 2013 and whether the available grassland was comparable with the number of dairy cattle in both periods. If the numbers of dairy cattle were to be a major driver of the production of grass in Denmark, we should expect a relationship between these two parameters in both periods.

Based on the hypothesis that Starling abundance is directly related to the extent of grazed grasslands, we related the densities of Starlings (recorded during the period of Atlas survey work in the mid-1990s) in each of Denmark's 13 local count areas to the number of dairy cows at that time in each of these areas. We also applied generalised linear models taking the standard error (SE) of the indices into account by weighting each index value by the degree of their imprecision. We weighed each point by 1/SE and tested to see if there was a linear relation between Starling breeding indices and the number of outdoor grazing dairy cattle in the periods 1982–2002 (high ratio of grazing cattle) and 2003–2015 (declining ratio of grazing cattle), incorporating the periods as covariates. For comparison we ran the same model with all cattle instead of only the grazing cattle and used ANOVA to compare the models.

2.6. Grazing pressure 2001–2014

The agricultural statistics provide information about the area of grassland but not the type, extent and grazing intensity of different grazed and ungrazed grassland areas. We therefore used agricultural registers from the Ministry of Food, Agriculture and Fisheries for 2001–2014, which provides data on the extent of grazing grassland on each farm to at least attempt to assess regional changes in grazing pressure over time.

For each year and each farm unit the number of dairy cattle units were derived. One unit of dairy cattle is defined as the number of cows, which produce 100 kg nitrogen per year. We applied animal units in order to control for races, ages and changes in animal sizes over time. In 2014, one typical Danish dairy cow corresponded to 0.85 animal units. Dairy cattle were divided into organic and conventional animals due to the large difference in number of grazing days relating to these two groups.

The number of grazing animal units (*GAU*) was calculated as:

$$GAU = AU \times \left(\frac{GDY}{DY}\right)$$

where *AU* is the number of animal units, *GDY* is the number of grazing days per year and *DY* the number of days per year (365). The mean number of days per year a dairy cow grazes on grass on a conventional farm declined from 55 to 18 days between 2002 and 2007 (O. Aaes, pers.comm. Seges 2015). This dramatic decline was primarily the result of dairy cattle being kept indoors, which is increasingly more economically favourable than grazing outdoors. For organic cattle, there is a legal requirement that they are allowed to graze for 150 days of the year (Danish AgriFish Agency 2014), so this value was entered in the calculations for organic cattle.

For each farm unit, the area of rotational grassland was extracted from the agricultural registers. Rotational grassland includes all grassland types (including clover), which are part of an annual rotation cycle, and which can potentially be grazed by dairy cattle. Permanent grassland was not included in the analysis, because most such grassland is no longer of sufficient quality to support dairy cows, which increasingly require highly intensive management to produce swards that are economically viable. Since the registers do not contain information on whether a specific grassland parcel is actually grazed or not, rotational grassland here also includes ungrazed grassland.

For each farm unit, an indicator for grazing pressure (*GP*) was calculated as follows:

$$GP = \frac{GAU}{RG}$$

where *GAU* is the number of grazing animal units and *RG* is the area of rotational grass on the farm unit. We calculated the area with different grazing pressure into four levels, 0–0.5, 0.5–0.75, 0.75–1 and ≥1 grazing animal units per hectare and summed these numbers per region and level for each year. The lowest level, 0–0.5 is hereafter referred to as low grazing pressure (considered to be of the very least attraction to foraging Starlings) and the highest level, ≥1 is considered as high grazing pressure most likely to maintain a short sward most attractive to breeding Starlings based on the literature (see Discussion). We compared the regional changes in Starling population indices to the change in area of high grazing pressure ($GP > 1$) for 2001–2014.

3. Results

3.1. National and regional starling trends

Data from the Danish point counts show that Starling abundance has continuously declined during 1976–2015, at a mean annual rate of −2.24% ± 0.39 (95% CI, Fig. 1a). This corresponds to a decline in overall abundance of nearly 60% over four decades. The Danish breeding population was estimated at 400,000–600,000 pairs in 2000 (Birdlife International 2004), so assuming that these estimates were accurate, Denmark has lost 313,000–470,000 breeding Starling pairs since the mid-1970s. Excluding Bornholm (which showed a significant positive trend), there were negative trends throughout the country, with largest declines in East and Central Denmark, 2.3–2.7 times more rapid than the decline in West (Table 1).

