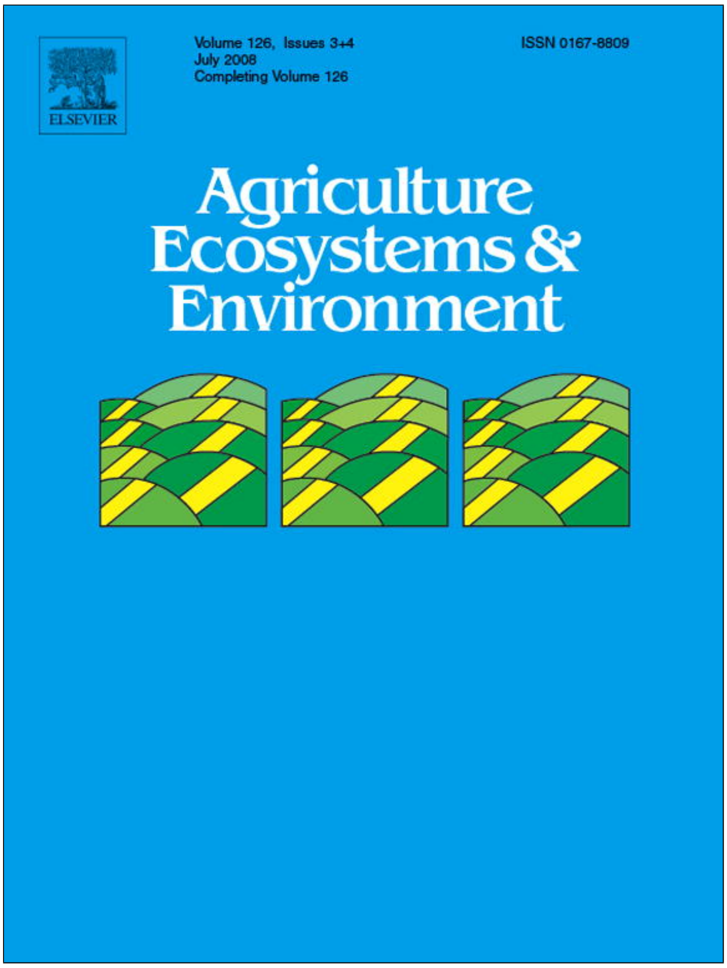
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Which regional features of Danish agriculture favour the corn bunting in the contemporary farming landscape?

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ABSTRACT

Corn buntings *Miliaria calandra* were abundant throughout arable agricultural landscapes in Europe, but have catastrophically declined since the mid 1970s with changes in farming practice and now give serious conservation cause for concern. Corn buntings declined in Denmark during 1976–1993, but (almost unique in Europe) have since increased (by up to 11% per annum) in some areas without specific conservation recovery actions. Based on breeding bird surveys in the mid 1990s, highest corn bunting densities occurred on mixed agriculture in west Denmark (Jylland); the species was rarer or absent in regions of highest arable land cover. Corn bunting density and extent of rotational and permanent grassland were correlated, but not with spring sown barley (all known to constitute important corn bunting winter habitat). The extent of spring barley rapidly declined in Denmark during the 1980s, but since 1990, most counties have since shown 2–3% annual increases in this crop, except in Nordjylland, where high densities of corn buntings have remained stable. Elsewhere in Jylland, corn buntings have increased in counties supporting highest densities during the mid 1990s, contrasting stable or declining trends in south and east Denmark where densities were originally lower. After dramatic decreases everywhere in Denmark, corn buntings retain highest breeding densities associated with mixed agriculture, especially where grassland and spring sown barley remained in greatest extent. Although purely based on land use correlation and bird surveillance, these results show an association between mixed farming and favourable conservation status of a species now red-listed throughout much of Europe. Further investigations of habitat use at small spatial scales and throughout the annual cycle are urgently required to better enlighten specific recommendations for wider applicability of guidelines for corn bunting recovery actions elsewhere.

1. Introduction

The corn bunting *Miliaria calandra* is so much associated with "pure" arable agriculture (i.e. intensive tillage with little pasture, Petersen, 1998) throughout its current northern range in the western Palearctic that it is difficult to envisage the species here in its original natural steppe habitat. Despite this association with tillage, numbers have declined severely throughout northern Europe since the 1960s or earlier (Donald et al., 1994), associated with intensification of agricultural landscapes upon which the population had become dependent (Tucker and Heath, 1994; Donald and Hustings, 1997; BirdLife International, 2004). The British population declined by more than 86% during 1967–2005, more than most other common bird species (Baillie et al., 2007), with extinctions across large areas of its former range (Gibbons et al., 1993; Fuller et al., 1995), resulting in the red-listing of the species. Rapid declines and contractions of range are typical throughout northern Europe (e.g. Hustings, 1997; Eislöffel, 1997) so the species requires urgent and widespread conservation action if its present (much reduced) distribution and abundance is to be maintained.

The causes of the declines are unknown, but are attributed to increased winter mortality and poor reproductive success resulting from food shortages during both periods of the annual cycle (Donald, 1997). In Britain, loss of winter stubbles, improved harvesting efficiency and storage are considered to have denied the species winter food and survival habitat (Donald and Evans, 1994; Donald, 1997). Intensification of arable agriculture, including

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increasing pesticide use, has caused widespread declines in invertebrate prey abundance as food for nestlings (Brickle and Harper, 1999; Brickle et al., 2000). However, productivity in the national population was stable through the late 1970s and 1980s, being generally higher after 1970 than before (Crick et al., 1994; Crick, 1997), suggesting that reproductive success was not substantially depressed during the period of most spectacular declines. The frequency of successful breeding attempts was likely reduced by autumn sowing and early harvesting of cereals which reduced available nesting habitat later in the season (Donald et al., 1994; Brickle and Harper, 2002).

