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What measures should be taken to improve conditions for Swedish Farmland Birds, as reflected in the Farmland Bird Index?

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Why do we conduct this evaluation?

This report is part of the evaluation of Swedish operational programme for the European Agricultural Fund for Rural Development.

The Secretariat of Evaluation at the Swedish Board of Agriculture is responsible for evaluating EU programmes where the Swedish Board of Agriculture is the managing authority. This means that the Secretariat of Evaluation order and undertake evaluations for the Swedish operational programmes for the European Agricultural Fund for Rural Development, the European Maritime and Fisheries Fund, and Community-led local development with support from the European Regional Development Fund and the European Social Fund. The programme evaluations are conducted both separately by programme and collectively in multiple programmes. The evaluations are in relation to targets of the operational programmes as well as the overall EU2020 targets.

External actors conduct most evaluations. We rely on the expertise of scientific researchers to review the reports prior to publication. The reviewers' comments are at the end of the report. We publish all reports in a separate series of reports and authors are responsible for the conclusions. The conclusions do not constitute the official position of the Swedish Board of Agriculture.

/ The Secretariat of Evaluation at the Swedish Board of Agriculture

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Summary

Many birds species connected to the agricultural landscape have for several decades fared poorly in Sweden, as well as in Europe as a whole. This is reflected in the decline of the Farmland Bird Index, an official EU indicator for farmland birds specifically, and biodiversity in general. The Swedish Board of Agriculture invited us to propose measures that will improve the conditions for farmland birds in Sweden. In this report, we have briefly summarized the scientific literature on potential drivers of farmland bird numbers, analysed temporal trends in farmland birds and some farming practices, and modelled the spatial distribution of farmland birds in relation to farming practices. The bird data come from the Swedish Breeding Bird Survey, and the farming practise data from the Swedish Land Parcel Information System (Swedish Board of Agriculture). Based on our findings, we propose a suit of measures concerning the quantity and quality of farmland that would improve the future conditions for farmland birds. At the more general level, farmland birds would benefit if the ongoing loss of farmland in general and important semi-natural habitats in particular was halted. We also propose that farmland birds would benefit from measures taken to promote mixed farming (combined animal husbandry and crop production at the same farms), notably to increase crop farming in the north and animal husbandry on the plains. Increased use of set-asides of various kind, not least those of varied vegetation structure and year-round cover, would also benefit farmland birds. Furthermore, farmland birds would most likely also benefit from more wetlands in the agricultural landscape, reduced use of pesticides and inorganic fertilizers, and more spring-sown crops. They may benefit from higher crop diversity at the farm level, and we found some evidence for this. Some more directed measures may also benefit the Farmland Bird Index; we found support for the benefits of wild bird cover ("fågelåkrar"), skylark plots ("lärkrutor"), buffer strips ("skyddszoner") and appropriately managed ecological focus areas ("ekologiska fokusområden").

Fyra jordbruksfåglar - storspov, stare, buskskvätta och sånglärka - som minskat signifikant i antal sedan 2002.
Four of the farmland bird species dealt with in this report, which all have declined significantly in numbers since 2002: Eurasian Curlew, European Starling, Whinchat and Skylark.

Sammanfattning

Många fågelarter som är typiska för jordbrukslandskapets har minskat kontinuerligt i antal de senaste decennierna, både i Sverige och i övriga Europa. Detta avspeglas bland annat i "Farmland Bird Index", en officiell EU-indikator för jordbruksfåglar specifikt, men även för biologisk mångfald generellt. Jordbruksverket gav oss i uppdrag att föreslå åtgärder inom jordbruket som skulle kunna vända den generella nedgången i jordbruksfåglarnas antal. Vi har i denna rapport sammanfattat den vetenskapliga litteraturen om vilka faktorer som påverkar hur det går för jordbruksfåglarna. Vi har också beskrivit och analyserat tillgängliga data om storskaliga förändringar över tiden i såväl några viktiga odlingsparametrar som fågelbestånden, med fokus på de senaste 20 åren. Därtill har vi modellerat hur dagens jordbruksfåglar är fördelade i Sverige i förhållande till den rumsliga variationen i ett antal odlingsvariabler. Fågeldata kommer från Svensk Fågeltaxerings nationella fågelövervakningssystem och jordbruksdata från offentlig statistik samt Jordbruksverkets ”Blockdatabas". Baserat på vår litteraturstudie och våra analyser av fågel och jordbruksdata föreslår vi ett antal åtgärder med potential att leda till ett ökat antal jordbruksfåglar i Sverige. Dessa berör antingen kvantiteten eller kvaliteten av Sveriges jordbruksmark. Om minskningen av antalet jordbruksfåglar skall vändas, måste den pågående förlusten av jordbruksmark och viktiga småbiotoper i Sverige stoppas. Även insatser för att gynna "mixed farming" (djurhållning och grödproduktion på samma gård) kan bidra till att vända trenden. Detta innebär i praktiken ökad spannmålsproduktion i norr och i skogsbygderna (där djurhållning dominerar), samtidigt som fler gårdar på slätten håller djur (med därtill hörande gräsmarker). Ytterligare åtgärder med potential att öka jordbruksfåglarnas populationer är att gynna trädor (särskilt sådana med varierad vegetation och bitvis öppna ytor, där marken lämnas ifred över både sommar och vinter och där rena svartträdor undviks), att anlägga eller återskapa våtmarker, att reducera användningen av växtskyddsmedel och mineralgödsel, och att gynna vårsådd på höstsåddens bekostnad. Även högre diversitet av grödor per gård kan gynna jordbruksfåglarna, vilket vi fann stöd för. Mer specifika åtgärder som vi föreslår kan vara effektiva är fågelåkrar (sädesfält som inte skördas och lämnas åt fåglarna), lärkrutor (små fläckar av åkrar som inte sås), skyddszoner och ekologiska fokusområden.

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1. Background

Many birds species connected to the agricultural landscape have fared very poorly for several decades, in Sweden as well as in the rest of Europe (Fig. 1). The overall fate of farmland birds is often expressed through the Farmland Bird Index (FBI), an official EU indicator for farmland birds specifically, and biodiversity in general (http://ec.europa.eu/eurostat/statistics-explained/

index.php/Archive:Agri-environmental_indicator_-_population_trends_of_farmland_birds). The Swedish Board of Agriculture has invited our research group at Lund University to propose measures that will improve the conditions for farmland birds in Sweden, eventually leading to a reversal of the negative trend in the Farmland Bird Index (FBI). The suggested measures should be possible to combine with "profitable farming" ("ett rationellt jordbruk").

It should be noted that there is no unambiguous way of defining a "farmland bird" (but see Butler et al. 2012). Since the focus of our work explicitly is on the effects on FBI, we focus on the fourteen species reported from Sweden to the European FBI, based on the European species selection (see below). However, for practical reasons, the species selection will sometimes differ between the different analyses and interpretations. For example, a slightly different set of species is used in the farmland indicator for the Swedish Environmental Objectives ("miljömålen"), which was developed to fit Swedish conditions better than FBI (see below).

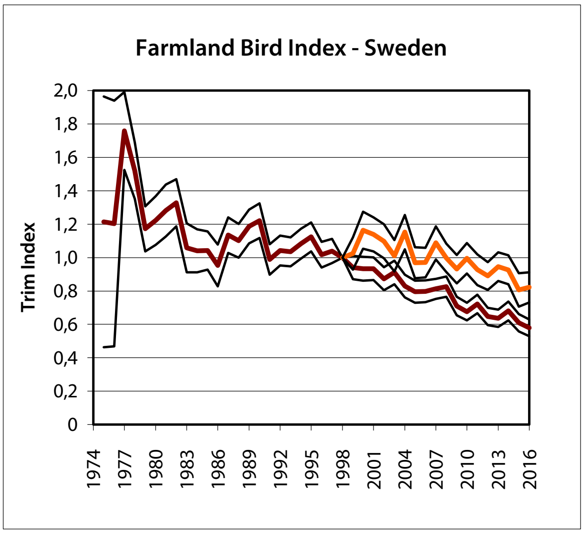


Figure 1. The average trend (with 95 % confidence intervals) in Sweden for 14 bird species connected to farmland, as recorded by two different monitoring schemes: the free choice point counts from mainly southern Sweden (brown line), and the Fixed routes covering all of Sweden in a representative way (orange line). The index has declined by 50–60 % since 1975 and 20–40 % since 1998.

It should also be noted that farmland birds can be affected in many different ways by farming practices and farmland composition and structure (e.g. Butler & Norris 2013). Any given practice and structure will affect different species differently, since each of the farmland birds have their own specific ecological requirements. For example, some farmland species breed on the ground in the fields, whereas other breed in nearby "small biotopes" such as stone walls or piles, single trees, bushes, hedges and field margins and mainly use the fields for foraging. In addition to the conditions related to farming activities, Swedish farmland birds can of course be affected by factors independent of farming practices in Sweden, such as climate (e.g. Jørgensen et al. 2016). Some "farmland birds" also spend parts of their year outside farmland. Clearly, both climate, non-farmland habitats and conditions outside Sweden are largely outside the influence of the Swedish Board of Agriculture.

We first describe how we have addressed the topic and within which limits we have worked. Then follows three sections based on different types of information gathering on how farmland birds have fared recently: a literature review, an analysis of Swedish farmland bird trends, and finally, statistical modelling using bird survey data and agricultural statistics from the Land Parcel Information System (LPIS, “Blockdatabasen”). Finally, we suggest measures that may be taken by the Swedish Agricultural Board in order to reverse thee declining FBI trend in Sweden.

2. Methods

2.1 Setting limits to our analysis

The poor fate of farmland birds, and the potential causes of their population declines, is clearly a huge and complex topic. We have therefore, by necessity, been forced to set limits to our work. These limits are listed and discussed below.

Already determining *what is a farmland bird* is a complex issue. There is an ever-ongoing debate about which species should be considered "farmland birds", and in the literature there are many different species sets referred to as "farmland birds" (see e.g. Gregory et al. 2005; Butler et al. 2012; Siriwardena et al. 2014). The reason is that different sets of species may be relevant given the specific question asked, but also for example that the relative dependence on farmland of a given species may vary geographically (Stjernman et al. 2013) and even over time (e.g. most Ortolan Buntings nowadays occur in forest clear-cuts, Ottvall et al. 2008). As stated above, we focus on the species subset included in the Swedish FBI. However, it should be clear that there are more species that to varying extent depend on farmland for their existence, such as Curlew *Numenius arquata* and Wheatear *Oenanthe oenanthe* (which are included in the species selection of the Swedish Environmental Objective "A varied agricultural landscape"). We have therefore in our analyses taken a flexible approach, and consider data and results from more species when practical and biologically meaningful.

Farmland birds occur all over the World, and their ecological conditions may accordingly vary enormously. We have for biological and practical reasons focussed on *conditions for farmland birds in Sweden*. This is particularly the case when it comes to trend analysis and modelling which is entirely based on data from Sweden, but is also reflected in our literature search.

Even the *definition of farmland* is not obvious. In principal, our focus has been on land included in the LPIS. This includes fields with a variety of different crops, managed grasslands and semi-natural grasslands. A very special type of "farmland" are coastal grazed meadows, with a special and threatened bird fauna. Given that the total area of this habitat is relatively small and geographically limited, and that most of the land is protected and under special managing regimes, we will not deal with coastal meadows explicitly, although it shares several of the problematic features connected to semi-natural grasslands (for more information on coastal grazed meadows, see e.g. Green 2012).

Eleven of the 14 species included in the Swedish Farmland Bird Index are migratory. That is, they live outside Sweden for at least six months of the year. Clearly, the causes behind population changes can theoretically be found in any part of *the annual cycle*. There are good reasons to believe that conditions in Sweden, and during the breeding season, indeed affect population trends in Sweden (Wretenberg et al. 2007, Smith et al. 2012), and that actions taken in Sweden may benefit birds also if the primary reason for decline is to be found elsewhere (cf. Sutherland 1996). Thus, given the mission to propose measures in Sweden this is what we will focus on.

2.2 Literature survey

A large body of the scientific literature on European farmland birds concerns the United Kingdom, but in recent years, a growing number of studies have been published from other European countries or have taken a pan-European approach. We focus on studies carried out in Sweden, but refer to non-Swedish studies when biologically relevant. In this respect, the reviews of Newton (2004), Vickery et al. (2004), Roberts & Pullin (2007), Stoate et al. (2009) and Dicks et al. (2013) were particularly useful.

We searched Web of Science (all databases) for information on farmland bird requirements in Sweden (search terms: (((agri* OR agro*) bird*) OR (”farmland bird” OR ”farmland birds”)) AND (Sweden OR Swedish). To that we added studies that we knew of beforehand, or found cited in other studies. The Swedish studies range from large-scale correlative studies based on monitoring data (Wretenberg et al. 2006, 2007, Stjernman et al. 2013) to detailed field studies at the local scale (e.g. Hiron et al. 2012). Even in Sweden there is a regional bias of field studies. A majority of the identified studies deal with conditions in South-Central Sweden (mainly in Uppland), due to the work of Åke Berg, Tomas Pärt and others at the Swedish Agricultural University in Uppsala. A second well-studied area is the very southernmost province of Sweden, Skåne, through the work of our group at Lund University. On the other hand, these two areas belong to the largest and most intensively farmed areas in Sweden.

Overall we have used the published information to elucidate which factors may be important drivers for farmland bird population changes in Sweden.

2.3 Trends in farming and farmland birds in Sweden

2.3.1 Farming trends in Sweden

We collated data on some key farmland statistics from several sources. Data on areas of total agriculture land, pasture, and fallow/unused arable land 1975–2000 were taken from Jordbruksverket & Statistiska centralbyrån (2011). Detailed data of grown areas of different crops, harvest/ha, and land-use were downloaded from the Swedish Board of Agriculture’s homepage (http://statistik.sjv.se/PXWeb/pxweb/sv/Jordbruksverkets%20statistikdatabas/?rxid=5adf4929-f548-4f27-9bc9-78e127837625). Data on “normal” harvest of spring barley were extracted from official Swedish statistics from 2000 to 2015 (Jordbruksverket 2000–2015).

2.3.2 Farmland bird trends

Farmland birds are monitored in Sweden mainly by two monitoring schemes (for more details, see Lindström et al. 2007, Green et al. 2016, and the project homepage www.fageltaxering.lu.se). It should be noted that in both schemes all encountered bird species are counted, not only farmland birds.

The summer point count scheme started in 1975 (“Point counts”, “Old scheme”). The surveyor determines her/himself where to count. Each route consists of 20 points in the terrain where all birds heard and seen are counted during five minutes, once per year, by the same observer, in late spring or early summer. This scheme mainly covers the more populated areas of southern and eastern Sweden.

The Fixed routes started in 1996 ("Fixed routes", "New scheme"). Each of the 716 routes is a square-shaped 8 km line transect along which the surveyor walks and counts all birds heard or seen, once per year, in late spring or early summer. The route outline is predetermined by the coordinators. The surveyor may shift between years. This scheme covers the whole of Sweden in a representative way. Because the number of routes surveyed annually was rather low the first years, national trends are calculated from 1998, and regional trends from 2002 (see below). For historical reasons there are two sets of farmland bird indicators, with slightly different species selection (Table 1).

The first Swedish indicator was based on a European species selection, aimed at following the farmlands of Europe (Gregory et al. 2005). From the original selection of 37 species, Swedish trends could be calculated for 14 species: Lapwing (*Vanellus vanellus*), Skylark (*Alauda arvensis*), Barn Swallow (*Hirundo rustica*), Meadow Pipit (*Anthus pratensis*), Yellow Wagtail (*Motacilla flava*), Whinchat (*Saxicola rubetra*), Common Whitethroat (*Sylvia communis*), Red-backed Shrike (*Lanius collurio*), Rook (*Corvus frugilegus*), European Starling (*Sturnus vulgaris*), Tree Sparrow (*Passer montanus*), Linnet (*Carduelis cannabina*), Ortolan Bunting (*Emberiza hortulana*) and Yellowhammer (*Emberiza citronella*). A varying proportion of the individuals of these species occur also outside farmland in Sweden (Stjernman et al. 2013), but all individuals recorded are included in the calculation of the indicator. This indicator has been calculated using data from both the Old and New scheme (Fig. 1).