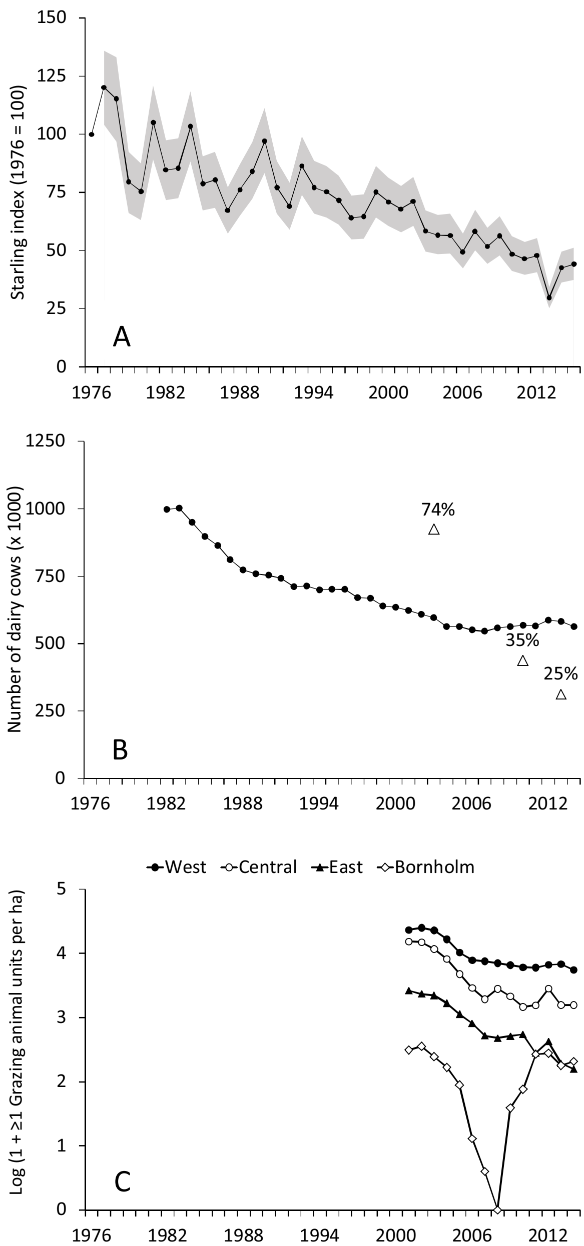

Fig. 1. A) Annual indices ± SE (shading) for the Danish population of Starling *Sturnus vulgaris* during 1976–2015 (1976 = index 100) based on breeding bird point counts. The population has significantly declined at −2.24 ± 0.39% (index ± 95% CI) per annum over the period. The noticeable decline in 2013 was a result of a prolonged winter, which affected the populations in all regions. The indices are based on data from the Danish Common Breeding Bird Monitoring programme run by DOF BirdLife Denmark. B) The annual total number of dairy cows in Denmark during 1982–2014 (circles) and the proportion of these grazing outside on grassland (triangles). C) The total areas (log transformed) of rotational grassland in the four regions of Denmark defined in Supplementary material Fig. 3 indicated by the grazing pressure of ≥1 animal units per hectare rotational grassland. West, shown by black circles declined by 76.4%, Central, open circles by 89.8%, East, grey triangles by 94.0% and Bornholm, open diamonds by 33.4%.

3.2. Cattle and grassland

The relative density of Starlings registered during the nesting period in 1993-96 was significantly positively correlated with the numbers of dairy cows in the 13 local count areas (Linear regression (±SE); $y = 2.37 \times 10^{-6} \times (\pm 7.65 \times 10^{-7}) + 0.90$, $n = 13$, $r^2 = 0.47$, $p = 0.010$; Fig. 2), with highest densities of Starlings and dairy cattle in the west of the country (Jutland; Supplementary material Fig. 3). Since there are very few cows in the Greater Copenhagen area, dominated by urban and suburban areas but also with extensive areas of farmland, and this point is an outlier, we recalculated the regression with the same data minus Greater Copenhagen area and found an improved model fit ($y = 3.08 \times 10^{-6} \times (\pm 5.64 \times 10^{-7}) + 0.71$, $n = 12$, $r^2 = 0.75$, $p \ll 0.001$; Fig. 2).