Winter stubble loss resulted in the decline of the species (Mason and MacDonald, 2000), especially barley stubbles (Donald and Evans, 1994) which retain significantly more bare ground and higher seed abundance (and corn bunting abundance and occupancy), than wheat stubbles (Moorcroft et al., 2002). Mason and MacDonald (2000) stressed the importance of grassland as winter feeding habitat for the species, although elsewhere this was only used in proportion to its area (Donald and Evans, 1994). Corn buntings strongly selected for the limited extent of grass in an arable-dominated study area, which was used throughout the winter, whereas stubbles were selected mostly in late winter (Mason and MacDonald, 2000), implying that although quintessentially a bird of arable agriculture (Donald and Evans, 1995; Donald, 1997) and one typically lost from grassland landscapes where arable agriculture has been lost (Robinson et al., 2001), the species does also require grassland, perhaps at certain critical periods in the annual life cycle to fulfil particular functions.

Corn buntings showed signs of decline in Denmark from the 1930s–1940s, but were still widespread and common in the mid 1970s (Dybbro, 1976). By the mid 1990s the species had dramatically declined, showing substantial contractions of range, especially on Sjælland, Fyn and in south-eastern Jylland (Grell, 1998). After serious declines in the 1980s, the corn bunting has shown signs of increases in some parts of Denmark (Fox, 2004; Heldbjerg, 2005, 2007) a feature almost unique in Europe and remarkable given the same agricultural intensification as elsewhere in western Europe (Fox, 2004). Although the area of cereal production increased dramatically in Denmark to peak at 1.85 million ha in the late 1970s, falling to 1.53 million ha in 2002, the nature of this production had changed considerably. Barley is mainly spring-sown in Denmark and the area under barley cultivation more than halved between the 1970s and late 1990s as the area under wheat (mostly autumn sown) increased (Fox, 2004). The growth in rape cultivation (initially spring sown, now more commonly autumn sown) as well as the extensive growth of rye (traditionally autumn sown) meant a sudden shift from 66 to 75% spring sowing of the four major tillage crops in the mid 1980s to less than 50% by the 1990s (Fox, 2004). On better soils in the south and east, the tradition for mixed pastoral agriculture has been abandoned in favour of intensive arable farming in these areas earlier than elsewhere. Although this trend continues, most rearing of sheep and cattle persists in western Denmark on mixed farms, especially in Jylland (Ejrnæs et al., 1998; Fox, 2004).

The varying population trajectories in Denmark and contrasting regional agricultural patterns in its relatively small land area offer the opportunity to test specific hypotheses about the potential factors affecting the species, not least because the corn bunting is known to show regional differences in abundance and population change over recent years (Grell, 1998). In this paper, we use data from point counts undertaken since 1976 to assess the relative change in summer and winter abundance of the corn bunting, using regional (county) data where these are sufficient. We present relative bird density data from the Danish Breeding Bird Atlas period (1993–1996) to assess regional differences in relative density at that time (Grell, 1998). We also use the national annual agricultural statistics (accessed from Statbank.dk) to test specific hypotheses about regional effects of agricultural land-use and land-use change over time and their relationship to corn bunting densities and population change over an extended period. Specifically, we expect corn bunting densities to be highest in those areas with the greatest extent of spring sown barley (as a proxy for winter stubble and offering suitable cover for later nesting attempts) and grassland.

2. Methods

Point count data from the Common Birds Census compiled by the DOF-BirdLife Denmark during 1976–2006 (see Heldbjerg, 2007 for details) were used to construct corn bunting population trends. Surveyed point count routes throughout Denmark that recorded corn bunting exceeded 100 (mean 116 ± 2.4 S.E.) in all years since 1990 except 2003 (96) in contrast to years before 1990 when sample sizes fell below the levels necessary to provide confidence in the long term trends (Heldbjerg, 2005, 2007 and see below). For this reason, although long-term trends are provided back to 1976 for historical context, detailed analysis is restricted to the period since 1990. Trends were calculated by fitting log linear regression models to point count data with Poisson error terms using the software TRends and Indices for Monitoring data (TRIM; Pannekoek and van Strien, 2001), where the count at a given site in a given year is assumed to be the result of an interaction between 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. Annual indices were generated from a baseline year when the index was set to unity. 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, 2001). Data for the corn bunting are available from the summer (during 1 May and 15 June in 1976–2006, as a measure of breeding abundance) and winter (20 December until 20 January in 1975–2006, as a measure of the post-breeding population size).

We related differences in local corn bunting abundance to regional differences in Danish agriculture during the Atlas fieldwork period (1993–1996). We expressed the 15 major agricultural land-use types (characterised by specific crop areas in hectares, available from Statbank.dk, listed in Table 1) as the percentage of total agricultural area in each of 12 counties (Fig. 1). Only land use types relevant for corn buntings were used (i.e. managed grassland and tillage areas as a proportion of the total cultivated area, excluding for example all water, areas of human habitation or forestry). Mean percentages were extracted for the years 1993–1996 inclusive and subjected to a principal components analysis. PCA was carried out on the correlation matrix of untransformed variables from each, because set-aside was introduced in Denmark in 1993, introducing greater variance in between year variance than would be expected at other times in the recent past. Agricultural variables were inevitably serially correlated, but the PCA was used to summarize gross regional differences in agricultural activity between regions within Denmark during a period for which good bird density data existed. During fieldwork for the Danish Breeding Bird Atlas in 1993–96, observers counted birds of all species at points distributed within 10 km × 10 km, giving a measure of relative bird density (bird encounters in each square per unit effort) throughout the country. We calculated means from data for corn bunting summed by counties from these years to compare with regional farming types during this period.