A second farmland bird indicator was developed a few years later, this time to match the Swedish Environmental Objective "A varied agricultural landscape". To better match Swedish conditions, a slightly different group of species was selected: we excluded Meadow Pipit (mainly occurs outside farmland), Rook (has a restricted geographical occurrence), and Ortolan Bunting (rare, and mainly occur outside farmland). We restricted Yellow Wagtails to the southern subspecies *M. f. flava* (the northern subspecies *thunbergi* mainly occur outside farmland). Finally, we added Curlew and Wheatear. For the latter we only included birds from outside the Swedish mountain range. This indicator has been calculated using data from the New Scheme only, which covers all of Sweden in a representative way.

For this second indicator we also calculated regional trends, as well as sub-indicators for species tightly connected to "meadows and grassland" (Lapwing, Eurasian Curlew, Barn Swallow, Yellow Wagtail (*M. f. flava*), Wheatear, Whinchat, Common Whitethroat, Red-backed Shrike, European Starling, Linnet and Yellowhammer), and "small biotopes" (Wheatear, Whinchat, Common Whitethroat, Red-backed Shrike, European Starling, Linnet and Yellowhammer), respectively.

Having two different indicators for one topic is of course slightly inconvenient, but on the other hand, a few more relevant species were included when the second indicator was created. And as will be seen, the trends of the two indicators are very similar. Clearly, the exact species selection does not affect the overall picture of the fate of farmland birds in Sweden.

For each species or subspecies, we calculated yearly indices and log-linear trends using TRIM (for details, see Green et al. 2016). The indicator value for a given year is the geometric mean of the species-specific indices (following Gregory et al. 2005).

Table 1. The species selection of the two Swedish farmland bird indicators.

English name	Swedish name	Scientific name	Farmland Bird Indicator	Swedish Environmental Objective
Lapwing	Tofsvipa	*Vanellus vanellus*	•	•
Eurasian Curlew	Storspov	*Numenius arquata*		•
Skylark	Sånglärka	*Alauda arvensis*	•	•
Barn Swallow	Ladusvala	*Hirundo rustica*	•	•
Meadow Pipit	Ängspiplärka	*Anthus pratensis*	•	
Yellow Wagtail	Gulärla	*Motacilla flava*	•	
Yellow Wagtail (southern Sweden)	Sydlig gulärla	*M. f. flava*		•
Wheatear	Stenskvätta (outside mountains)	*Oenanthe oenanthe*		•
Whinchat	Buskskvätta	*Saxicola rubetra*	•	•
Common Whitethroat	Törnsångare	*Sylvia communis*	•	•
Red-backed Shrike	Törnskata	*Lanius collurio*	•	•
Rook	Råka	*Corvus frugilegus*	•	
European Starling	Stare	*Sturnus vulgaris*	•	•
Tree Sparrow	Pilfink	*Passer montanus*	•	•
Linnet	Hämpling	*Carduelis cannabina*	•	•
Ortolan Bunting	Ortolansparv	*Emberiza hortulana*	•	
Yellowhammer	Gulsparv	*Emberiza citrinella*	•	•

2.4 Statistical modelling of bird abundance

In contrast to the trend analyses referred to above, we here take advantage of the spatial variation in land-use present throughout the main farmland regions in Sweden. We again used data from the bird monitoring scheme (the Fixed routes only). This dataset have the advantage of being a representative sample of the actual types of land-use present throughout Sweden. Land-use data was extracted from the LPIS. We applied up-to-date sophisticated statistical techniques to estimate the relationships (including parameter uncertainties) between a set of land-use types and the abundances of farmland birds. Inferences from the models gave valuable information about general as well as species-specific habitat requirements of the farmland birds as reported below.

3. Results

3.1 Information in the scientific literature

Two aspects of agricultural change are thought to be the major drivers of loss of farmland biodiversity including birds; agricultural abandonment and intensification (Wretenberg et al. 2006, Stoate et al. 2009, Reif 2013). While less productive agricultural landscapes, often characterized by mixed farming, has suffered from abandonment, more productive areas have experienced agricultural intensification such that the agricultural production per unit area has increased. The consequences of abandonment will obviously depend on what farming is replaced with, but often has predictable negative effects on farmland birds because of loss of suitable habitat (Stoate et al. 2009).

While the effect of agricultural intensification on farmland birds is well established (Donald et al. 2001, 2006), it is often difficult to deduce the mechanisms causing the declines, because intensification is caused by a suite of correlated measures to increase agricultural productivity, many with potential impact on birds. This includes increased use of inputs, loss of semi-natural habitats, drainage, simplified crop rotations, and structural simplification of landscapes because of farm enlargement and specialization (Newton 2004). Furthermore, different farmland bird species may react very differently to agricultural change depending on their ecological traits (Butler et al. 2010). As a result, multiple lines of evidence is often required to deduce the relationship between agricultural change and the population changes of farmland birds. Such evidence includes relating trends of farmland birds to agricultural change, investigating the consequences of agricultural change by comparing otherwise similar farmland areas that differ in key aspects (‘space-for-time substitution studies’), experimental studies at landscape scales, and detailed studies of the ecology of farmland birds to infer mechanisms. Based on key syntheses (Newton 2004, Roberts & Pullin 2007, Stoate et al. 2009, Dicks et al. 2013, Reif et al. 2013), supplemented with a thorough compilation of studies of farmland birds in Sweden, we try to describe what is currently known about the drivers of changes in the birds linked to the Farmland Bird Index in Sweden.

Loss of ecological heterogeneity at multiple spatial and temporal scales, resulting from agricultural intensification, has been suggested to be a main driver of biodiversity loss in farmland (Benton et al. 2003), including birds (Shrubb 2003). Loss of heterogeneity results from several interdependent processes.

At larger scales, structural rationalization of agriculture has resulted in farms becoming specialized towards plant production or animal husbandry, with less variation in what is produced on an individual farm (Stoate et al. 2001, 2009, Wretenberg et al. 2007). This may result in key resources for farmland birds no longer being spatially associated. Within farms, habitat conversion and field enlargement has resulted in loss of semi-natural habitat (Newton 2004, Stoate et al. 2009). Since semi-natural habitat is important as relatively undisturbed habitats in an otherwise highly disruptive environment, they are key to provide food, shelter and nesting sites for many organisms. Within fields, increased used of agricultural inputs, more competitive crops, subsurface drainage etc. has resulted in more homogenous swards, less weeds and fewer invertebrates with negative consequences for foraging of farmland birds (Potts 1986, Newton 2004). This literature survey is structured along this hierarchal loss of heterogeneity, starting with consequences of regional specialization (including farm abandonment) and ending with loss of critical resources at field scales.

The decline of farmland birds can be targeted by reversing trends found to be involved in their loss, such as conserving semi-natural habitats or recreate incidental habitats in intensively farmed landscapes. However, also approaches based on an understanding of what limits farmland bird population sizes can be used to formulate novel instruments to reverse trends, such as supplemental feeding (Siriwardena et al. 2007) or provision of artificial nest sites (von Post & Smith 2015). We try to cover both these aspects.

There exist a plethora of agricultural policies aimed at reversing the negative trends for farmland biodiversity, including agri-environment schemes (Roberts & Pullin 2007) and the recent greening of the Common Agricultural Policy (CAP) (Pe'er et al. 2014). The consequences of these policies will depend on their uptake, and if taken up, on whether they change farm management, and finally on if any change in farm management has consequences for birds. Hence, evaluating the consequences of these policies require the comparison of counterfactual scenarios, which demands both socio-economic and ecological analyses. In this report, we focus on the ecological consequences of measures as such on farmland birds. However, when evaluating which strategies are most cost-efficient for reversing the decline of the Farmland Bird Index, a broader approach ultimately needs to be taken.

Since biodiversity is not an additive measure, benefits to local diversity at e.g. a field or a farm, may not scale up to benefit biodiversity at landscape scales (Schneider et al. 2014). Thus, benefitting common species in farmland may not always result in positive consequences for rare species (Kleijn et al. 2015). Since the species included in the Farmland Bird Index are relatively common birds (making it possible to monitor their abundance in generalized schemes such as the as the Swedish Breeding Bird Survey), we focus on the consequences of the abundance and diversity of birds at scales from fields to farms.

Farmland birds are not only affected by agricultural change in Sweden, but also by changes at their winter quarters (Ockendon et al. 2012; but see Morrison et al. 2013) and by climate change (Jørgensen et al. 2016). While these effects are obviously of importance, we have not included them in this report, since the ambition is to identify measures to reverse negative trends of farmland birds that can be implemented in Swedish farmland.

3.1.1 Agricultural abandonment

Concurrently with agricultural intensification, there has been loss of farmland across Europe. This has mainly affected landscapes with lower agricultural productivity in Southern, Northern and Eastern Europe (Keenleyside & Tucker 2010) with negative consequences for farmland birds (Reif et al. 2013). For example, abandonment in northern Europe has been most common in less productive regions with predominantly grassland and low quality arable fields, often related to a decrease in non-profitable livestock management (Stoate et al. 2001; 2009). In Sweden, loss of farmland has occurred throughout Sweden, being proportionally larger further north (Fig. 3), thus affecting forest regions and mosaic farmland and farmland birds associated with these landscapes (Wretenberg et al. 2007).

The consequence of farmland abandonment on farmland birds is complicated by the fact that many birds defined as farmland birds (e.g. included in the Farmland Bird Index) exist both inside and outside farmland (Fuller et al. 2004, Stjernman et al. 2013). The loss of farmland birds as a consequence of agricultural abandonment therefore needs to be evaluated by predicting the net loss of farmland birds, e.g. using habitat association models (see section "Habitat association modelling"). Such habitat association models have been used to predict the consequences of changes in policies that contribute to the continued use of marginal farmland in Sweden (e.g. Smith et al. 2016). In this report, we focus on the conclusions made from one such habitat association model.

It is important to note that the policy instruments used to counter farmland abandonment also may have impact on what type of agriculture that will prevail in marginal areas. Thus, support of agricultural systems presently dominating these areas, such as the agri-environmental payment scheme for grassland and the compensatory allowance, may fail to reverse or even enhance trends in agricultural management with potentially negative consequences for some farmland birds (see below on landscape simplification in marginal areas). However, notably such measures may also benefit the maintenance of semi-natural grasslands because they make continued animal husbandry economically profitable, even if the effect may be small (Hasund et al. 2017).

In Sweden, agricultural abandonment has been proportionally larger in more northerly areas (Fig. 3). However, it is worth noting that abandonment affects all parts of Sweden, potentially with a disproportionate loss of farmland heterogeneity if it mainly affects marginal areas.

3.1.2 Landscape simplification

Regional specialisation results in a spatial homogenisation of the landscape (Stoate et al. 2001, 2009). In more productive regions, the concentration of farming to larger, more efficient farm units with mainly arable farming has resulted in a loss of semi-natural habitats (pastures, field margins, and woody vegetation), simplified crop rotations, and loss of animal husbandry. Fallows, a relatively undisturbed habitat that may provide nesting and feeding resources to farmland birds, are used less frequently in the more productive landscapes, where they therefore do not contribute to much needed landscape heterogeneity. In more pastoral systems, on the other hand, homogenisation is due to the loss of open arable fields, where farmland is dominated by improved grasslands maintained for fodder or grazing. Hence, while multiple habitat types may prevail at larger spatial scales, they may not be in close proximity anymore, with negative impact on the population viability of birds that needs nesting and foraging resources to be close to each other (Bruun & Smith 2003), or sedentary birds which need forage resources during different seasons (von Post 2013). As a result, the response of farmland birds to habitat availability (e.g. arable vs. grassland) may be frequency dependent, with a mixture of habitats being optimal (Robinson et al. 2001).

While there is little evidence to evaluate the importance of habitat complementation (cf. Dunning et al. 1992) directly, there is abundant evidence that simplification of landscapes towards either landscapes dominated by either plant production or husbandry and grasslands is detrimental to farmland bird diversity. Below we discuss key elements of such landscape simplification. However, it is important to realize that while it may be specific aspects of landscape simplification that affect a particular bird species or farmland birds in general, various aspects of landscape simplification are highly correlated. For example, in Scania in South Sweden, agricultural land-use variation could be described along one dimension related to the proportion of arable land (closely related to crop yield), whereas additional dimensions related to the multivariate structural landscape complexity and farm type depended on at which spatial scale the analysis was performed (Persson et al. 2010). Likewise, while there has recently been an increased attention on crop complexity, the simplification of crop rotations as a consequence of agricultural intensification means that indices of crop complexity are strongly correlated to other indices of landscape simplification (A. Persson, personal communication), but the strength of correlations depends on the scale at which landscapes are analysed at (Purtauf et al. 2005). Thus, even if a particular study has related farmland birds to a particular aspect of simplification that does not necessarily mean that this particular aspect of simplification is the driver of population changes. Only a few studies have explicitly tried to isolate a single aspect, or disentangle the effect of multiple aspects, of landscape simplification.

Farm-scale heterogeneity might not benefit all farmland birds. A heterogeneous landscape may be particularly attractive to non-crop nesting species that benefit from the presence of non-crop habitats (e.g. habitat islands, farmsteads, semi-natural pastures, forest edges, Berg et al. 2015). In contrast, several farmland bird species avoid tall structures such as hedges and require large open fields, particularly the Skylark and the Lapwing (Vickery & Arlettaz 2012). However, the consequences may be different for different aspects of heterogeneity, e.g. for Skylarks preferring arable landscapes, but still benefitting from small fields and crop diversity (Guerrero et al. 2012).

The concept of landscape simplification is strongly associated with the loss of semi-natural habitats and simplification of agricultural production in intensively farmed areas. However, there is also a trend that marginal areas become dominated by animal husbandry and managed grasslands, resulting in a simplified agricultural landscape with low availability of arable fields that may be important for some farmland birds (Robinson et al. 2001). This aspect of landscape simplification has, however, been less studied.

In this section, we will cover studies that have related farmland birds to various indices of landscape heterogeneity, occurrence of mixed farming, amount of semi-natural grasslands, amount of small biotopes including field borders and amount of forest edges, while realizing that what actually drives the variation in farmland bird populations is not always known.

Semi-natural habitats

Semi-natural pastures, unused semi-natural areas such as field borders, and incidental habitats, represent relatively stable areas in a landscape otherwise regularly disturbed by farming activities. As such, they may provide foraging areas for farmland birds, as well as functioning as sources for maintaining populations of plants and invertebrates in the wider landscape that are used by birds as food. Several farmland bird species nest and forage in semi-natural grasslands and other grassland habitats within the agricultural landscapes, such that the loss of this habitat may reduce the abundance and diversity of farmland birds both at the landscape scale and in the arable fields (e.g. Smith & Bruun 2002, Pe’er et al. 2014). Also smaller semi-natural habitats, such as field-borders and small biotopes are important as foraging and nesting areas for farmland birds, thus contributing to their abundance and diversity at landscape scales (Vickery & Arlettaz 2012). They may also function as vantage points for foraging and nesting places, not least if they contain bushes and trees that are scarce in the rest of the landscape.

The presence of small biotopes cannot be deduced from general agricultural statistics, but has been investigated by analysing aerial photographs and maps. Ihse (1995) and Irminger Street (2010) found increased field sizes and a dramatic decrease in the presence of small biotopes in particular in the plains. These studies cannot determine if the decline in small biotopes continued during the period that the Farmland Bird Index has been monitored. Since 1991 small biotopes in farmland has been protected by law (Carlsson et al. 2013). However, in a more recent study, Theorin (2012) found a continued decline in the availability of small biotopes in a landscape in Uppland post 1982.