The number of dairy cattle in Denmark declined by 43.7% in 1982–2014 to c. 560,000, although this has stabilized since 2004, and the proportion of these grazing outside on the grassland declined from 74% in 2003 to 25% in 2013 (Fig. 1b).

The majority of Danish dairy cows are now raised in Jutland, mainly in the western and southern parts (Danmarks Statistik, 2014). Most of the grassland is also restricted to the same municipalities (see Supplementary material Figs. 1 and 2) and there was a very highly significant relationship between the area of grassland and the number of dairy cows in the 98 Danish municipalities, based on the mean of 1989 and 1999 (Linear regression (±SE); $y = 4.59$ $(\pm 0.08) + 595$, $n = 98$, $r^2 = 0.973$, $p \ll 0.001$) as well as in 2010 ($y = 1.38$ $(\pm 0.04) - 1550$, $n = 98$, $r^2 = 0.93$, $p \ll 0.001$). We therefore consider the number of dairy cattle as a good measure of available grassland throughout Denmark, and conclude that the density of dairy cattle supported by the area of grassland has clearly fallen over this time period.

3.3. Changes in numbers of cows grazing outdoors

Bornholm showed the smallest reduction in the number of dairy cows, with largest reductions in Central and East (Table 1), similar to differences in Starling trends in the four regions.

For 2001–2014 we have an indirect measurement of the number of cattle grazing on a given area of available rotational grassland in each region using the calculation of grazing pressure described in 2.6. This showed that the area of grassland subject to high grazing pressure is declining all across the country (Fig. 1c), although in the West, the relatively larger grassland area has shown a relatively less pronounced decline (Fig. 3). This region still supports a larger area of grassland subject to high grazing pressure than the other regions (4 times more than Central, 20 times more than East), while the absolute area of high grazing pressure has changed little on Bornholm. Albeit that 4 points are too few to contribute to a meaningful regression model, there was a positive correlation between the regional relative change in high grazing pressure and the Starling population trend in the four regions (Fig. 3), implying that the greater the regional reduction in the area with high grazing pressure the greater the decline in Starling abundance.

At the same time, the area of grassland with the lowest level of grazing pressure has increased in all regions. The ratio of the area with a low grazing pressure to the area with a high grazing pressure has changed from a factor of 2.8 to a factor of c. 35 indicating a clear decline in grazing pressure across the country. As could be expected due to the steady decline in both parameters, there was a highly significant correlation at the national scale between the number of dairy cows and the Starling index during 1982–2002 (Linear regression (±SE), $y = 5.1 \times 10^{-5} \times (\pm 1.5 \times 10^{-5}) + 38.8$, $n = 21$, $r^2 = 0.36$; $p = 0.01$; see filled symbols, Fig. 4). Based on the only existing results from the three years of surveys undertaken between 2003 and 2014, there was a steep decline in the proportion of the dairy cows that were grazed outside (Fig. 1b). As a result, the area of actively grazed grassland fell and during this period, there was no correlation between the number of dairy cows and Starling index (Linear regression, $y = -1.36 \times 10^{-4} \times (\pm 1.73 \times 10^{-4}) + 127.34$, $n = 12$, $r^2 = 0.06$; $p = 0.45$; see the open symbols in Fig. 4). For the latter period, we also correlated the Starling index to the estimated number of grazing dairy cattle (calculated by multiplying the number of dairy cattle reported in the national