Table 1
The 15 agricultural variables used to summarize regional and temporal changes in Danish agriculture during 1993–96, using PCA

Land use type	PC axis 1	PC axis 2
Autumn sown wheat	−0.418	0.060
Spring sown wheat	−0.119	0.095
Rye	0.164	0.314
Autumn sown barley	−0.224	0.260
Spring sown barley	0.274	−0.369
Oats	0.068	0.397
Triticale	−0.136	0.254
Potatoes	0.337	−0.049
Sugar beet	−0.206	−0.383
Fodder beet	0.349	0.116
Autumn sown rape	−0.282	0.315
Spring sown rape	0.084	0.324
Maize	0.087	−0.113
Rotational grass and clover	0.398	0.105
Permanent grassland out of rotation	0.322	0.223
Set-aside (mostly grass)	−0.042	−0.153

Variables are shown with their eigenvector loadings on the first two PCA axes, which explained 33.5 and 19.1% of the variance in the analysis.

We tested specific hypotheses relating to the purported importance of grass and spring barley using simple regression analysis, modelling corn bunting density estimates from the atlas period on the basis of the percentage extent of (i) grass and (ii) spring barley in each of the counties, based on the predictions that the greater the relative extent of these two crop types in each of the counties, the greater the density of corn buntings.

Finally, because agriculture has not been static in Denmark over the last 25 years (Fox, 2004), we attempt to account for changes in the relative abundance of the corn bunting with respect to changes in the relative frequency of (i) grass (ii) spring barley and (iii) set-aside in each of the counties.

Fig. 1. Map showing the former counties of Denmark referred to throughout the text. (1) København (city), (2) Frederiksberg (city), (3) København (county), (4) Frederiksborg, (5) Roskilde, (6) Vestsjælland, (7) Storstrøms, (8) Fyn, (9) Sønderjylland, (10) Ribe, (11) Vejle, (12) Ringkøbing, (13) Viborg, (14) Nordjylland, (15) Århus and (16) Bornholm (inset). Note that for the purposes of this analysis, areas 1–5 constitute "Hovedstadsområdet", 1–6 constitute "Sjælland" and 9–15 constitute "Jylland" in the text.

3. Results

3.1. Changes in the summer and winter abundance of corn buntings in Denmark

Corn buntings declined in Denmark from the late 1970s onwards (Fig. 2). Changes in abundance since 1990 based on summer point count data start from a population level at a low point in its trajectory compared to previous years (Fig. 2). The summer index showed a statistically significant 2.20% (±0.006 S.E.) increase per annum over the period 1990–2006 ($P < 0.01$), with a clear increase from 1993 balanced by very recent declines (Fig. 2). Similarly, the winter count data show a recovery in the annual index since 1990, resulting in a 11.3% (±0.026 S.E., $P < 0.01$) increase per annum over the available time series, most markedly since 1993 (Fig. 2).

3.2. Differences in agriculture and corn bunting densities between different areas of Denmark

The first PCA axis of agricultural variables for the period 1993–96 accounted for 34% of the variation in the data and described the dominant gradient in Danish farming from mixed pastoral agriculture in the west (characterized by the high positive loadings of permanent and rotational grass and fodder beet and negative eigenvectors of autumn sown wheat, Table 1), to the predominantly arable agriculture (dominated by winter cereal) in the east. The distribution of the individual Danish counties based upon their scores on this axis reflects this, with the western Jylland counties of Ribe and Ringkøbing represented by heavy positive scores (extensive grassland areas) contrasting the more arable rich counties of eastern Jylland (e.g. Vejle and Århus) and the lowest scores amongst the predominantly arable farming of the eastern counties of Sjælland, Fyn, the southern islands (Storstrøms) and Bornholm (Fig. 3). The second PC axis explained 19.1% of the overall variance, but was subject to greater influence from a variety of land use types (Table 1), notably positive scores of rape, rye (which are especially common in Hovedstadområdet) and oats, as well as large a negative weighting of sugar beet (which explains the discrete separation of Storstrøm, where this crop is grown in considerable quantity compared to elsewhere in Denmark).

Corn bunting density varied between counties during the Breeding Bird Atlas project (Fig. 4). Six counties with greatest densities were in Jylland (characterised by mixed pastoral and arable agriculture) and the lowest were in south-eastern Denmark in arable dominated landscapes, reflecting agricultural practice in the different counties. Corn bunting densities were highly significantly correlated with their scores on PC axis 1 ($r = 0.79$, $F = 16.4$, $P < 0.01$, Fig. 3). Hence, during 1993–1996, there were differences in relative abundance of corn buntings throughout Denmark reflecting regional differences in land cover types.

3.3. Corn bunting density correlates with grass and spring sown barley during 1993–1996

Corn bunting density based on encounter rates during Atlas fieldwork was positively correlated with the mean percentage area of rotational grassland ($r = 0.64$, $F = 6.3$, $P < 0.05$ after arc sine square root transformation, Fig. 5) and permanent grassland ($r = 0.71$, $F = 9.2$, $P < 0.05$), but not that of spring sown barley ($r = 0.49$, $F = 3.1$, $P > 0.05$) nor set-aside ($r = 0.26$, $F = 0.73$, $P > 0.05$, all $n = 12$).