Several studies in southern Sweden have demonstrated that farmland bird abundance and diversity is positively related to the presence of semi-natural habitat, such as semi-natural grasslands and small biotopes (Smith et al. 2010a). For example, Hiron et al. (2013a) found effects of both semi-natural grasslands and small habitat elements managed for their cultural values such as old buildings, infield non-crop islands, stone walls and ditches. In a study in Uppland and Västmanland, the abundance of some farmland birds was positively associated with a measure of heterogeneity that reflected the inter-dispersion of non-arable habitat among the arable fields (Berg et al. 2015). Olsson et al. (2009) found that farmland bird diversity was positively affected by the presence of woody vegetation along field borders in landscapes in Scania that differed in heterogeneity. A study in Uppland found that small farms contained a higher abundance and diversity of birds, which was explained by higher habitat heterogeneity on smaller farms units (Belfrage et al. 2005). Habitat heterogeneity was calculated as a diversity index on multiple habitat types including various semi-natural habitats, but no single habitat measure had a strong relationship to bird abundance.

Carlsson (2013) investigated the effect of ceased grazing in a large grassland area on a number of farmland birds. Within five years, when the vegetation height increased steadily, Lapwings, Skylark, Starlings, and Linnets decreased significantly in numbers, whereas Meadow Pipits, Corncrakes (*Crex crex*), and Whinchats increased. Although some farmland species benefitted from ceased grazing, they would most likely all disappear within yet a few years, unless grazing was resumed.

In Denmark, a detailed analysis of Starling population numbers revealed that their long-term decline was highly correlated to the number of cattle and level of grazing. The combined effect of fewer cattle and less intense grazing in Denmark has reduced the amount and quality of crucial feeding sites for Starlings during breeding (Heldbjerg et al. 2016). Smith & Bruun (2002) found the number of breeding Starlings in nest-box colonies to be strongly related to the amount of grazed grassland in the surrounding landscape, and Granbom & Smith (2006) found breeding success of Starlings to be positively affected by proximity to grasslands.

Wheatears have higher breeding success and survival in short-grass habitats, and much lower in habitats with tall field layers such as crop fields and ungrazed grasslands. Accordingly, Wheatears may have declined in farmland due to loss of grazed semi-natural grasslands (Arlt et al. 2008). In a study of House Sparrow during the breeding season, large-scale homogenous farmland devoid of semi-natural habitat had poorer feeding opportunities than heterogeneous farmland landscapes, which was linked to lower population densities and reproductive success (von Post et al. 2012).

Animal husbandry

Specialization on plant production in more productive agricultural landscapes have resulted in loss of animal husbandry. This has major implications on the farming system (loss of semi-natural grasslands, changes in crop rotations etc.), which are treated elsewhere. However, it also means a loss of farm-associated animals at the farmsteads, which may affect farmland birds that use the farmsteads for breeding and/or foraging. Loss of open stables may result in loss of indoor nesting places and reduced handling of fodder and manure may mean missed foraging opportunities. A recent meta-analysis found a positive effect of livestock farming on barn swallows, but not on other farmland birds (Musitelli et al. 2016). Effects of changes in the way animals and manure are handled seems to be lacking.

In Uppland, Ahnström et al. (2008) found a positive relationship between manure at the farm and the abundance of several farmland birds. In south Sweden, the number of farmland bird species and individuals was higher in farmsteads than in semi-natural pastures and infield non-crop islands, and the highest abundance of farmland birds was found in farmsteads with animal husbandry (Hiron et al. 2013b). A study in Sweden found higher occurrence of House Sparrows on farms with cattle (von Post 2013).

A preliminary study of regional Barn Swallow trends in Sweden suggest that they may be driven by the increase in horse keeping presently going on over large parts of Sweden (J. Yourstone et al., unpublished results), supporting Henderson et al. (2007) who found a strong positive correlation between cattle and horse numbers and the presence of Barn Swallows. The Swallow is one of few Swedish farmland birds presently increasing in numbers (Green et al. 2016).

Set-aside

Fallows and set-aside may contribute to farmland biodiversity by offering a relatively undisturbed habitat where plant and animal populations may avoid agricultural disturbance (Van Buskirk & Willi 2004). In general, set-aside supports high densities of arable weed seeds (although only in the first 1–2 years in non-rotational set-aside), broad-leaved plants and invertebrates, providing foraging habitat for a range of bird species (Vickery et al. 2004). As such they may provide a valuable habitat for birds and contribute to farmland heterogeneity. Although there is variation between studies, farmland birds generally benefit from set-aside both during breeding and during winter (Roberts & Pullin 2007, Stoate et al. 2001, 2009, Williams et al. 2013). However, the value of fallow may depend critically on its management and interpretation of data is complicated by lack of consistency in definitions and categorizations of fallows (Kleijn & Baldi 2005). Fallows may be part of the crop rotation or may be in place for longer time-periods e.g. supported by agri-environment schemes, and they may be sown or left to natural regeneration of vegetation, with potential different value for different farmland birds. For example, non-rotational set-aside may be beneficial to breeding birds (Bracken & Bolger 2006). The same holds for rotational set-aside (stubble followed by summer fallow) which provide a sparse and patchy sward preferred by open breeding birds like Lapwing and Skylarks (Vickery et al. 2004). Stubble fields left for regeneration as rotational fallow may provide foraging resources during winter for seed-eating birds (Wilson et al. 1996). Set-aside may be particularly beneficial to declining farmland birds (Buckingham et al. 1999) and effects on farmland bird populations may be sufficiently strong to have effect on national population estimates (Wretenberg et al. 2007, Herzon et al. 2011).

Reflecting the results in studies elsewhere, a Swedish study found higher densities of Skylark, Linnets, Common Whitethroats and Whinchats on fallows compared to arable fields (Berg & Pärt 1994). At the national scale in Sweden, in a period in 1987–1995 when farmers were paid to permanently set arable land aside to prevent over-production, many species increased in abundance, probably as an effect of the set-asides being good habitat for farmland birds (Wretenberg et al. 2007). In line with this, a study of the change in farmland bird abundance over 20 years found changes in species richness of farmland bird abundance to be positively related to the changes in non-rotational set-aside (Wretenberg et al. 2010), but few effects on individual bird species (Berg et al. 2015).

Berg & Hiron (2012) studied habitat choice of the Corncrake, a classic Swedish farmland bird species (but not included in the FBI due to too few data). The study, carried out in South-central Sweden, found that Corncrakes preferred sites with tall vegetation, moist ground, and locations close to ditches, but also abandoned unmanaged wet meadows, mown wet meadows, leys and non-rotational set-asides.

Forest-farm mosaics

The dominating land-use in Sweden is forestry (more than half of the Swedish land area), to compare with only 8% constituting various forms of agricultural land-use. This means that much farmland constitutes a farmland-forest mosaic, which can be regarded as a special form of landscape heterogeneity with a strong interface between agricultural fields and forests. Some farmland bird species may be positively affected by increasing availability of forest edges. Even though sufficient nesting and feeding resources may be available for open grassland specialists in open arable agricultural systems, such systems may be devoid of more vegetated, bushy areas which are necessities for most shrubland and generalist species’ breeding and feeding needs.

A study of farmland-forest mosaic landscapes in central Sweden concluded that mosaic structures (woodland, edge) and residual habitats (grasslands, shrubs, ditches) has a strong impact on bird communities (Berg 2002).

Agricultural fields in landscapes with a high amount of forest contain lower densities of field-nesting bird species, which avoid vertical structures such as forest edges and farms with high predation pressure, for example Lapwing and Skylark. Landscapes with forests attract non-crop nesting species, indicating that non-crop habitats and habitat elements (e.g. forest edges, habitat islands, farmsteads, semi-natural pastures) are important for many farmland bird species (Berg et al. 2015).

Berg & Hiron (2012) suggested that a strategy to conserve Corncrake populations should focus on forested landscapes by maintaining moist natural and sown grasslands (unmanaged or mown late) with tall vegetation. The reason is that many other meadow birds that are more dependent on management (e.g. yearly mowing or grazing, not beneficial for Corncrakes) prefer open landscapes. This can be seen as a good example of how measures to improve conditions for farmland birds in some instances should differ between regions and habitats.

Söderström & Pärt (2000, see also Pärt & Söderström 1999) found that abundances of farmland birds in semi-natural grazed pastures were generally higher when they were situated in agricultural-dominated or mosaic landscapes, compared to more forested landscapes, suggesting that arable fields functioned as complementary habitat.

Short-rotation coppicing may contribute to farmland heterogeneity in similar ways as forests. It has been suggested that Salix plantation are beneficial for farmland birds in intensively farmland landscapes devoid of woodlands and other semi-natural habitats (Göransson 1994, Sage & Robertson 1996).

Ponds and ditches

Wetlands were previously an integral part of farmland, but has declined dramatically as a result of lowering of water tables, field drainage and filling of small water bodies to benefit farm operations (Ihse 1995; Shrubb 2003; Herzon & Helenius 2008). It is well appreciated that this has multiple environmental effects, but it also has consequences for farmland birds (Bradbury & Kirby 2006). Loss of open ditches and wetlands may affect birds directly, because they use wetlands as breeding and foraging habitat, but wetlands may also benefit farmland birds more generally by contributing to farmland heterogeneity and by subsidising the surrounding landscape with invertebrates emerging in the aquatic habitat (Bradbury & Kirby 2006; Herzon & Helenius 2008; Marja et al. 2013).

In Sweden, several studies have evaluated the positive effect of wetlands in farmland on birds that directly utilize such habitat, whereas the effect on farmland birds in general is scant (see Stjernman et al. 2016). A study in Scania, southern Sweden, found that farmland ponds related to the abundance of farmland birds at landscape scales, with stronger positive effect of ponds with biodiversity benefits as the objective (Stjernman et al. 2017).

Crop diversity

Agricultural intensification has resulted in simplified crop rotations, with loss of crop heterogeneity in both time and space (Benton et al. 2003). Loss of crop diversity may result in lower species richness, because of a lower local availability of niche space (Fahrig et al. 2011). However, the evidence to support it is rather scant (Dicks et al. 2013), not least because the collinearity between crop complexity and other measures of heterogeneity makes it challenging to analyse the effect of crop heterogeneity separately (Josefsson et al. 2017). However, different farmland bird species may show different reactions to variation in crop complexity, resulting on moderately strong responses in diversity (Gottschalk et al. 2010). It is also not clear how local biodiversity effects translate into effects at large spatial scales, i.e. while the biodiversity at a farm scale may benefit from greater crop complexity, the total number of the individual species may not have changed from a changed spatial distribution of crops. Loss of crop diversity may negatively impact bird species that require multiple habitats, e.g. in sequence over the season or year (cf. Dunning et al. 1992), such that seasonally varying nest requirement (Wilson et al. 1997). Simplified crop rotations may also be associated with loss of ley in rotations, with concomitant negative effects for bird biodiversity in terms of feeding resources or intensity of farming.

A Swedish study found that crop diversity was positively related to the richness of non-crop breeding birds but not to that of field-nesting farmland birds (Josefsson et al. 2017), but it was the structural rather than the crop identity diversity that was crucial. The effect was stronger in arable compared to forest dominated landscapes. One study in Finland and one in Sweden, respectively, found farmland bird species richness and abundance to be positively related to the proportion of grasslands on arable land (Piha et al. 2007, Hiron et al. 2013a).

3.1.3 In-field intensification

In-field intensification refers to a number of measures used to increase productivity in individual fields, without fundamentally changing how land is used. Hence, here we do not treat forms of land-use conversion that results in loss of farmland heterogeneity, such as conversion of semi-natural to managed grasslands, but rather changes in the intensity by which semi-natural grasslands and arable fields are managed. Semi-natural grasslands may be intensified by removing woody vegetation to reduce shading and enhance fodder production, but also by increasing stocking densities. Production in arable fields may be increased by increased mechanical or chemical inputs, subsurface drainage, and more competitive crops. Although agricultural intensification is thought to be a main driver of loss of farmland birds, it is not clear what the effect of separate drivers such as these are. We will discuss what is thought to be the main drivers below (Stoate et al. 2001, 2009, Newton 2004).

Management of semi-natural grasslands

By semi-natural grasslands, we here refer to grasslands used for grazing or mowing that have not been reseeded and where pesticides and fertilizers are not applied. Management intensity may affect how suitable these are, by affecting the availability of nesting sites and food. There is a large volume of research both internationally and in Sweden relating biodiversity in semi-natural grasslands to management, but the focus is largely on plants and invertebrates. This research has identified grazing intensity as a key variable, where too strong grazing pressure may negatively impact plants and flower-visiting insects (see overview in Smith et al. 2016). Also loss of heterogeneity provided by overzealous removal of woody vegetation negatively impact biodiversity. However, different species respond differently. Regarding birds, much of the relevant work is performed in Sweden and is presented below.

In a study covering grasslands across Sweden, Söderström & Pärt (1999) demonstrated that farmland birds, including declining farmland birds, generally benefitted from an increasing proportion of the pasture that contained a short field layer (reflecting grazing intensity). The overall species richness, but not that of farmland birds, was positively related to the availability of thorny shrubs.

In a study of 25 bird species, Söderström et al. (2001) found that large insectivores preferred moderately grazed pastures and small insectivores preferred pastures with intensive grazing pressure. The authors suggest that pastures should be managed under varied moderate and high grazing pressure. For wetlands, Zmihorski et al. (2016) found that total species richness was higher in grazed as compared to mowed grasslands except in dry non-flooded grasslands and in flooded as compared to non-flooded sites.

Jacobsson & Lindborg (2017) found that bird species richness and abundance increased with tree and shrub density in Swedish semi-natural grasslands. Different bird species were differently affected, such that homogenization of pastures by removing trees risk reducing overall diversity. However, notably, the birds listed in the Farmland Bird Index were more associated with low cover of trees and shrubs.

Increased use of pesticides and inorganic fertilizers

Pesticides may affect birds both directly and indirectly. Historically, persistent pesticides played a large role in reducing farmland bird populations by directly affecting mortality and fertility, but today indirect effects of pesticides are thought to be most important (Newton 2004). Insecticides may directly lower the amount of food available to insectivorous birds (Campbell et al. 1997; Hallmann et al. 2014) Herbicides reduces the abundance of weeds, which reduces food availability to birds both by reducing seed production, and by having secondary effects on invertebrates that act as food for birds (Campbell et al. 1997; Boatman et al. 2004). Increased use of inorganic fertilizers on arable fields and leys, results in faster growth of crops and denser swards, which may affect bird foraging (Atkinson et al. 2004) and nesting (Wilson et al. 1997) negatively. For example, the Ortolan Bunting may suffer from the loss of bare ground in agricultural fields as a result of increased use of fertilizers (Menz & Arlettaz 2012). However, nitrogen application may also increase the availability of soil-living invertebrates that act as food for birds (Atkinson et al. 2004) and benefit herbivores such as geese (Hassall & Lane 2001). Increased use of fertilizers may also result in reduced densities of weeds (Lindström 2008), and benefit grasses at the expense of herbs (Inouye & Tilman 1995), with repercussions on birds.

Very few studies have been able to investigate the effect of these factors alone, and much of the information comes from studies of organic farming (see below). However, some measures targeting a specific measure have demonstrated effect on birds.

Conservation headlands results from the restriction of the use of pesticides and sometimes inorganic fertilizers on the outer part of the fields, and has been found to have positive effects on plants, invertebrates and gamebirds (Jönsson & Smith 2017). In Sweden, it was found that Grey Partridges *Perdix perdix* benefitted from conservation headlands (Chiverton 1999).