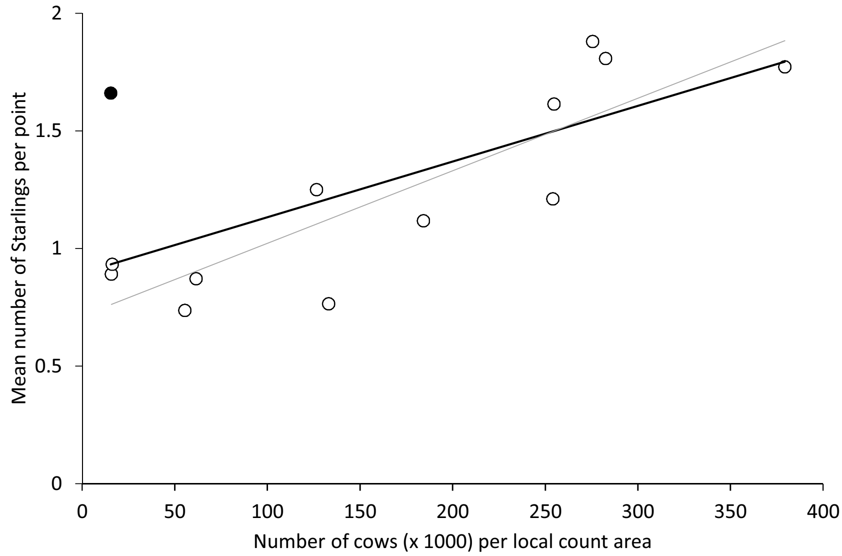

Fig. 2. Regression of the mean number of Starlings recorded per point during fieldwork for the Danish Breeding Bird Atlas in 1993–1996 (n = 4258 points on 452 routes; 13 local count areas) as a function of the mean of 1989 and 1999 numbers of dairy cows registered in the same areas. The regression is shown with (all circles, heavy line $r^2 = 0.47$) and without Copenhagen area (open circles, thin line $r^2 = 0.75$), see text for details.

statistic surveys by the percentage known to be grazing outside; see Fig. 1b). With only three years of data (diamond symbols in Fig. 4), we extended the regression using data from 1982 to 2002 (filled symbols in Fig. 4) and found a significant relationship, with the three points falling within the confidence limits of the regression model (Linear regression ± SE), $y = 6 \times 10^{-5} \times (\pm 8 \times 10^{-6}) + 30.9$, $n = 24$, $r^2 = 0.72$; $p \ll 0.001$; Fig. 4).

We found a significant relationship between the number of estimated number of grazing dairy cattle and the Starling index in 1982–2015 and no difference in the trend whether we included the period with declining grazing cattle or not (Table 2), indicating that the same pattern continued unchanged across the two periods.

4. Discussion

This study shows that the dramatic decline of breeding Starlings in Denmark during the last four decades appears related to the extent of suitably grazed grassland, which is in turn largely driven by the numbers of dairy cattle. Our results showed that Starling density in the breeding season was highly significantly correlated with numbers of dairy cows in the 13 local count areas in the mid-1990s. Nationally, it could be shown that the Starling breeding abundance index correlated with numbers of dairy cows between 1982 and 2002, and (because of the increasing trend to keeping cows indoors since then) with numbers of dairy cattle units grazing outside in fields since that date. Finally, we showed that regional differences in changes in the extent of very short grazed grassland during 2001–2014 correlated with regional changes in Starling abundance. This study therefore confirms that it is not only the extent of the grassland available to breeding Starlings that affect their relative abundance, but also that the management and consequently the quality of these grasslands that is of importance. The Starling needs grassland of short sward height to be able to benefit from access to their prey items in the upper soil horizons

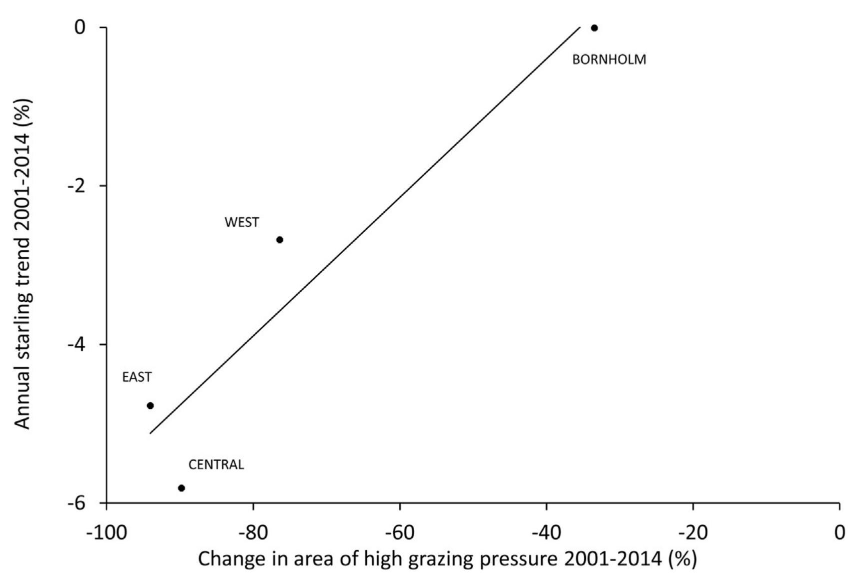

Fig. 3. Mean annual trend of Starlings (2001–2014) in four regions of Denmark (defined in Supplementary material, Fig. 3) as a function of the change in high density grazing pressure (>1) in the regions (2001–2014).