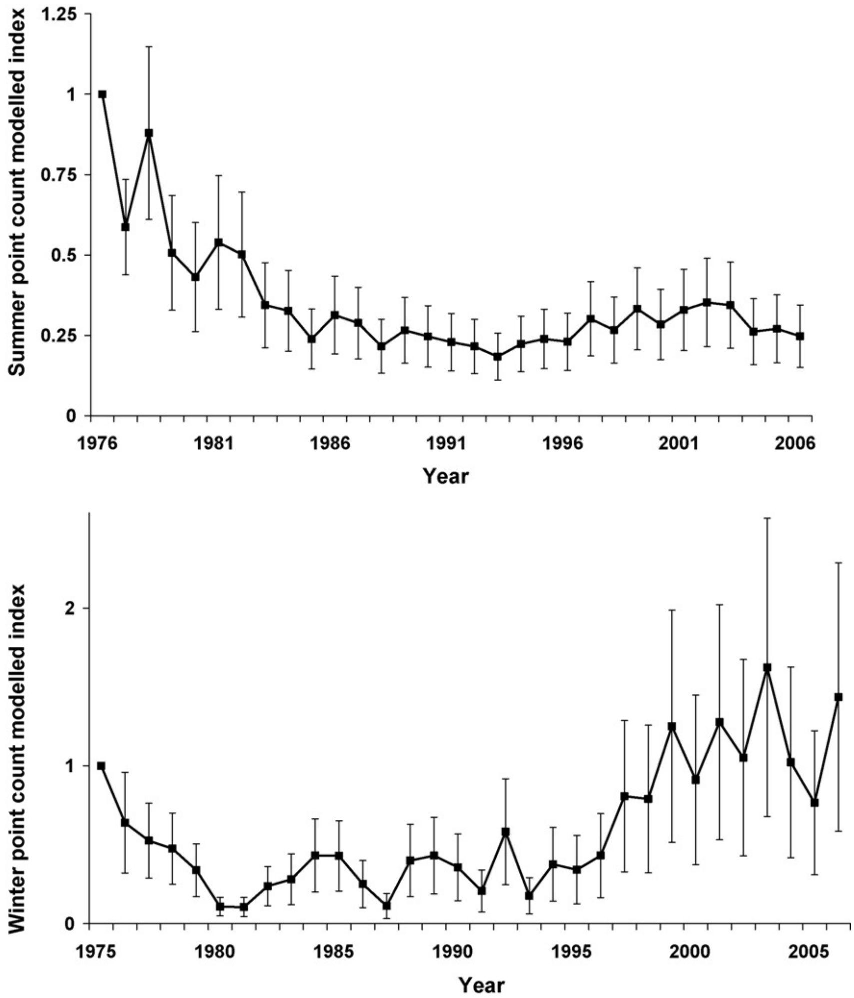

Fig. 2. Results of log linear model fitting to Danish breeding and wintering bird point count data, showing annual geometric mean of abundance indices for summer (±S.E. upper, 1976–2006) and winter (±S.E. lower, 1975–2006).

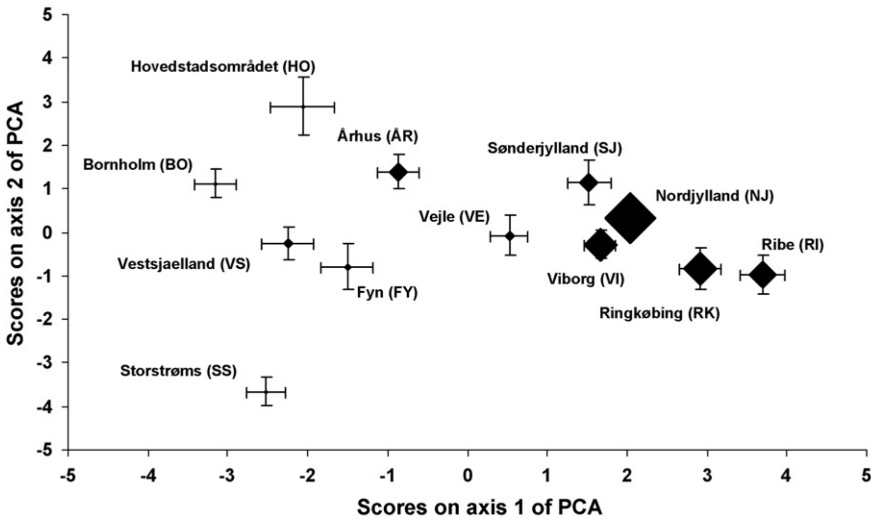

Fig. 3. Graph of principal components analysis of agricultural land use variable scores for each of the major Danish counties (based on 15 agricultural variables relating to land-use area shown in Table 1). Values shown represent mean PCA values generated from land-use data from the years 1993 to 1996 inclusive, ±S.E. to give some assessment of the relative variation resulting from the introduction of set-aside during that period. The size of symbols marking the mean for each county reflect the relative density of corn buntings in each county in these years, generated by the fieldwork associated with the Danish Breeding Bird Atlas project (Grell, 1998), values for which are shown in Fig. 4. The loadings of the land use variables on axes 1 and 2 are listed in Table 1.