Leaving small patches (10–25 m2) of autumn-sown arable fields unsown ("Skylark plots") have been shown to increase density and reproductive success of Skylarks on conventional farms (Morris et al. 2004, Schmidt et al. 2017). A few studies have been carried out in Sweden, with varying results. Jansson (2013) found a small but significant positive effect of Skylark plots on Skylark breeding densities on conventional farms (autumn-sown field), with a gradually more positive effect later in the season. In contrast, Berg & Kvarnbäck (2011) found no effect at all of Skylark plots on autumn-sown fields on organic farms. An explanation for the latter result may be that the density of the crops on the investigated organic fields was not dense enough to cause trouble for the breeding Skylarks, and hence, there was no clear habitat improvement for the birds (Berg & Kvarnbäck 2011).Intensification of the management of managed grasslands (i.e. leys) may affect birds negatively, by making leys increasingly unsuitable as breeding and foraging grounds for birds compared to less intensively managed grasslands (Vickery et al. 2001). Although effects vary between taxa, many invertebrates that are potential food for birds are negatively affected by more intensive grassland management (Schekkerman & Beintema 2007, reviewed in Hasund et al. 2017) and denser swards make invertebrates less accessible to birds

(Vickery et al. 2001; Wilson et al. 2009). Furthermore, intensification with faster growth and increased use of silage that does not need to dry, allows mowing much earlier, during a time when many ground nesting bird species are sensitive. This may harm farmland birds by increasing mortality of nests and chicks (Olsson et al. 2010). For example, there is evidence from other European countries (e.g. Broyer 2003; 2009; Green et al. 1997; Grubler 2008; Humbert et al. 2008; Nocera et al. 2005; Tyler et al. 1998) that early mowing of ley or meadows is detrimental for a range of ground nesting farmland birds, such as Curlew, Corncrake, and Whinchat. To our best knowledge, no such studies have been performed in Sweden, but the effects are very likely the same here.

Spring- and autumn-sown crops

The switch from spring-sown to autumn-sown cereals, with the resulting loss of winter stubbles, is thought to be a major reason for the decline of seed-eating farmland birds (Newton 2004; but see also Stoate et al. 2009). However, the shift may also affect birds during breeding, by reducing the habitat quality for birds depending on shorter swards (Henderson & Evans 2000). The effect on breeding habitat quality may depend on location, with more positive effects in northerly latitudes where autumn sown crops had not reached the height and density that impact farmland birds negatively, whereas in southerly latitudes the breeding success of some farmland birds may depend on the availability of spring-sown crops with shorter swards (Stoate et al. 2009).

In a study in south-central Sweden, the amount of autumn-sown crops (mainly wheat) increased between 1994 and 2004, and three species (Starling, Wheatear, White Wagtail *Motacilla alba*) showed negative trends connected to that (Berg et al. 2015). In a study in south-central Sweden, Eggers et al. (2011) found that autumn-sown crops held fewer species and smaller numbers of ground-nesting farmland birds than spring-sown fields. This was not true for Skylarks, though, which first chose autumn-sown fields and later in the breeding/growing season moved to the shorter vegetation spring-sown fields (Eggers et al. 2011, Hiron et al. 2012).

To compensate for loss of winter food, various measures have been tried to increase food availability to farmland birds. Instead of directly providing food (e.g. Siriwardena et al. 2007), wild bird cover has been proposed as a way to benefit survival of seed-eating farmland birds during winter (Stoate et al. 2003). A large-scale experiment in the UK showed that such seed-producing patches left over winter had a big impact on winter bird densities but also on breeding bird densities the following summer (Hinsley et al. 2010).

In Sweden, the endangered Corn Bunting *Milaria calandra* has most likely benefitted strongly from a few winter bird fields where the harvest of wheat, barley or oats have been left on the fields over winter (Ivarsson 2003, 2005).

Lindström (1989, 1990) found that large numbers of finches foraged intensively on stubble fields of summer oil seed rape (i.e. spring-sown) both in autumn and spring, due to the large amounts of spill seeds on these fields. Most finches seen were Chaffinches and Bramblings (*Fringilla coelebs* and *F. montifringilla*), which normally breed in forest. However, also species connected to farmland, like Linnet, were seen regularly on these fields (Å. Lindström, pers. obs.) showing the importance of spring-sown fields to birds also outside the breeding season.

Minimum tillage and No-till "direct drilling"

The ploughing of a field buries seeds, reduces weed density, and has negative impacts on the soil fauna. Hence, ploughing may reduce the availability of food to birds (reviewed by Cunningham et al. 2004). No and minimum tillage reduces some of these effects, by minimizing soil cultivations to what is necessary for establishment of the crop. However, these regimes may depend on increased use of herbicides to treat weeds, offsetting some of the potentially positive effects on birds. It has been shown in the UK that farmland birds such as Skylarks and granivorous passerines prefer minimum tillage fields during winter (Cunningham et al. 2005) and may benefit insectivores during breeding (Filippi-Codaccione et al. 2009). We found no Swedish studies on the impact of minimum tillage on birds.

Organic and extensive farming

Organic farming may benefit birds, because of the avoidance of inorganic fertilizers and pesticides, with resulting changes in crop rotations to allow productive farming. International compilations have found effects of organic farm on biodiversity of multiple taxonomic groups, including birds (Hole et al. 2005; Tuck et al. 2014), but results vary between species (Smith et al. 2010; Wilcox et al. 2014) and are generally stronger in simplified agricultural landscapes (Tuck et al. 2014).

In a study in southernmost Sweden, bird species richness was positively related to organic farming, both during breeding (Smith et al. 2010) and during migration (Dänhardt et al. 2010). The effect was stronger in intensively farmed landscapes, because insectivores (during breeding) and granivores (during migration) were mostly affected in intensively farmed landscapes. Similarly, Belfrage et al. (2005) found an effect of organic farming on bird abundance that was higher on larger farms than on small farms.

Hiron et al. (2013a) found no relationship between farmland bird species richness or abundance and the amount of organic fields at the local scale (i.e. within a 250 m radius), but at the landscape scale (25 km2) there was a correlation which was positive in homogenous landscapes and negative in heterogenous landscapes. Josefsson et al. (2017) found that organic farming had little positive influence on farmland birds except for field-nesting species in the most arable-dominated landscapes. In forest-dominated landscapes, organic farms even held lower field-nester densities compared with conventional farms, possibly due to the dominance of grasslands on organic farms that in these landscapes support lower densities of field-nesting species compared with cereals.

3.1.4 Other factors

Changes in farming practices and the structure of the farmland landscape are of course not the only factors influencing the number of farmland birds. Below we discuss evidence concerning predation and disease, since they have been put forward as important drivers of the decline in farmland birds.

Predator abundance

A reduced hunting pressures on predators in recent times may have increased predator populations with potentially negative impact on farmland birds (Newton 2004). In addition, structural changes of the agricultural landscape may both subsidise predators and increase the predation risk due to e.g. lack of shelter (Evans 2004). However, there is no clear evidence that negative trends of farmland birds is caused by increased predation, except possibly for a few ground nesting species (Newton 2004), and furthermore there are few cases of predators that have increased in Sweden. Based on data from the Swedish Breeding Bird Survey, Marsh Harrier (*Circus aeruginosus*) increased between 1975 and the mid 1990-ies, and Red Kite (*Milvus milvus*) has increased strongly, but only in southernmost Sweden, whereas other raptors have been more or less stable. Among Corvids, which can be important predators on nests and chicks, Raven (*Corvus corax*) has increased strongly, Hooded Crows (*Corvus corone cornix*) have declined strongly, whereas Magpies (*Pica pica*) and Jackdaws (*Corvus monedula*) have been more or less stable. Still, this does not mean that reduced predation pressures is not a way to benefit farmland birds (e.g. Donald et al. 2002) and in general predator removal benefit bird populations (Smith et al. 2010b). In the UK, predator culling has long been part of the recipe to protect farmland birds (Aebischer et al. 2016). In Sweden (Öland), a project with hunting directed towards the predators of the waders breeding on coastal semi-natural grassland showed mixed results, but the reduction of predators (by hunting and sarcoptic mange ["rävskabb"] on red foxes, *Vulpes vulpes*) had some positive effects on the breeding success of the waders (Ottvall 2014). In studies in South-central Sweden, Roos and Pärt (2004) found that reproductive success of Red-backed Shrikes was negatively affected by local densities of magpies and crows, and populations of magpies were potentially subsidised by other resources on farmsteads. Additionally, two ground nesting species of fowl, Pheasants (*Phasianus colchicus*) and Black Grouse (*Lyrurus tetrix*), had population increases during the 1980-ies, coinciding with the dramatic decline in red fox population due to the mange. Both before and after that period Pheasants as well as Black Grouse have been in decline. Also habitat management can be used to mitigate predation effects (Brickle & Peach 2004). See also Gibbons et al. (2007) and Widemo (2008) for reviews of predators and predator management in relation to birds.

Disease

Disease is not mentioned as a major driver of farmland bird declines in recent syntheses. However, this is an emerging research field which much progress expected as a result from new molecular methods (Tomkins et al. 2011). Disease and parasites has been invoked as drivers for some specific farmland birds, with potential connection to changes in farmland. In the UK, it has been suggested that Grey Partridges suffer from shared parasites with the Ring-necked Pheasant, such that release of Pheasants may contribute to population declines (Tomkins et al. 2000a, 2000b). The Greenfinch *Carduelis chloris* is a seed eating bird species loosely connected to the farmland landscape (not included in the FBI, though) that has suffered great losses the last decade in several North Europe countries due to a protozoan parasite *Trichomonas gallinae* (Lehikoinen et al. 2013). Also in Sweden, the Greenfinch decline has been very strong (Green et al. 2016). This disease has been reported also in Yellowhammers and the Swedish population curve of the Yellowhammer shows an increased rate of decline in the same years as the Greenfinch curve starts to decline (Green et al. 2016). The spread of diseases may be important to consider when designing programs to supplement farmland birds with winter food (Lawson et al. 2012).

3.2 Trends in farming and farmland birds in Sweden

3.2.1 Farming trends in Sweden

Trends in six measures of Swedish farmland practices in 1975–2015 are presented (Fig. 3). Each of them are separated on the eight official Production regions (PO) of Sweden (Fig. 2). The different POs are: (1) Götalands södra slättbygder, (2) Götalands mellanbygder, (3) Götalands norra slättbygder, (4) Svealands slättbygder, (5) Götalands skogsbygder, (6) Mellersta Sveriges skogsbygder, (7) Nedre Norrland, and (8) Övre Norrland, where POs 1, 3 and 4 are the more productive lowland plains.

There are some clear trends within Swedish farming practices over the last 40 years (Fig. 3). The total area of farmland dropped in Sweden with about 9 % from 1975 to 2015, but the proportional loss varied considerably between POs (Fig. 3A). The largest loss was in the north, being 15 %, 18 % and 24 % in POs 6, 7 and 8, respectively. In the more productive farmland plains of Sweden, POs 1, 3 and 4, the loss of farmland was somewhat smaller, about 9 %, 5 % and 10 %, respectively.

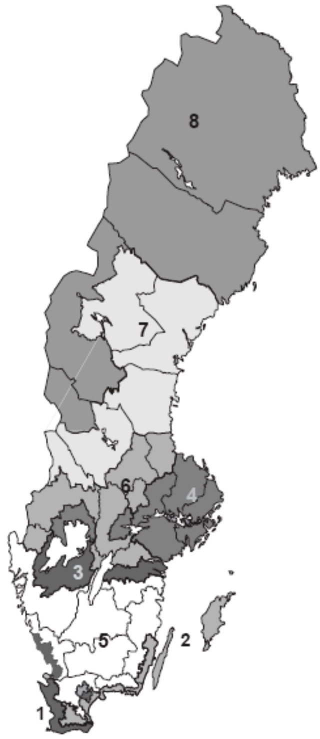


Figure 2. Sweden is divided into eight different Production regions (PO) based on the natural conditions for farming. The map is from Jordbruksstatistisk Årsbok 2013.

In PO 2, the amount of farmland increased by 8 %, but this is apparently not a real increase. For most POs the total agriculture land "increased" around 1995 and 2005, not least PO 2, which was mainly caused by an increase in the area of pasture. It should be noted that this was most certainly an effect of changed subsidies creating an incentive for farmers to report more of their land, and not a real increase in the area of pastures (Eklöf 2007). It is not clear to us why this should have been particularly pronounced in PO 2. Accordingly, the overall decrease in farmland area in Sweden may actually have been larger than the estimate of 9 %.

A major change in farming practice in Sweden has been the switch from spring-sown to autumn-sown crops. Figure 3B shows the total area of spring sown cereals as a fraction of all agricultural land (minus ley, in this particular case), and is intended to show how the amount of stubble fields (beneficial to many birds) has changed over time in Sweden. The fraction of spring-sown crops declined on average by 37 % in Sweden from 1975 to 2015. We know that a corresponding switch from spring-sown to autumn-sown oilseed rape has taken place in Sweden, but could not find relevant statistics. Spring-sown oilseed rape stubble fields are very attractive for seed-eating birds (Lindström 1989, 1990).

The fraction of ley of total farmland area has increased by about 70 % over the last 40 years (Fig. 3C). The largest increases took place in the plains (+82–129 %), but in these regions the proportion of ley of the total farmland area is still relatively low, that is, 15–30 %. In northernmost Sweden (POs 7 and 8), the proportion of ley of the total farmland area is nowadays as high as 66–68 % (Fig. 3C).

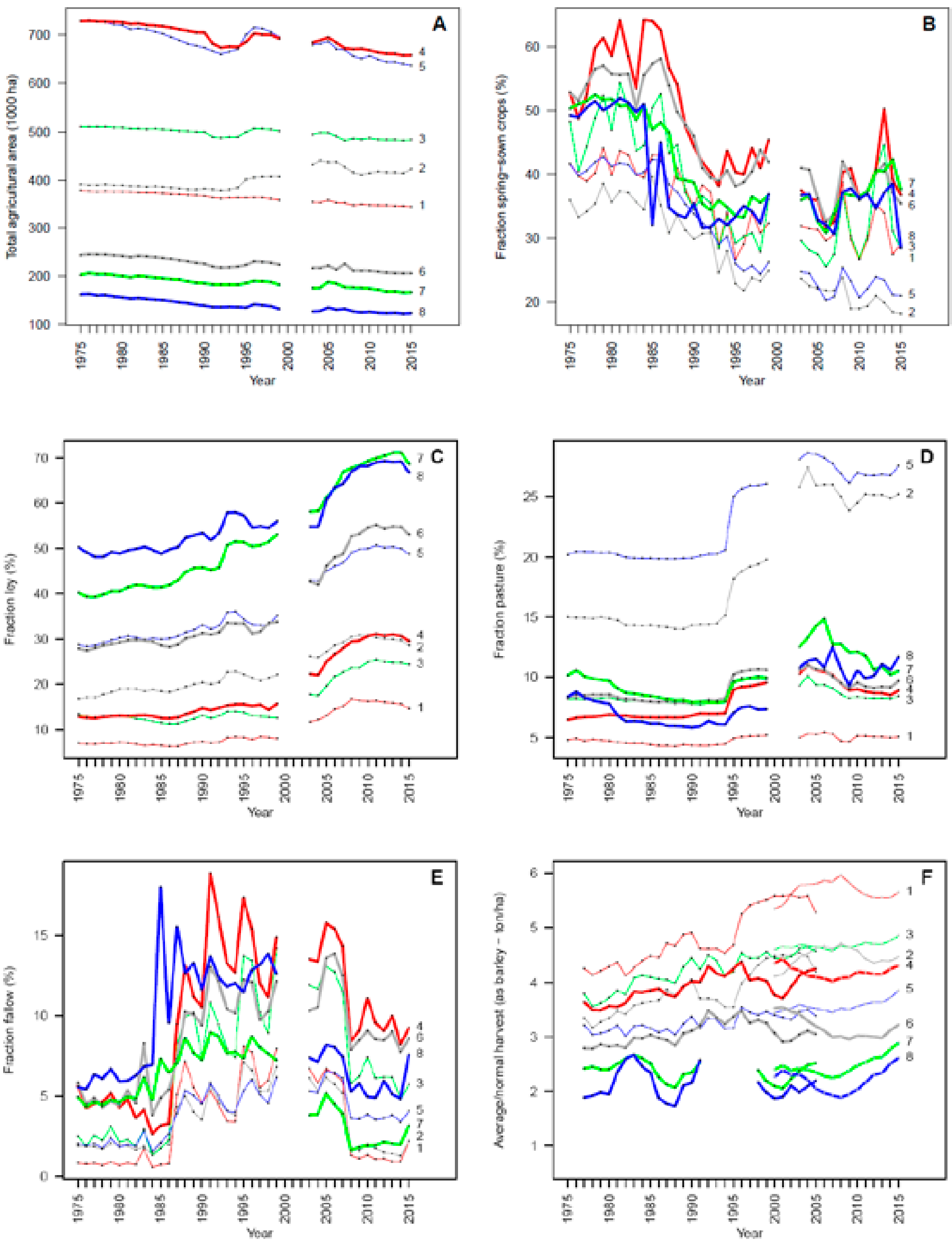


Figure 3. (A) Total agriculture area in the eight production regions of Sweden, including arable land, ley, pasture and fallow, (B) fraction of the total agriculture land that were sown during spring (NB! In B, ley is not included in total farmland area), (C) fraction ley of all agricultural land, (D) fraction pasture of all agricultural land, (E) fraction fallow of all agricultural land and (F) average/normal harvest, where barley harvest were used as a proxy for average/normal harvest. The data is presented as a rolling average window of five years (the averages are shown as black dots), also normal harvest is plotted for the period 2000 to 2015 (grey dots).