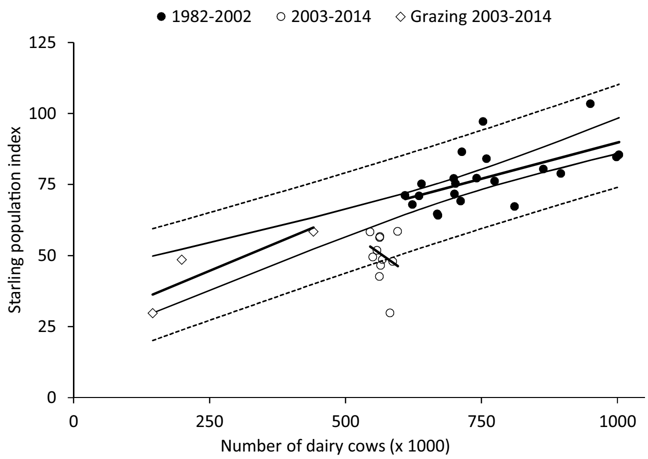

Fig. 4. The changes in the annual Danish Starling breeding population index as a function of the number of dairy cows. There is a significant linear correlation in 1982–2002 (r^2 = 0.36), but no such correlation in 2003–2014 (r^2 = 0.06). The estimated number of grazing dairy cows are also used as an alternative for 2003–2014 (see text).

(Devereux et al., 2004). Such habitat requirements are likely met by grazing cattle that continuously maintain a short sward throughout the Starling breeding season. Contemporary animal husbandry increasingly keeps dairy cattle herds indoors all year round and the expansion in the relative area of rotational silage grassland that has increasingly replaced grazed grasslands very likely contributes to the adverse effect on Starling breeding abundance.

4.1. Starling trends

We found a significant annual national decline of 2.24% in Starling abundance during 1976–2015 and significant mean annual declines of 1.7–4.5% in the three major areas during 1990–2015, in contrast to the increasing mean annual trend of 1.5% for the small population on Bornholm (Table 1).

The rate of decline amongst Starling trends in the Central and East regions of the country were more rapid than in the West. Some large local Starling populations persist in areas of grassland with grazing cattle in the East region of Denmark (own observations), showing that even in the areas showing most rapid declines, where suitable feeding conditions continue to prevail, there still remains the potential to support a healthy local breeding Starling population. The slightly higher density of Starlings in the Greater Copenhagen area compared to the rest of the East region is heavily influenced by two large Starling observations (4.7 and 7.8 times the mean of the rest) in two nature management areas retaining extensive areas of grassland grazed by cattle but is probably also a result of the areas of grazed grasslands managed to support large numbers of horses, kept for riding in the outskirts of Copenhagen (and in North Zealand), where horse densities in some Municipalities are up to 6 times the mean for the country as a whole (Danmarks Statistik, 2016). Telemetry studies of the foraging areas used by breeding Starlings provisioning young confirm that Starlings forage in horse grazed areas in the absence of grazing cows (Heldbjerg et al. in prep.).

The moderate increase in the Starling population on Bornholm is, by comparison, unusual. Bornholm is a small island, with a relatively long coastline that might provide an additional and more stable habitat for Starlings. It also differs geologically from the rest of Denmark in being rocky and hilly, which retains more marginal grazed areas and fewer biotopes modified by agriculture (Gravesen, 1996). Bornholm farms are smaller and more diverse than average for Denmark, with four times the density of cattle compared to that in the East of Denmark (Table 1), however it remains unclear why these differences should support an increase in Starling abundance, which would repay further investigation.

4.2. Starlings in relation to extent of suitably grazed grassland

The significant positive relationship between the number of dairy cows and the mean Starling density in 13 local count areas in the mid-1990s strongly suggested that the breeding density of the species depended on the extent of cattle grazing. The marked change in the significant relationship between the area of grassland and the number of dairy cows in the 98 municipalities between the 1990s and 2010 showed that the dairy farming industry has been able to support many fewer cows on the same area of grazing land in more recent years. This development has been possible by the increasing amount of indoor dairy husbandry, with fewer cows allowed to graze outside. This results in changes in the nature of the swards available to Starlings, which favour very short sward heights maintained by sequential grazing by stock. This relationship is also confirmed by the finding that changes in Starling regional abundance in Denmark correlated with regional changes in the extent of highly grazed grassland.