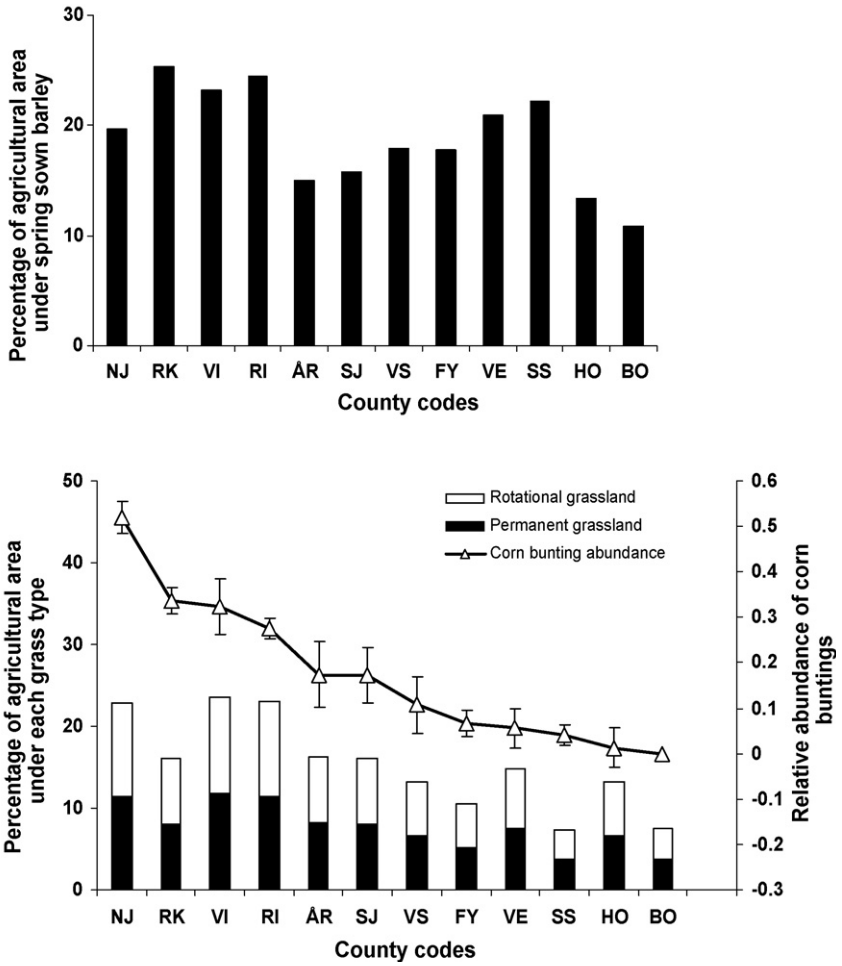

Fig. 4. Relative extent of spring barley (upper histogram), rotational and permanent grassland (lower histogram) in each county identified by codes shown in Fig. 3. Also shown are mean number of corn bunting registrations recorded per visit in each of the Danish counties during Breeding Bird Atlas fieldwork 1993–1996 (open triangles ± S.E.).

3.4. Changes in corn bunting densities in different parts of Denmark

For most counties, there was insufficient point count data for corn buntings from which to generate meaningful annual indices. Those for which this was possible are shown in Fig. 6. This demonstrates the diversity of population trajectories taken by the species in different parts of Denmark. Because of the species' rarity in south and east Denmark, these areas proved the most difficult to compile adequate data to generate meaningful trends. Combining all of Sjælland and the southern islands, there was a slight decrease (−1.13% per annum ±0.02 S.E., although not statistically significant $P > 0.05$), although the fact that the generated estimates and their standard errors for all but the second and fourth years in the time series lie below the starting level of unity in 1990 suggests a population level persistently below that of earlier times. There was no significant change in population size in Nordjylland (−0.32% ±0.01, $P > 0.05$). In contrast, numbers increased by 3.43% (±0.01 S.E.) per annum in Ringkøbing ($P < 0.01$), 7.04% (±0.01 S.E.) per annum in Viborg ($P < 0.01$) and 8.89% (±0.03 S.E.) in Sønderjylland ($P < 0.01$). Small sample size constrained the amalgamation of Århus, Vejle and Fyn, representing central Denmark and eastern Jylland, where corn bunting trends showed significant increase (8.01% ±0.04 S.E. per annum, $P < 0.05$), although the large variance in the model estimates (Fig. 6) warns caution with regard to the model fit in this case. These trends showed no significant relationships with changes in the extent of grass (rotational, permanent or combined) which either declined at a very slow rate or remained stable over the period (see Table 2). There were no relationships with changes in set-aside, which was introduced from 1993, the relative area of which ranged between 4.3 and 10.3% of the farmed landscape with no clear regional trends and

Table 2
Table summarising corn bunting abundance and trends with respect to extent and changes in area of spring sown barley and grass each of the regions of Denmark

	Corn bunting		Spring barley area 1990–2006		Grass area 1990–2006	
	Density 1993–1996	Trend 1990–2006	Mean extent	Trend	Mean extent	Trend
Fyn/Vejle/Århus	Low/med	Stable	Low/med	+2%	Low/med	−0.4%
Nordjylland	High	Stable	Medium	−2%	High	−0.4%
Ringkøbing	High	+2%	High	+2%	High	−0.5%
Viborg	High	+4%	High	+2%	High	−0.4%
Sønderjylland/Ribe	Med/high	+5%	Medium	+3%	High	−0.5%
Sjælland + islands	Low	Stable	Medium	+3%	Low	Stable