The fraction pasture of all farmland has increased over time (Fig. 3D), but as stated above the increase is not a real increase, but an increased propensity to report pasture among farmers. In comparison with other land-uses, the proportion of pasture most certainly has changed relatively little over the last 40 years.

The fraction of fallow (set-aside) land increased dramatically in Sweden in the mid-1980s (Fig. 3E), when farmers were paid to permanently set arable land aside to prevent over-production (Wretenberg et al. 2007). The amount of fallow dropped dramatically in 2008 and has since stayed at a lower level. It should be noted that the definition of "fallow" changed markedly when Sweden joined the EU in 1995. After 1995, "fallows" were no longer only fields taken out of production, but could include, for example, oil rape grown for bioenergy purposes. From a bird's perspective, the latter would not be different from ordinary oil rape production.

The harvest rate of cereals (tons/ha) has increased rather continuously in Sweden (Fig. 3F), with the largest increases taking place in the plains of southern Sweden.

In summary, Sweden has lost about 10 % of its total farmland area since 1975, and the loss is ongoing. Within the remaining farmland, large structural changes have taken place, notably a considerable switch from spring-sown to autumn-sown cereals (with the resulting loss of stubble fields), the amount of ley has increased considerably, and the productivity (tons/ha) continues to increase.

3.2.2 Farmland bird trends in Sweden

In Sweden there are systematic large-scale data on farmland bird populations since 1975, from the two monitoring schemes that started in 1975 and 1998, respectively. The species-specific trends of the 16 species/subspecies of farmland birds being the focus of our analyses are presented in Appendix 2 (Fig.A2.1).

The Farmland Bird Index (European species selection)

The FBI based on the two monitoring schemes have been presented already in the Introduction, but is shown again here (Fig. 4), for the comparison to the indicator for the Swedish Environmental Objective "A varied agricultural landscape" (see below). The indicator for the Old Scheme has declined from about 1.5 to 0.6 over 40 years. The indicator based on New Scheme declined from 1 in 1998 to 0.8 in 2016.

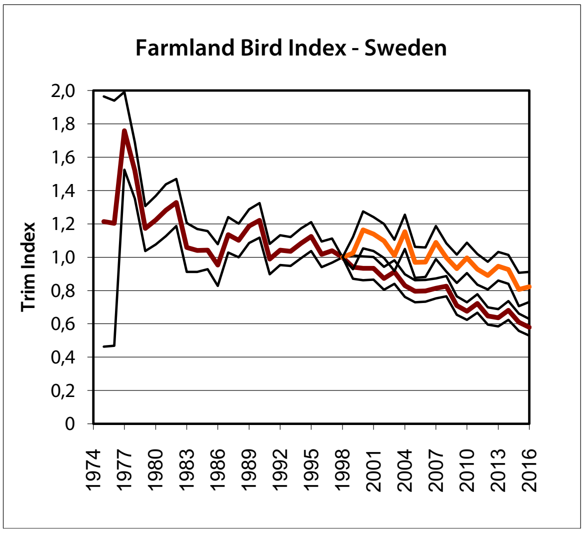


Figure 4. The average trend (with 95 % confidence intervals) in Sweden for 14 bird species connected to farmland, as recorded by two different monitoring schemes: the free choice point counts from mainly southern Sweden (brown line), and the Fixed routes covering all of Sweden in a representative way (orange line). The yearly values are the geometric means of the species-specific indices, as estimated by log-linear Poisson regression (TRIM). The species selection follows the Pan-European Farmland Bird Index (www.ebcc.info).

In the indicator based on the New Scheme, starting 1998, there are 2 species with increasing trends (Barn Swallow and Common Whitethroat) and 4 species with "stable" trends (Yellow Wagtail, Red-backed Shrike, Tree Sparrow and Linnet). The other 8 species are significantly declining in numbers.

The Environmental Objective Indicator (Swedish species selection)

The indicator for the Environmental Objective "A varied agricultural landscape", which starts at 2002 (when the whole of Sweden was covered in a satisfactory way), has a slightly different set of species than the FBI with the European species selection. The Environmental Objectives indicator is also declining, but not as dramatically (Fig. 5, www.miljomal.nu). It has declined from 1 to 0.9 between 2002 and 2016. Among the 13 species, there are 3 with increasing trends (Barn Swallow, southern Yellow Wagtail and Tree Sparrow), 3 with "stable" trends (Common Whitethroat, Red-backed Shrike and Linnet), and the other 7 are significantly declining (Lapwing, Eurasian Curlew, Skylark, Wheatear, Whinchat, Starling and Yellowhammer).

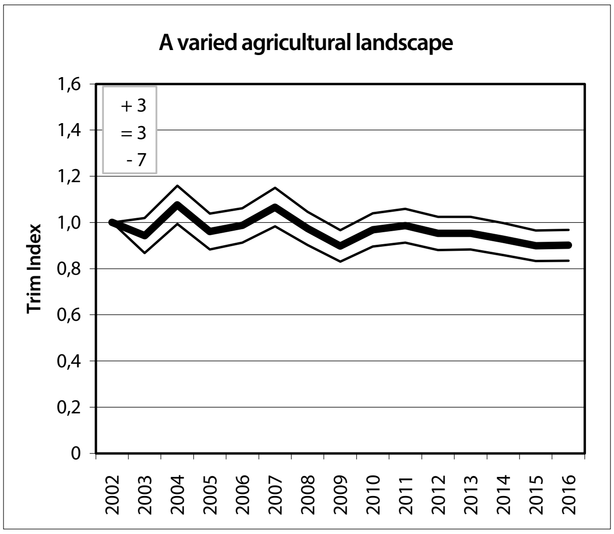
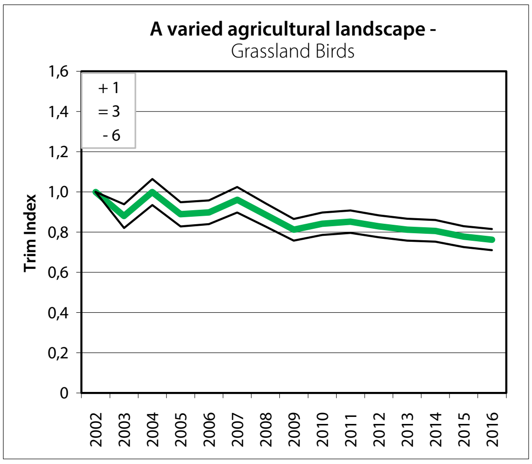


Figure 5. The national bird indicator for the Environmental Objective "A varied agricultural landscape", based on 13 bird species connected to farmland in Sweden. The thin black lines are 95 % CI. The numbers in the small box show the number of species with significantly increasing (+), decreasing (-) and non-significant trends (=).

The 13 species' indicator is further divided into two official sub-indicators, for birds connected to meadows and pasture ("grassland", n = 11), and small biotopes (n = 7),



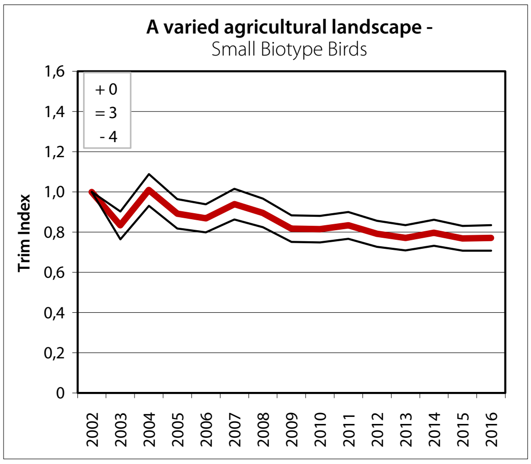


Figure 6. Indicators for farmland birds connected to meadows and pasture (left graph, n = 10) and small biotopes (n = 7, right graph), according to the species selection of the Environmental Objective "A varied agricultural landscape". The number of increasing (+), stable (ns) and declining (-) species in each indicator are also shown.

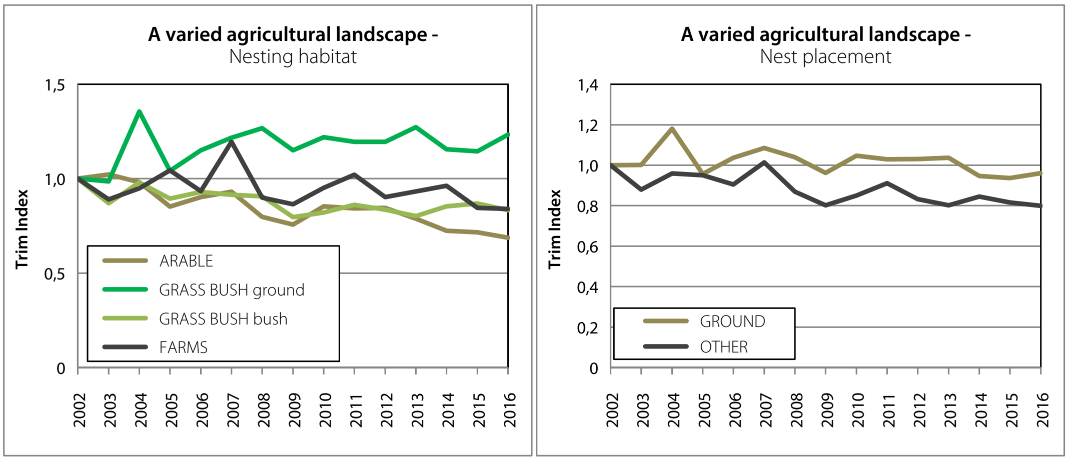


Figure 7. Indicators for farmland birds in relation to their nesting habitat (left graph, n = 13) and nest placement (n = 13, right graph), according to the species selection of the Environmental Objective "A varied agricultural landscape".

respectively. Both groups are doing more poorly than the main indicator, numerically because two increasing species (Yellow Wagtail and Tree Sparrow) drop out from both, and the third increasing species (Barn Swallow) drop out from the indicator for Small biotopes (Fig. 6).

For this report we calculated two more indicators based on the 13 species (Fig. 7). The first is for breeding habitat and nest placement: arable fields, nest on the ground (Lapwing, Eurasian Curlew and Skylark), grassland and bushes, nest on the ground (Wheatear, Whinchat, Common Whitethroat and Yellow Wagtail), grassland and bushes, nest in bushes (Red-backed Shrike, Linnet and Yellowhammer), and farms and trees (Barn Swallow, European Starling and Tree Sparrow), respectively. The second indicator deals with nest placement only, either on the ground (7) or elsewhere (6). Grassland birds putting their nests on the ground are doing relatively best, whereas the three species breeding in arable fields, all with their nests on the ground, are doing worst. When it comes to nest placement, the ground nesters are doing better on average. This suggests that the breeding in arable land is worse than ground breeding as such. However, we put in a note of caution here. The southern Yellow Wagtail a species normally connected to grassland, has in recent years started to breed in arable fields in Skåne, where they appear to be doing very well.

Regional farmland bird trends in Sweden

The national indicators for the Environmental Objectives also come as six regional indicators (Fig. 8). The regions are clusters of the counties (länen) in Sweden. For the four southernmost regions, the species composition is the same, that is, all 13 species are included. Two of the 13 species are lacking in "Södra Norrland" (southern Yellow Wagtail and Linnet), giving a total of 11 species there. In the northernmost province, "Norra Norrland", an additional three species are lacking (Common Whitethroat, Red-backed Shrike and Tree Sparrow), giving a total of 8 species. There are clear regional differences in the indicator trends, with the most positive general trends in the south and east, and most negative in the north and east.

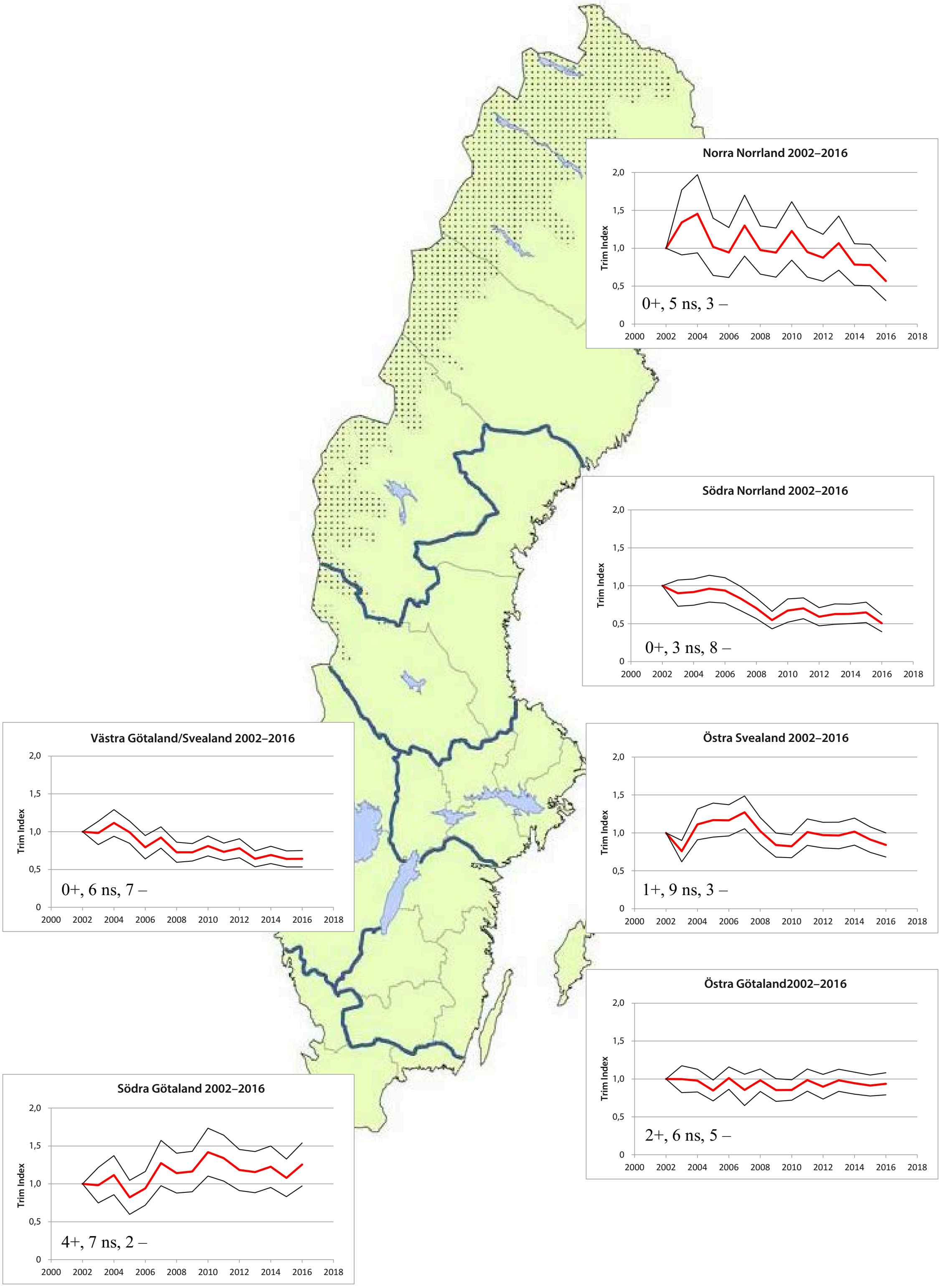


Figure 8. Regional trends of 13 farmland birds in Sweden 2002–2016, according to the selection of the Environmental Objectives. The number of species included per region varies, since not all species are present in sufficient numbers in all regions. The number of increasing (+), stable (ns) and declining (-) species in each region are also shown. The species lacking in "Södra Norrland" and "Norra Norrland" are Linnet and Yellow Wagtail, and in "Norra Norrland" also Common Whitethroat, Red-backed Shrike and Tree Sparrow.