Grassland is largely maintained in the Danish landscape to provide cattle food. There are now strong economic reasons for keeping cattle indoors, which have major effects on the current and future management of grasslands. Grass is now largely cut for silage to feed cattle indoors, instead of being grazed. Increasingly, even non-rotational areas are cut for silage, whilst in many valley bottom grasslands grazing has been abandoned. As a result, the decline in the dairy cow population has not been associated with a change of the same magnitude in the grassland area. This can partly be explained by the extra energy intake of the dairy cows which produced 18.5% more milk in 2012 than in 2000 (Danmarks Statistik, 2016), but it is also an effect of the termination of set-aside schemes in 2007/2008 and the subsequent removal of set aside from the Danish landscape, much of which has been converted into grassland area.

Traditional grazing by dairy cows, which ensured daily heterogeneous applications of small amounts of manure and urine to grasslands, has been replaced by infrequent and uniform applications of large amounts of concentrated manure, which has likely affected invertebrate abundance and diversity and limited access to food by birds (Plantureux et al., 2005). Invertebrate

Table 2
Linear models on Starling indices and number of cattle in 1982–2015 showing estimates and *p*-values of each linear model and F and *p*-values for ANOVA's indicating if the incorporated periods are significantly different from each other (see also text).

Cattle	Period, covariate	LM		ANOVA		
		Estimate ±SE	*p*-value	F-statistic	DF	*p* value
Estimated grazing	No	6.56e–05 ± 9.08e–06	4.06e-07			
Estimated grazing	Yes	4.55e–06 ± 1.98e–05	0.821	0.053	2,21	0.821
All	No	4.64e–05 ± 1.78e–05	0.014			
All	Yes	−3.43e–05 ± 7.74e–06	0.0001	19.60	2,30	0.0001

abundance and diversity also declines with a reduction in sward diversity and structural complexity (Vickery et al., 2001). Food abundance for grassland foraging insectivore birds tends to increase with sward height but food accessibility also declines with sward height (Atkinson et al., 2004; Buckingham et al., 2004). *Tipulidae* larvae form the main food item for the Starling nestlings (Rhymer et al., 2012) but since Starling field use was inversely correlated with sward height (Fuller et al., 2003), access to food may be the critical factor (Atkinson et al., 2005).

Hence, in addition to changes in sward height caused by changes in grazing regimes, there is a possibility that changes in the contemporary management of grassland, like structural complexity and use of fertiliser may change the abundance and diversity of prey from that available in earlier forms of regularly grazed and managed grassland.

This study showed that there were regional relationships between grassland management and the population trends for breeding Starlings. These relationships are only correlative, because such species/habitat linkages are very difficult to establish but the general declines in cattle/grass coincide with declines in the Starlings. Processes at small spatial scale such as the local loss of good foraging habitat has been suggested as the main reason for the general decline in the Swedish Starling population (Smith et al., 2012) and we will have to study their foraging ecology and breeding biology in areas with different farmland management as well as different aspects of the Starlings demography to understand what causes the significant decline in Denmark which is reflected in population trends throughout much of Northern and Western Europe (BirdLife International, 2015).

5. Conclusions

This study provided evidence that developments in the dairy sector in Denmark have had major consequences for the breeding Starling in Denmark. Our results reveal that regional declines in grazing dairy cattle correlate with declines in breeding Starling abundance. Latterly, during a period of stability in managed grassland area, the increasing trend to keep dairy cows fed indoors has likely contributed to the reduction in very short grazed grassland that is most attractive to nesting Starlings. To better understand how we might investigate positive management for Starlings in the future, we need to undertake further studies to:

1. investigate effects of changes in grassland management on invertebrate abundance, diversity and accessibility to foraging adult Starlings for feeding nestlings
2. confirm the relationship between different types of grassland and grassland management and Starling reproductive success in Denmark and throughout Europe, and
3. Use the results from these to address policy needs to recognize the effects of agricultural changes on Starling populations in Denmark and throughout Europe and consider how agri-environment schemes could safeguard appropriate grazing regimes to restore the Starling to more favourable conservation status.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.agee.2016.05.025.

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