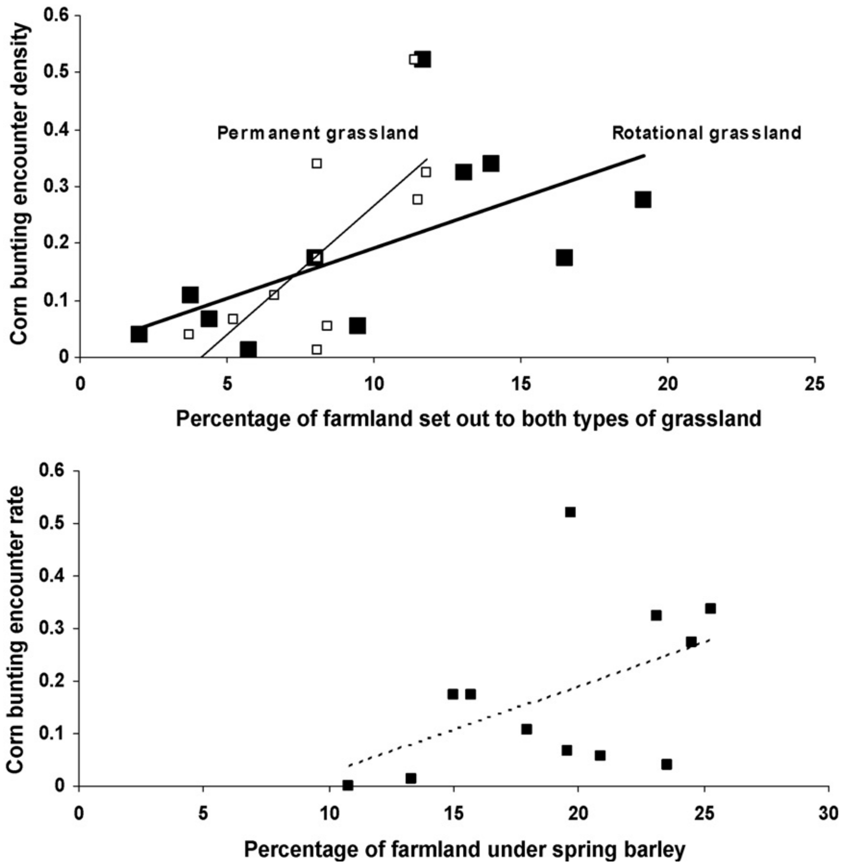

Fig. 5. Relationships between the extent of different grassland types (upper) and extent of spring barley (lower) in each Danish county compared with the mean density of corn bunting encounter rate. Data for land use are expressed as percentage of total farmed area in each county. Fitted regression least squares models are shown fitted to untransformed data merely as a guide, arc sine square root transformed models were significant for both grassland types, but not for spring barley. The outlier centre upper for both grassland types is Nordjylland, with medium grass cover, but high corn bunting densities.

which has changed little since that time. After the dramatic declines in the extent of spring barley grown throughout Denmark during the 1980s (Fig. 7), there has been a recent slight revival since 1993 (amounting to an increase of 2–3% per annum in all regions except Nordjylland, Table 2), but again, there was no correlation between these patterns and those of corn bunting abundance in the regions considered here. Significantly, Nordjylland supported highest corn bunting densities in the mid 1990s, but was the only county to show declines in spring barley area since 1990 and currently has the lowest area of any Danish county. In contrast to the other west Jylland counties (where extent of cultivated spring barley increased), corn bunting abundance has not changed here during 1990–2006 (Fig. 6).

4. Discussion

It is important to be mindful that count routes followed in sampling the point counts reported here were chosen by the observers themselves, and that there has been turnover amongst the observers as new routes enter the scheme and others leave, both factors which could introduce potential bias and error to the compilation of species trends. Nevertheless, since the late 1980s the absolute number and the distribution of routes between habitats has been relatively constant, with a high (>75%) retention rate of routes in any consecutive pair of years and we see no reason to suspect any regional bias in changes that could potentially affect these results. We are therefore confident that, despite much more serious declines throughout their range in former times, corn buntings have increased in Denmark during 1990–2006. In spite of continued agricultural intensification (see Fig. 8 in Fox, 2004), Danish surveillance point counts have shown increases in the species during summer and winter (Heldbjerg, 2007). The greater and more sustained increases in winter compared to summer indices are interesting and may result from increased flocking and concentration (and enhanced detectability) outside the breeding season. This could result from loss of small scale winter habitats that force birds into larger flocks, or the result of being attracted to new habitats (e.g. set-aside), but deserves further research. In contrast, this highly territorial species is encountered during breeding at much lower densities. Danish corn bunting population levels of the early 1990s were much lower than formerly, following declines potentially since the 1930s, but especially during the 1980s (e.g. Dybbro, 1976; Jacobsen, 2002; Fox, 2004). Furthermore, the changes in national breeding numbers (2.2% increase overall per annum) are modest, although locally greater (exceeding 7% per annum in central Denmark, Viborg and Sønderjylland). Nevertheless, this study is the first to demonstrate that the consistent increases (11% per annum in winter numbers) since 1990 show that corn bunting population recovery can occur in a modern and highly dynamic agricultural landscape in the absence of any specific targeted recovery action programme for the species. It is important to understand the causes of increases in Denmark (e.g. Viborg) and identify potential general management options to enhance the conservation status of the corn bunting for wider application in other agricultural systems where the status of the species is considerably more critical than presently the case in Denmark.

Breeding bird atlas results from the mid 1990s (Grell, 1998) showed variation in corn bunting densities throughout the country, being generally highest in the north and west of the