The differences between the regions could in principle be due to the different species composition in the different regions. But when comparing only the eight species that are present in all six regions, the pattern largely stays the same (Fig. 9). The slope of linear regressions (a proxy for the overall trend) for the three regions in the south-east which have the least negative trends in the full indicator sets, are -0.008, -0.014 and 0.013, respectively. In the west and north ("Västra Göta- och Svealand", "Södra Norrland", and "Norra Norrland"), the slopes are 0.035, -0.032 and -0.036, that is, considerably more negative. We can safely conclude that the farmland birds are doing worst in western and northern Sweden.

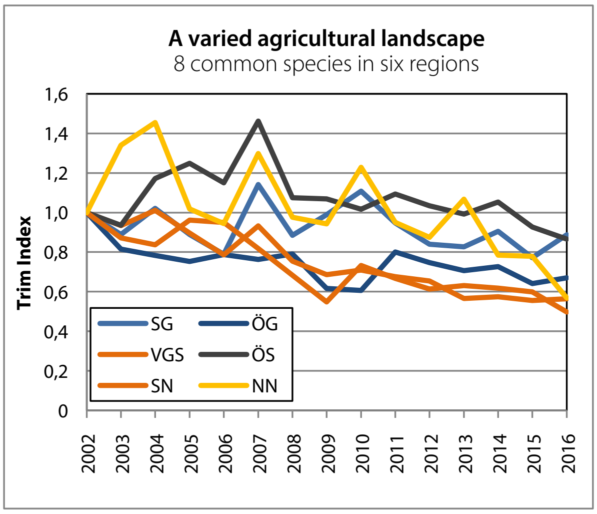
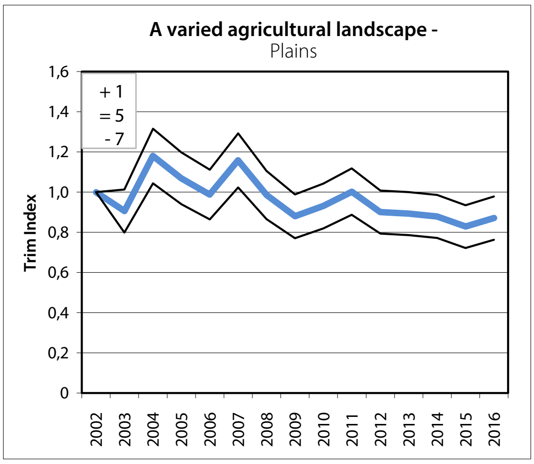


Figure 9. The regional bird indicators for the Environmental Objective "A varied agricultural landscape", based on the 8 of the 13 bird species connected to farmland in Sweden that are present in all regions.

Bird trends in areas of different farming intensity

The most productive farming in Sweden is in the lowland plains (Fig. 3F), that is, POs 1, 3 and 4 (Fig. 2). We calculated separate indicators for the plains (POs 1, 3 and 4) and the remaining parts of Sweden ("Mixed and Forest landscapes", POs 2, 5–8), respectively (Fig. 10). The overall slope of the two indicators are similar (linear regression, -0.015 and -0.010, respectively), and the species-specific TRIM-slopes do not differ between the two areas (average -1.5 and -1.1 %/year, respectively; paired t-test, t12=0.62, p=0.54). Whereas the trends for a given species normally are similar between the two groups, there are notable differences for some species (Table 2).



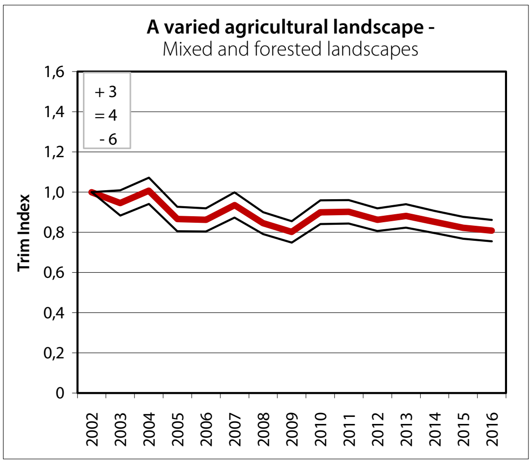


Figure 10. Indicators for farmland birds for Fixed routes situated in the plains (POs 1, 3 and 4, left graph) and mixed and forested landscapes (POs 2, 5–8, right graph), according to the species selection of the Environmental Objective "A varied agricultural landscape". The number of increasing (+), stable (ns) and declining (-) species in each indicator are also shown.

Table 2. Species-specific farmland bird trends (Δ, (%/yr) in 2002–2016 in the more productive Swedish plains (POs 1, 3 and 4) and in Mixed and forest landscapes (POs 2, 5–8) of the 13 farmland species included in the Environmental Objectives indicator "A variable agricultural landscape". Statistically significant trends are shown by * (p<0.05) and *** (p<0.001).

	Plains		Mixed and forest	
Species	**Δ**	**Sign**	**Δ**	**Sign**
Lapwing	-3,6	***	-2,8	***
Eurasian Curlew	-8,6	***	-2,1	***
Skylark	-1,5	***	-1,3	***
Barn Swallow	2,0	***	0,9	*
Wheatear	1,1		-1,0	
Whinchat	-0,5		-3,0	***
Common Whitethroat	0,1		0,8	*
Yellow Wagtail	0,0		-0,5	
Red-backed Shrike	-0,1		-0,3	
European Starling	-5,1	***	-4,8	***
Linnet	1,4		0,4	
Yellowhammer	-3,6	***	-3,6	***
Tree Sparrow	-1,2		3,4	***

For most species the trends are very similar between the two sets of POs, but there are some striking differences (Table 2). The Eurasian Curlew and the Tree Sparrow have been doing relatively much more poorly in the plains, whereas the Wheatear, Whinchat and Linnet seem to have managed relatively better in the plains.

In summary, Swedish birds tightly connected to farmland have on average been doing poorly in recent times, although not all species have declined in numbers. There are some general patterns emerging, but clearly, almost all of them have exceptions. The species connected to grasslands and small biotopes have been doing relatively poorly. Birds breeding mainly in arable fields are doing worse than those breeding in grassland or close to humans. However, when looking at all species that put their nest on the ground, they are doing relatively well. Together this suggests that it is breeding in arable land that causes problems, not ground nesting as such, but again there is an exception in the Yellow Wagtail in Skåne.

At the regional level, farmland birds in the west and north of Sweden have been doing less well than the birds in the east and south. When dividing Sweden into regions of higher (the plains, situated in southernmost and south-central Sweden) and lower productivity (mixed and forested landscapes in southern and northern Sweden), there are no obvious general differences in population trends. At the species level however, three species do better and two species do worse in the plains.

Overall there are no solid general relationships in the farmland bird trends. This is not unexpected, given the varying ecological requirements of the species included, but it nevertheless complicates the process of suggesting specific measures to reverse the negative trends.

3.3 Habitat association modelling

Using information from the Fixed routes of the Swedish Breeding Bird Survey and agricultural statistics from the Land Parcel Information System (LPIS, "Blockdatabasen"), we modelled the abundance of farmland birds in relation to agricultural land-use. Here we summarize the modelling and the results and refer to Appendix 1 for a detailed description.

3.3.1 Introduction

Using habitat association modelling, we analyse how a set of farmland characteristics affect the abundance of a set of farmland birds while accounting for any residual co-variation among them. To this end, we used a joint species modelling approach where all species are modelled simultaneously, yielding species-specific estimates of land-use dependence while taking interactions among species (co-variation) explicitly into account. (Ovaskainen et al. 2010, Clark et al. 2014, Pollock et al.2014).

3.3.2 Methods

Model specifics – predictors and responses

The "joint habitat association modelling" can broadly be described as relating a set of predictors to a set of responses. The predictors are descriptors of the habitat (the farmland landscape) and will in the following interchangeably be referred to as predictors, variables and factors and their relationship to the responses as effects, dependencies or coefficients. The responses are species-specific counts of farmland birds and may be referred to as counts, abundances or responses. We used a multivariate version of a negative binomial regression to model species responses (counts) to a set of land-use variables. Effects were estimated using a Bayesian approach, taking samples from the posterior distributions of parameters using Markov chain Monte Carlo (MCMC) algorithms in the programs R and Stan (R development Core Team 2009, Stan Development Team 2016).

Data

The predictors – Land-use

The variables used as predictors in our modelling came exclusively from the LPIS (Land Parcel Information System, LPIS, "Blockdatabasen"). The LPIS gives uniquely detailed information on what different fields were used for, allowing us to predict consequences of changes in agricultural land-use on farmland birds. However, our analyses were therefore limited to studying variables that readily can be extracted from the database. These variables are likely to be important, but are not necessarily the only or even the most important predictors of farmland bird abundances. Furthermore, we can only use land-uses with sufficient spatial extent. Although we used a spatially representative and extensive dataset on bird abundances (the Fixed route monitoring scheme, see below), the total area covered by this scheme is low. Given that farmland constitutes only 7–8% of total land area in Sweden, the farmland area covered by the scheme is even lower. Thus, variables we can study the effect on birds of need to be common throughout Swedish farmland. As an example, we cannot study the effect of "bird fields" (fågelåkrar), because these are so rare that they do not show up in the routes and the effects of organic farming cannot easily be studied due to its low proportion of farmland and spatially heterogeneous uptake.

The variables we selected are represented in routes more or less throughout Sweden and are intended to measure various aspects of agricultural change that might be important for recent farmland bird declines. The land-use variables are as follows:

Farmland area. This variable is included to measure the importance of farmland per se. Farmland area is measured as the area of all farmed land as reported in LPIS, excluding some land-uses that can either be considered as forest, considered irrelevant or where the coding is unclear or variable over years.

Proportion semi-natural habitat. This measures the importance of semi-natural habitat in the farmed landscape. We chose two land-use classes from LPIS: semi-natural pastures (including meadows) and fallow. Both provide feeding and nesting habitat for farmland bird species although some species prefer one over the other. Although field borders may also be considered important semi-natural habitats for farmland birds we chose not to include them in this measure as field-borders are not directly represented in the LPIS. Proportion semi-natural habitat is calculated as the proportion of areas of fallow and pasture of total farmland area.

Proportion extensive crop. This measures the importance of extensive management, and is calculated as the proportion of ley and buffer strips on arable land where arable land is farmland area, excluding fallows and pastures. That is, it is intended to measure the role of extensification of farming on arable fields with less disturbance and less application of agrochemical inputs (at least pesticides).

Crop diversity. This variable measures the diversity of crops on arable fields. We used the Shannon diversity (= the exponentiated Shannon index, $e^{\text{Shannon index}}$), which can be viewed as the number of effective crops in the arable fields. The number of effective crops is the translation of the actual relative proportions of crops into a number of equally common crops. Crops from LPIS are grouped into 17 groups according their structural and temporal appearance. That is, consideration is taken both to what the crop looks like (from a bird's perspective, i.e. differentiating between cereals, oil-seed rape, vegetables, root crops etc.) and time of sowing (autumn vs spring sown).

Proportion spring sown crops. This is a measure of the importance of timing of sowing. The timing and type of management (ploughing, sowing, or over-winter stubble) as well as the development of the swards are features that differ between these two types and have been assumed to be of importance for farmland birds. It is calculated as the proportion of crops sown in spring among all annual crops grown on arable fields (e.g. excluding ley).

Table 3. Summary of variables used in the model. Note that this is based on the dataset used, i.e. due to repeated surveys each route can be represented more than once.

Variable	Unit	Mean	Standard deviation	Range
Farmland area	hectare	51.2	62.8	0 – 296.4
Prop. semi-natural	proportion	0.290	0.274	0 – 1
Prop. extensive	proportion	0.609	0.371	0 – 1
Crop diversity	number of effective crops	2.05	1.45	0 – 8.28
Prop. spring sown	proportion	0.528	0.443	0 – 1
Latitude	meter	6576021	289171	6161000 – 7436000

We included the five land-use variables described above, plus a latitudinal gradient, as main effects in the model. We also included all two-way interactions between land-use variables and latitude to measure regional differences in land-use dependence. Thus, in total we had 12 predictors (5 land-uses, latitude, 5 interactions and an intercept) in the model. Route and year was further included as random effects to handle non-independence among observations. All 5 land-use variables plus latitude were standardized prior to analysis (centred at their mean and scaled by their standard deviation, see Table 3).

There were overall low correlations between predictors with the exception of a correlation of 0.8 between crop diversity and farmland area (see Fig. A1.1 in Appendix 1). However, variance inflation factors can be considered low (Quinn and Keough 2002) with a maximum of around 2.76 for crop diversity and farmland area. Hence, collinearity should not pose serious problems in the analyses.

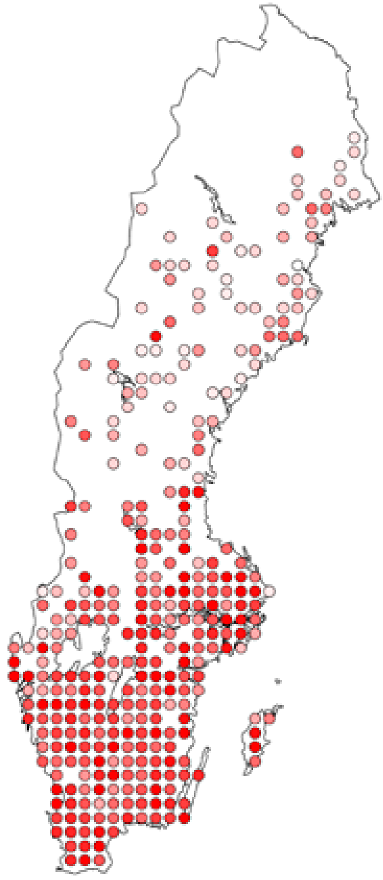


Figure 11. Map of all 327 Fixed routes included in the analysis (i.e. being surveyed at least once during 1999–2014 and having farmland). The darker the red the more years a route was surveyed (white = 4 years, red = 16 years).

The response – Bird counts

Bird count data came from line transect counts in the Fixed routes scheme (see above). We included 327 routes (Fig. 11) that were surveyed at any year during the period 1999-2014 (not all routes were surveyed all years) and had farmland (LPIS) within 200 m from the line transect. We included all 14 species within FBI plus the two species that are part of the index for the Swedish Environmental Objective no 13 "A varied agricultural landscape". Thus, in total we had 16 farmland bird species (Table 1). The routes in which each of the species have been counted at least once during the period 1999-2014 can be found in Appendix 1, Fig. A1.3.

Correlations in species abundance

As mentioned, our joint modelling approach enables estimation of species correlation patterns. The estimated correlations between species from the model are due to interactions between species either directly through competition or facilitation or indirectly through factors not included in the model and will henceforth be referred to as residual correlations. We also calculated correlations in species abundances due to factor that are included in the model, that is, correlations due to "the environment" (Pollock et al. 2014). We will refer to these as environmental correlations.

Comparing the two types of correlations provide important information about the relative importance of predictors included in the model versus other factors in explaining species' abundance patterns (Pollock et al. 2014). The environmental correlations can also be used to group species with common associations to the predictors, giving further insight into what drives the association between farmland birds and land-use (see further below). We used cluster analysis based on a dissimilarity matrix calculated from the environmental correlations to group species.

Reduced dataset

Concerns may be raised regarding using such a large spatially extensive dataset, as the inherent noisiness of such data might introduce spurious patterns that cannot be detected by modelling diagnostics. For example, we allowed for minimal amounts of farmland area in included routes (farmland area>0) and there is then less room for other predictors to vary (e.g. difficult to fit more than one or two crops in a small area of farmland). Further, the fact that some variable values could not be calculated for all cases (e.g. denominator in proportions were zero) forced us to set those to zero which might affect estimates of collinearity and hamper our ability to interpret results. To investigate whether our inferences were contingent on these limitations of using the large dataset, we decided to also run the same model on a reduced dataset that we as much as possible tried to optimise in these respects. We increased the minimum amount of farmland in routes to 10% and only selected routes in the southern half of Sweden (latitudinal coordinate<6736000). We also only included routes with crop diversity equal to or above 2. Finally, routes should be visited at least three times during the period 1999-2014. This resulted in a dataset of 103 routes and 1137 observations basically covering the main agricultural regions of Sweden (Fig. 12) and in which maximum collinearity between predictors was less than 2.0. We will refer to the results from the analysis using the reduced dataset when relevant (i.e. when results differ). In general, results where similar and strongly correlated to the analysis of the full dataset (see Figs. A1.9, A1.11-13 in Appendix 1).

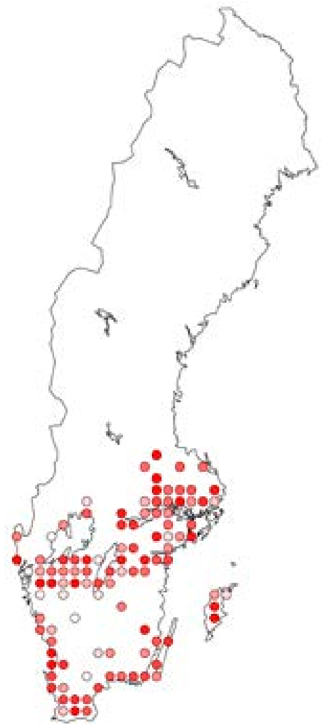


Figure 12. Map of the 103 Fixed routes included in the analysis of the reduced dataset. The darker the red the more years a route was surveyed (white = 3 years, red = 16 years).

3.3.3 Results and interpretations

How to interpret model parameters

A more detailed description of how to interpret model results can be found in Appendix 1. Here, it suffices to say that land-use dependence (see Fig. 13) is presented as the proportional change in abundance when changing land-use by one unit (the unit is the respective predictor's standard deviation, i.e. how much it varies in the routes included in the model).

The predictors of farmland bird abundance

The importance of the different land-use variables on farmland bird abundance is shown in Fig. 13 and discussed below. We will not discuss the effect of *latitude per se* as it is not the focus of our analyses but we do discuss the latitudinal gradient in effects (i.e. how effects change along latitude) of the other variables where applicable as regional differences in effects are of interest.

We begin by presenting discussing correlations between species abundances. As described, the relative strengths of correlations due to included (environmental correlations) versus those due to non-included predictors and/or other causes (residual correlations) can inform us about how important the studied land-use is for farmland birds in comparison to other factors. We found more significant positive than negative *residual* correlations among species (Fig. 14A). These correlations result from either direct interactions between species through facilitation (if positive) or competition (if negative) or from common responses to factors that were not modelled. We cannot separate these effects with the current modelling approach, but both types of effects probably contribute.

The estimated *environmental* correlations show that the predictors studied were very influential and that farmland species respond similarly to them (basically all being strongly positive, Fig. 14B). Hence, even though there clearly are factors affecting farmland birds that we were unable to capture in our model (see residual correlations in Fig. 14A), we do capture important effect of land-use on the farmland birds. As will be described further below, most of this pattern is due to the effect of farmland area per se. The remaining predictors (which are rather describing the quality of farmland) had less and more variable influence on the correlations between species (Fig. 14C).

Farmland area is most important

Farmland area stands out as the most important predictor with estimated coefficients vastly exceeding the other variables (Figs. 13 and 14). This is also illustrated by the cluster analysis (Fig. 15), which identifies three groups of farmland birds whose main discriminating characteristic is their response to farmland area.

The most distinct cluster is formed by Yellow Wagtail, Meadow Pipit, Eurasian Curlew and Rook. These four species showed strong dependence on farmland area in southern and central Sweden while they seem less dependent on the amount of farmland further to the north. For the Rook, this might be explained by its very restricted southern distribution. For the other species in this group the most plausible explanation should be that they are mostly found in alternative habitats, such as mires, bogs and forest clear-cuts, in the north.

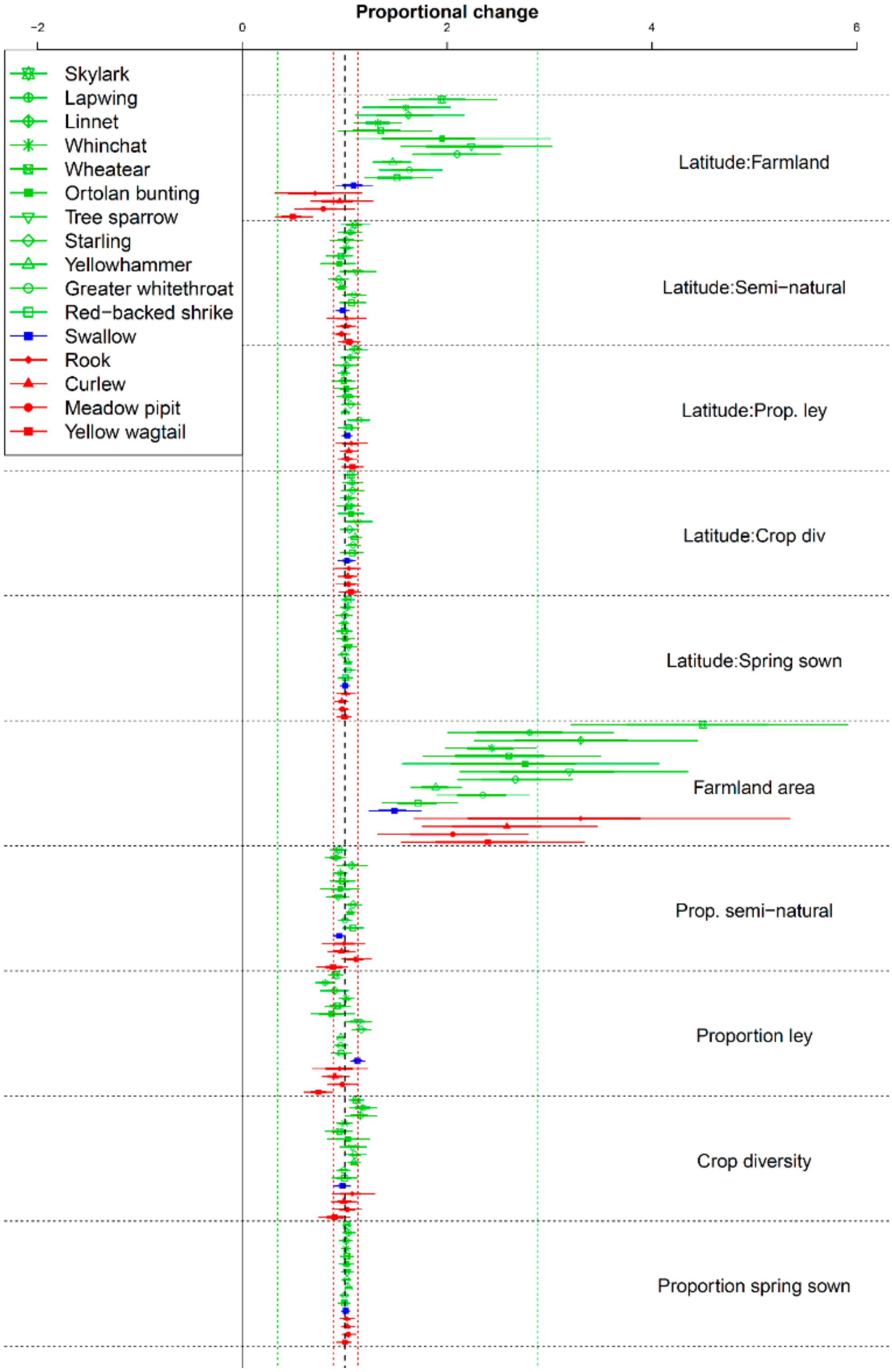


Figure 13. Coefficient estimates for predictors in the model (main effect of latitude is excluded for clarity). Coefficients are expressed as proportional change and the black vertical hatched line show a proportional change of 1 (i.e. no change). Colon (:) in effect names indicate interaction. The coefficient values (points) also include 68% (thick lines) and 95% (thin lines) CI. The symbol colours show group membership from the cluster analysis (Fig. 15). The vertical red and green lines show the 95% interval of year and route variation respectively (expressed as twice the estimated standard deviation on the proportional scale).

The Barn Swallow constituted a group of its own, having low farmland area dependence throughout the country. Most likely, this is due to Barn Swallows being strongly dependent on buildings, where they can put their nests and possibly by the effect of horse farms (see above). The density of neither farm buildings in general nor horse farms in particular is high in the more intensively farmed regions of Sweden where farmland is more extensive, possibly explaining this species' weak relationship with farmland area.

A large group was characterised by being strongly dependent on farmland area throughout the country, but with a relationship that was even stronger towards the north. It is possible that these species have fewer alternative habitats in the forest-dominated farmland routes in the north compared to the situation further south.

Availability of alternative habitats was suggested as a main determinant of the importance of farmland area for farmland birds in the analysis of the full dataset. Those species known to utilise also alternative open habitats in (northern) forested regions, or being dependent nesting sites with a weak association to arable land per se, exhibited lower farmland dependence. In the analysis of the reduced dataset, with a stronger focus on the main agricultural regions of Sweden, farmland dependence was strong

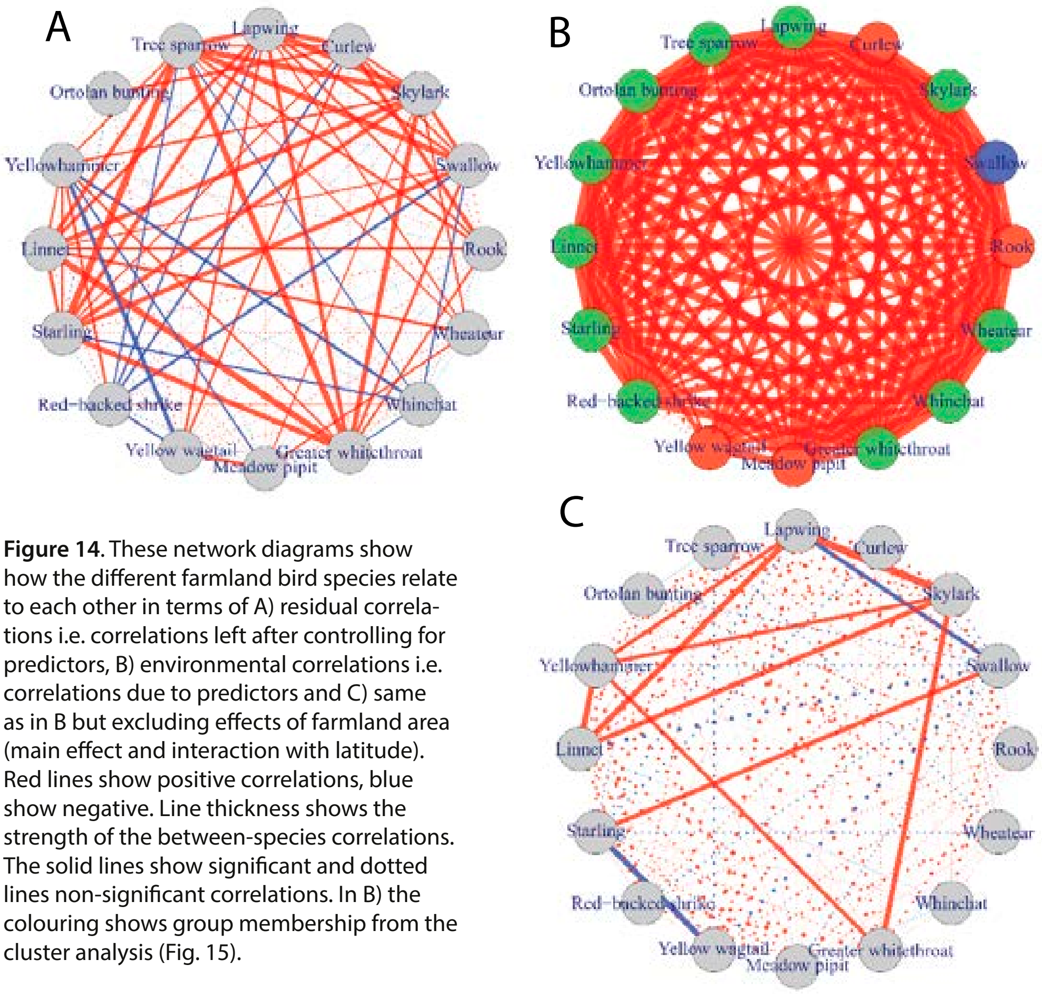


Figure 14. These network diagrams show how the different farmland bird species relate to each other in terms of A) residual correlations i.e. correlations left after controlling for predictors, B) environmental correlations i.e. correlations due to predictors and C) same as in B but excluding effects of farmland area (main effect and interaction with latitude). Red lines show positive correlations, blue show negative. Line thickness shows the strength of the between-species correlations. The solid lines show significant and dotted lines non-significant correlations. In B) the colouring shows group membership from the cluster analysis (Fig. 15).

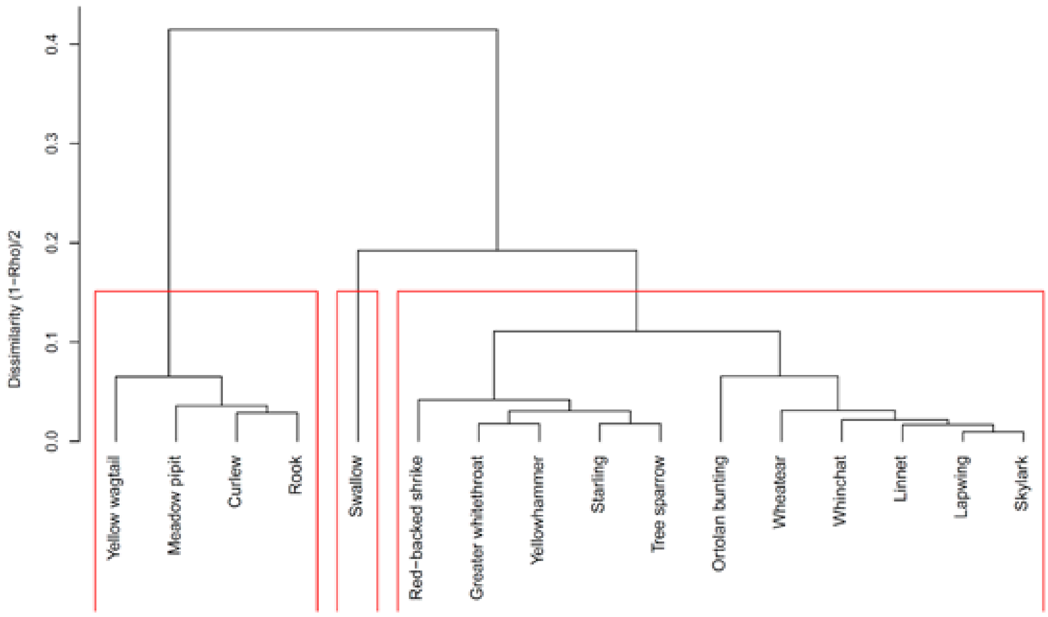


Figure 15. The dendrogram illustrates which farmland bird species are most similar to each other in terms of how their abundance is affected by the various farmland variables (based on the cluster analysis of the environmental correlations). Distinct clusters are delineated by red lines.

and similar for all farmland bird species. There was a weaker but generally positive latitudinal gradient suggesting that in the northern part of the main agricultural regions, the non-farmland habitats (mostly forests) do not to the same extent contain alternative open land (e.g. large mires or clear-cuts) and availability of farmland is therefore more important. However, also the smaller latitudinal range in the reduced dataset also limit the possibility to detect strong latitudinal gradients.