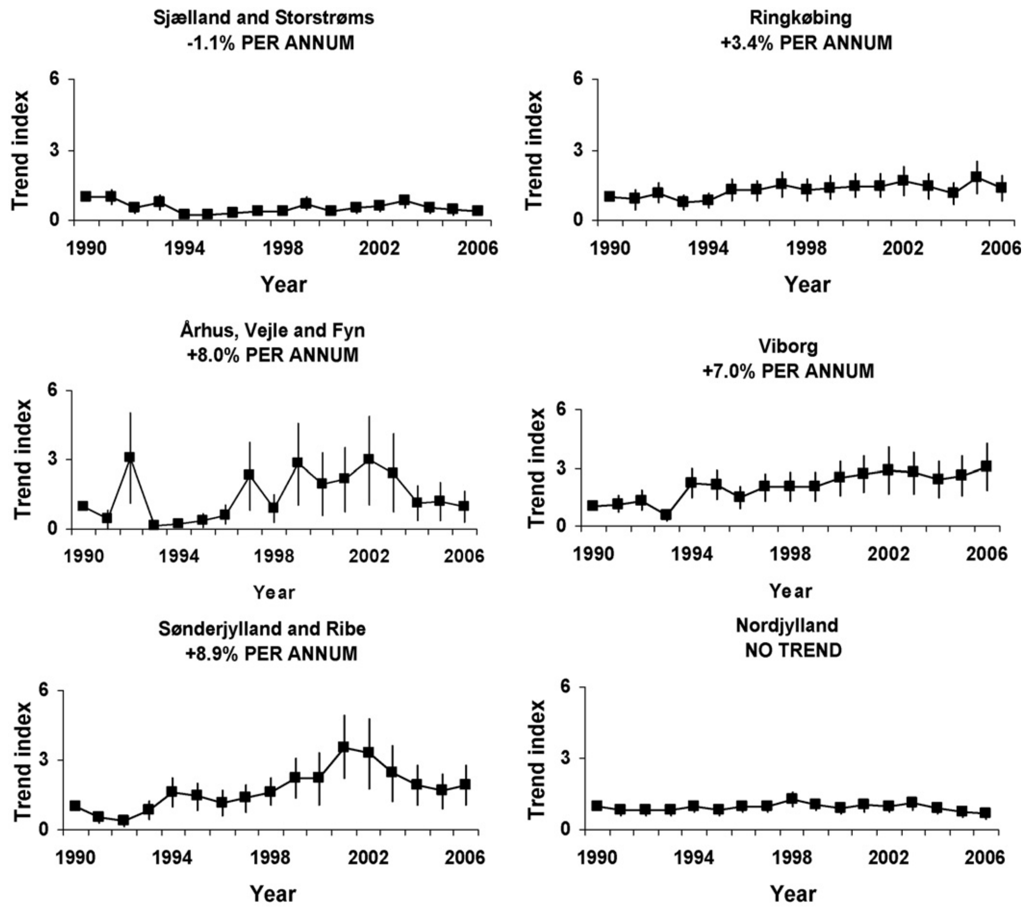

Fig. 6. Population trends for different Danish counties or groups of counties for which sufficient point count data exist from which to generate annual indices. Values are the results of fitted log linear models to count data, used to generate an index (±S.E.) showing change in abundance based on an index value of unity in 1990 as the start year.

country, becoming progressively lower in the south and east. Data from point count surveillance carried out during 1990–2006 confirm that these regional differences in abundance generally persist to the present day. These patterns in abundance reflect the strong west to east gradient in farming practice in Denmark, with highest densities associated with the mixed pastoral agriculture (whilst still retaining substantial cereal cultivation) predominating in the west and few or none occurring in the association with the increasing dominance of pure arable agriculture in better soils of the south and east. Ironically, the corn bunting is often traditionally associated with pure arable landscapes, not least in Denmark, so what features of the various regional farming landscapes are associated with corn bunting abundance?

There remain many competing hypotheses to explain the corn bunting decline in European agri-landscapes, but most consider winter stubble loss (especially barley stubble) and increasing pesticide use as key elements (Donald and Evans, 1994; Donald, 1997; Brickle and Harper, 1999; Brickle et al., 2000). Spring barley cultivation declined rapidly during the 1980s throughout Denmark (see Fig. 7), but remains a major feature of land use in all regions to the present day (see Fig. 4), generally enjoying a slight recovery since 1993 (see Fig. 7 and Table 2). However, there was no correlation between extent of spring barley cultivation and the corn bunting density during the Atlas period. Indeed, bird densities in Storstrøms county were amongst the lowest in the country despite some of the highest (>25%) coverage of spring barley. Given that spring barley varies little (ca. 25% of the agricultural landscape) throughout the country, this implies that bird density and the trajectory of population change in recent years is not wholly dependent upon this element of the contemporary Danish farming scene. However, we should be cautious about using spring sown barley statistics as a proxy for winter barley stubble; many spring barley fields are under sown with grass to maintain winter green fields, whilst others are ploughed, both of which affect the suitability of the aftermath of spring sown barley for wintering corn buntings. Hence, there may also be regional differences in the relationship between spring sown barley and extent of barley stubble. The lack of relationships between spring sown barley data and corn bunting abundance need not necessarily imply barley stubble has no importance for corn buntings in Denmark, because in some areas this habitat is known to support late winter densities of birds. In the mid 2000s, spring sown barley remains a major component of the national agricultural landscape (18–29%, much higher than the <1% in the UK, Chamberlain et al., 2000) and hence its prominence for providing potential winter stubble habitat may probably be important, in combination with other habitats, in maintaining the Danish corn bunting population. It may be also significant that Nordjylland (supporting highest corn bunting densities in 1993–1996) has experienced the most rapid decline in spring barley cultivation since 1990 (now the lowest in Denmark) and in contrast to the rest of Jylland has not shown significant increases in corn bunting abundance.

The application of insecticides, herbicides and fungicides has declined significantly in Denmark since the 1980s in terms of absolute sales and application rates in kg of active ingredient per ha (Fox, 2004). Unfortunately, such data are not available at the county level to account for regional differences, so we are unable to specifically test the hypothesis that this factor has contributed in

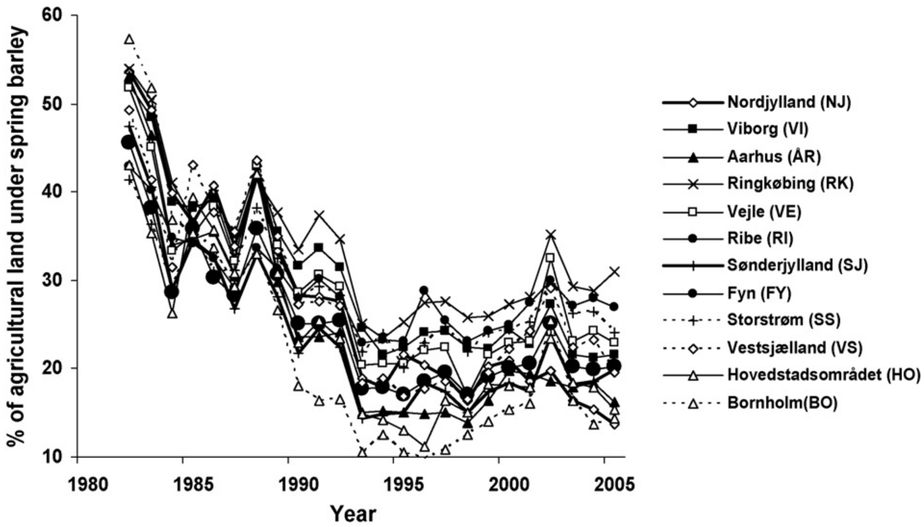

Fig. 7. Annual changes in the percentage area of agricultural land under spring barley in each of the Danish counties during 1982–2006.

some way to regional recoveries in corn bunting populations. Several predominantly west–east macro-environmental gradients existing in Denmark could also correlate with corn bunting distribution and abundance, such as rainfall, temperature and soil types. However, compared to neighbouring countries (e.g. UK, Germany and Sweden) these offer no clear support for hypotheses that these factors are causal and are more likely to contribute to shaping different agricultural practice within Denmark.

In contrast to spring barley, corn bunting abundance was weakly positively correlated with the extent of both rotational and permanent grassland on a county level. Although rarely seen in the large flocks typical of cereal stubble in late winter, the corn bunting is conspicuous in using Danish grassland habitats in early winter (pers. obs. in eastern Jylland). Although there is no obvious relationship with corn bunting abundance, the appearance of set-aside in 1993 (amounting to 4.9–10.8% of agricultural land in the counties and mostly consisting of grassland) may have been significant in adding winter "green fields" since then. No studies suggest that this habitat is important for the species, but Laursen (1980) established a positive correlation between the extent of winter green fields (i.e. grass and all other winter cover crops combined) and corn bunting breeding abundance in the 1970s before the major initiation of autumn sown cereal production that was implemented in the late 1970s to combat soil erosion and reduce fertiliser runoff. It may therefore be the case that the Danish situation supports the findings of Mason and MacDonald (2000) that grassland is important as a feeding habitat outside of the breeding season, overshadowed in the UK by the greater abundance of grassland elsewhere (Donald and Evans, 1994). Brickle et al. (2000) also demonstrated the selection of unimproved grassland and grassy field margins in British arable landscapes for adults provisioning food for nestlings in excess of their local availability.

5. Conclusions

These data shows that corn bunting recovery is possible in the absence of specific conservation actions in contemporary European agricultural landscapes, even left to the vagaries of the current economic and political climate. Contrasting corn bunting densities and population trajectories in different parts of Denmark gives hope for finding management prescriptions for the recovery of the species elsewhere. The species thrives in Denmark where mixed farming prevails, especially areas with extensive grass and spring barley, but is rarer in predominantly arable areas with extensive autumn sown wheat and less grassland. However, we should be prudent in concluding too much from simple correlations. The lack of power in the variation in spring barley to explain changes in corn bunting distribution and abundance shows the weakness of this type of approach given the known importance of the habitat provided to the species elsewhere, especially as there are no direct measures of the extent of winter barley stubble. Some of the highest winter densities (involving up and exceeding to 750 birds) have been reported from spring sown wheat stubble in Kolindsund (Århus County, pers. obs.). Spring sown wheat is extremely rare in Denmark (comprising generally much less than 1% of the farmed area of all counties), so this crop may constitute local importance. Aggregations of up to 100 birds have also been reported from maize stubble, suggesting winter survival habitat is associated with winter stubbles generally (based on records sent in to DOFbasen, which can be viewed at http://www.dofbasen.dk). The correlation between grassland extent and corn bunting density and conservation status may not represent any causal relationship, but may simply reflect the mix of pastoral and arable agricultural habitat that supports higher densities of the species in the west. Perhaps some other facet of animal husbandry characteristic of such mixed farming is the critical landscape element that explains the association with corn bunting abundance. Mixes of autumn- and spring-sown crops and hay/silage grass may be critical in allowing corn buntings to make more successful late nesting attempts in each breeding season than are possible in more monotonous forms of agriculture. Generally lower levels of overall pesticide application are also associated with livestock rearing compared to more arable landscapes. The intimate association of grassland and tillage in a close woven mosaic may simply be more effective at providing food locally throughout the year, by seasonal adoption of patterns of habitat use at relatively small spatial scales. This may be important for the corn bunting which is known to be highly sedentary through the annual cycle (median movement of ringed individuals 4 km, range 0–35 in the United Kingdom and 6 km, range 0–34 in Denmark, Harper, 1995; Shepherd et al., 1997; Wernham et al., 2002; Bønløkke et al., 2006). Finally, it is important to stress that even in Løppethin's (1967) time, when corn buntings had begun to decline but when they were very much more abundant in Denmark than today, he suspected greater densities in Jylland than in the south and east, confirmed by Laursen (1980), suggesting that climate and/or edaphic factors may play a more significant role in affecting abundance than through interactions with agricultural practice.

The important conclusion is that a bird that has exploited modern agricultural habitats and became a hostage to fortune when conditions in that landscape no longer favoured its conservation status does seem able to persist, and even increase, under prevailing circumstances of intensive food production in a western European country. This is in stark contrast to elsewhere in Europe where the species faces catastrophic decline throughout much of its range. This study shows a mixed farming practice retaining winter cereal stubble and grassland will likely favour corn bunting conservation status in northern European farming systems. Having defined this positive association with mixed farming in Denmark, the challenge now is to focus in at the individual level (potentially using direct observations or radio telemetry) to see how birds use different crops and vegetation types as both breeding and survival habitats through the course of the annual cycle. It would be especially illuminating to see under what agricultural circumstances the low densities of corn buntings that persist in the east of the country survive. Set-aside will disappear from 2008 onwards, so it is vital that we understand the management of former set-aside and other grassland types and whether these offer an important source of large carbohydrate-rich seeds and grains which are so favoured by this species. Given the highly sedentary nature of the species, it seems likely that the extent, quality and availability of these habitats at different periods of the year within a given range is highly likely to affect fitness measures of this species which in Denmark at least is almost entirely dependent on farming for its survival.

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