In summary, without doubt, the amount of farmland available to farmland birds is of great importance both as strongly affecting species specific abundances and as a driver of covariation among species. Abandonment is hence detrimental to the persistence of the farmland bird community in large parts of Sweden. Alternative habitats exist for some more generalist species and this is also reflected in our analyses. Several species showed a reduced farmland area dependence towards the north where they tend to utilize other habitats than farmland. Additionally, the Barn Swallow had the lowest farmland dependence and this species find nest sites and suitable foraging grounds in association farms with animals (including horses) which are more often found in extensive areas with a lower proportion of farmland. Nevertheless, many species are obligate farmland birds and further abandonment and/or deterioration of the farmland habitat are likely to cause further declines in the Farmland Bird Index.

Importance of the other land-uses

The other predictors included in the model had comparatively lower influence on farmland bird abundance. The positive correlations among species due to these predictors only, was greatly reduced (some even negative) indicating a more disparate pattern with more species-specific responses (Fig. 14C). Once again, the residual correlations indicated that there are factors affecting farmland bird co-occurrence that are not modelled, among which there might well be factors describing aspects of farmland quality or quantity that we cannot capture using the LPIS.

Semi-natural habitats

We found some support for the proportion of semi-natural habitats in the agricultural landscape to be of significant importance for farmland birds. Species associated with semi-natural pastures (e.g. Red-backed Shrike, Starling, Yellowhammer, and Meadow Pipit) showed positive relationships to this factor (Fig. 13). Also fallows may be important, since the two species with the clearest positive signal (Yellowhammer and Starling) are known to readily use this habitat. For many species strongly associated to arable fields (Skylark, Lapwing and Yellow Wagtail), there was a negative relationship to the proportion of semi-natural habitats. Comparing the full and reduced datasets, there were indications that the negative effects of more natural habitats can be due to increased areas of semi-natural habitat occurring at the expense of habitats such as open arable fields which these species prefer. The latitudinal gradients in the dependence of bird populations on the proportion of semi-natural habitats found in the analysis of the full dataset basically vanished in the reduced dataset.

In summary, semi-natural habitats benefit farmland species specifically associated to such habitats. For species that need large, open habitats (arable fields), too large proportions of semi-natural habitats might be negative as the availability of arable fields where they can nest is by necessity low.

Proportion of extensive crops

The proportion of extensive management on arable fields gave the most variable results in terms of main effects and this pattern was the same throughout Sweden, although with effects that are slightly more positive (or less negative) further north. Species common on annually tilled land (Yellow Wagtail, Skylark and Lapwing) where generally negatively affected by higher proportion of extensive crops, while species associated to animal husbandry (e.g. Starling and Barn Swallow) are positively affected by proportion extensive crops. The results from the reduced dataset was basically the same with the exception that for Starling the positive effect was gone completely. One possible explanation for these results is that leys differ in quality throughout the country. In productive regions (generally in the south), leys are probably more intensively managed and used for fodder production (in particular silage) and such leys are mown too early/often and are too densely vegetated to suit neither open field species nor species associated to semi-natural grassland. In regions with more extensive farming (mostly but not exclusively in the north) they are used for grazing (or more extensive hay production) and are more strongly associated to animal husbandry, hence, they are better suited for species like the Starling. Further, in these regions they may also constitute the only open habitat available, explaining the weak but generally positive latitudinal gradient for basically all species.

In summary, a few species benefit from increased proportions of ley on arable fields in southern as well as in northern Sweden, but for the bulk of species it is largely negative. This pattern is at least as clear in the more productive regions of Sweden. The general tendency of leys being more beneficial in the north may be due to it being the only open habitat there, but may also reflect the fact that leys in the north may be of better quality (more extensively managed and associated with grazing livestock).

Crop diversity

A higher crop diversity was clearly positive for several species, with effects exceeding that of semi-natural habitats. Species exhibiting significant positive associations with crop diversity are all known to generally use arable fields for foraging and nesting (Skylark, Lapwing, Linnet, Starling and Yellowhammer). There was a strong positive correlation in effects of spring-sown crops between the analyses of the two datasets. Even if effects were weaker, especially Skylark, but also Lapwing and Linnet, showed positive associations to spring-sown crops when the analysis was limited to routes with two effective crops or more (reduced data). Hence, although crop diversity may correlate with other variables that are more important drivers of these relationships, model diagnostics as well as the results from analyses where these problems are minimised do suggest that a high crop diversity is beneficial. The absence of a latitudinal gradient in effects in the main agricultural regions of Sweden while such a gradient was found when analysing the whole country indicate that going from having just one crop (often ley) to also include an additional (annual) crop will benefit many farmland species in less productive areas.

In summary, a high crop diversity may well be important for many farmland birds by providing alternative habitats for insect prey and a variable structure where birds can feed and find shelter. Crop diversity may correlate with other important factors but our analyses suggest that it is important by itself. Even adding just one or two crops may help, especially in regions with very few crops.

Proportion spring sown crops

The proportion spring-sown crops was the least important predictor as judged from our model outcome. The coefficients are low over all and there was basically no latitudinal pattern. In the full dataset we found that the Yellowhammer had a clear positive response to spring-sown crops. However, this effect disappeared in the reduced data. One explanation might be that in less productive regions, proportion spring-sown crops in routes with no annual crops was set to zero and therefore spring-sowing is contrasted against having no annual crop at all rather than against autumn sowing. This is not the case in the reduced data and, hence, it might be questioned whether Yellowhammers really are benefitting from spring sowing or perhaps just from annual cropping in general. Support for the benefit of spring sowing was found for the Lapwing, a ground-nesting species commonly found on arable fields, and the effect was even stronger in the reduced data.

In summary, although most species showed small or no effects, spring-sowing might benefit ground nesting arable field species as we found rather clear positive effects on one of these, the Lapwing. Even though we would also expect that species staying over the winter or arriving early would benefit from the fact that spring-sown fields are generally preceded by over-winter stubble, a species that would conform to this (the Yellowhammer) showed inconclusive results, perhaps due to spurious characteristics of the data. However, we note that some of the benefits from spring sowing accrue during the winter and will not be spatially closely associated with the breeding count data, because resident birds are distributed more extensively during the non-breeding season. Thus, there will be aspects of the benefits of spring sowing that we cannot capture using this habitat-association modelling approach.

4. What should be done to improve conditions for Swedish farmland birds?

The objective of this report is to propose measures that would reverse the ongoing decline of the Farmland Bird Index (FBI) in Sweden. The FBI is used as an indicator of the condition of biodiversity in farmland, both in Europe (Gregory et al. 2005) and in Sweden (Green et al. 2016). In a strict sense, it is not an index of farmland biodiversity, but a weighted average of the population sizes of a number of birds associated with farmland and, while declining, common enough to reflect the general situation for biodiversity in farmland.

While there is little agreement between estimates of biodiversity for different taxa at small spatial scales, including for example between bird and plant diversity (Pärt & Söderström 1999), it is likely that this agreement is better at larger spatial scales (Wolters et al. 2006; but see Billeter et al. 2008; Ekroos et al. 2013). However, for the FBI in Sweden this remains to be shown. Assuming that there is an agreement, it is then possible to propose actions than benefit the FBI and, thus, also the general situation for biodiversity in farmland.

Measures proposed can either be quite general, e.g. affecting farmland intensity or landscape heterogeneity, with likely consequences for both biodiversity in general and the FBI specifically. Alternatively, very specific measures affecting farmland birds, like supplemental winter feeding or Skylark plots, can be used. If such measures are used to reverse the declining trends for farmland birds, it is important to carefully evaluate the future utility of the FBI as general index for farmland biodiversity, for example by establishing that actions directed towards increasing FBI also have beneficial effects on farmland biodiversity as a whole.

Below we suggest mainly general measures with likely positive effects on farmland birds, based on the findings in our three ways of extracting important information about drivers of farmland bird populations: the literature review, the analyses of farming and farmland bird trends, and the spatial modelling. We think and hope our suggested measures would indeed have positive effects on farmland birds and farmland biodiversity in general (Benton et al. 2003). However, we also suggest some more specific measures that may prove efficient in reversing trends also for some of the most threatened farmland birds, such as the Ortolan Bunting and Corn Bunting (the latter is not included in the FBI due to its scarceness).

4.1 Halt the loss of farmland quantity and quality

There are two main lines of measures to be taken if we are to reverse the decline of the Farmland Bird Index for Sweden and they concern the *quantity* and *quality* of farmland. The first is to halt the ongoing loss of farmland, that is, the transition of farmland to forest, urban land and different types of infrastructure. The second is to improve the conditions in the farmland that is left.

4.2 Improve the conditions in existing farmland

The keyword for managing farmland towards being beneficial to farmland birds is variation (Vickery & Arlettaz 2012). Variation in time, variation in space, and variation at all spatial scales! Variation in farming practices at the field, farm and landscape level creates variation in bird habitat, which allows more species to find suitable habitats, and more species to find the variation in habitats needed for successful breeding, foraging and survival (Vickery & Arlettaz 2012). It should be noted that included in "variation" are also some areas of large-scale homogenous farmland landscapes, which may be beneficial for the breeding of some species like Skylark and Lapwing, and for other bird species during migration and winter (Dänhardt et al. 2010, Lindström et al. 2010, Vickery & Arlettaz 2012, Hiron et al. 2015).

4.3 Our recommendations

Stop the loss of farmland in Sweden

Given that the Farmland Bird Index is based on birds with a strong connection to farmland, it is a trivial conclusion that farm abandonment will have consequences for the Farmland Bird Index.

Nevertheless, our literature review showed that farmland abandonment is considered to be a main threat to farmland birds in Europe as well as in Sweden. Agricultural abandonment particularly affects areas with less productive agriculture, which in Sweden is the more northerly areas. In these areas, trends of farmland birds have generally been more negative than further south. Finally, our spatial modelling showed that of all investigated predictors, farmland area was the most powerful predictor explaining the present abundance of farmland birds. Thus, if the goal is to reverse the decline of the Farmland Bird Index, one of the most important actions is to avoid that farmland abandonment continues.

Reducing agricultural abandonment may or may not contribute to the policy goal of maintaining a rich agricultural landscape. Our literature review found that mosaic landscapes, with a mixture of forest and farmland, is beneficial for some species of farmland birds and our spatial modelling showed a stronger farmland dependence at more northern latitudes for most species. Since these landscapes are particularly prone to agricultural abandonment, this may result in important habitat for some farmland birds being lost. However, these marginal areas are also subject to agricultural simplification, as a result of increasing dominance of leys. This trend is reinforced by current policy instruments (e.g. compensatory allowance) intended to reduce agricultural abandonment in marginal regions and therefore adjustments to the instruments might be needed to increase crop diversity in these areas. Our bird-habitat modelling gave some support to this contention.

Stop the loss of, and create new, semi-natural habitats

Parallel to the loss of total farmland area there has been an even larger loss of semi-natural habitats, such as semi-natural grazed and mowed pastures, uncultivated field borders, stone piles and walls, hedges, single or rows of trees, and small wetlands. This has resulted in loss of relatively stable habitats in landscapes otherwise regularly disturbed by farming activities.

Our literature review showed a wealth of scientific information reporting the importance of semi-natural habitats to farmland birds by providing nesting sites and foraging areas, and function as sources for populations of plants and invertebrates which are used by birds as food. Further, the trend analysis showed that recent population trends have been particularly negative for the species depending on small biotopes.

However, the different farmland bird species have different habitat requirement, and there is not one solution for all problems in terms of protecting and recreating semi-natural habitat. Rather, our review demonstrated the importance of maintaining farmland heterogeneity at multiple scales, at the smaller scale by providing different forms of semi-natural habitats including semi-natural grasslands with different management, field-borders with different vegetation, and small biotopes of different forms. At the larger scales, it is also clear that there is a need to maintain a variation of different types of agricultural landscapes, including also the more intensively open plains, to maintain the whole suite of farmland birds. Given the ubiquity of farmland change, it is difficult to use comparisons of bird-trends between regions to infer the consequences of loss of semi-natural habitat on farmland birds, particularly since statistics regarding semi-natural grasslands is fraught by interpretational problems and there is a lack of statistics on regional differences in the loss of small biotopes.

In our statistical modelling we combined pastures (including meadows) and fallows in our measure of semi-natural habitat but was not able to specifically include any other type such as stone walls, bushes or field islands. Thus, inferences from the modelling cannot directly differentiate the roles of semi-natural habitats off (pastures) and on (fallows) arable fields, nor can it provide a full evaluation of all types of semi-nature in the agricultural landscape. We found that the species showing a clear positive response to our measure of semi-natural habitats were either typically associated with pastures (e.g. Red-backed Shrikes), or using both pastures and fallows (Yellowhammers and Starlings), indicating that increasing the proportion of these habitat should lead to higher abundances of at least these three species. Weak or no responses from other pasture and/or fallow inhabiting species (Wheatear and Whinchat) suggest that other aspects (e.g. quality) of semi-natural habitats are also important. The Wheatear rely on the presence of stone walls/piles for nesting and the Whinchat prefer open areas with a high grass sward, and these might not be present on many of the pastures. Our modelling results also showed that more or less obligate field-living species such as Skylark, Lapwing and Yellow wagtail show largely negative responses to the proportion of semi-natural habitat supporting the importance of maintaining a varied agricultural landscape (e.g. keeping arable fields in the north).

The preservation of semi-natural habitats is in general positive for biodiversity, including farmland birds, but both the literature review and statistical modelling show that it is important to realize that the way any preserved habitat is managed has important implications for their conservation value. For example, semi-natural grazed grasslands holds very different values to farmland birds depending on both grazing pressure and preservation of woody vegetation including trees. While removal of woody vegetation and short swards in semi-natural grasslands may benefit some of the birds in the FBI, a varied management will be beneficial to a larger suite of birds in the farmed landscape. Similarly, while open field borders are important feeding places for some farmland birds, other use woody vegetation as nesting and foraging places, arguing for a varied treatment of field borders also within farms. The location of the habitats also has importance, since semi-natural habitats often are complementary habitat that, for example, provides nesting places in the farmed landscape. This needs to be carefully considered when discussing ecological compensation as a way to move or create new small biotopes that constitute obstacle to farming operations.

Promote mixed farming (husbandry and crop production at the same farm)

Specialization on plant production in more productive agricultural landscapes has resulted in the loss of animal husbandry on many farms, to the disadvantage of the several farmland bird species that benefit from the presence of cattle and horses. In contrast, in the less productive regions of Sweden, most farms only do animal husbandry, to the disadvantage of those species benefitting from crop production. We suggest that farmland birds may benefit if animal husbandry is promoted in the arable plains while crop production is promoted in areas dominated by animal husbandry.

Our literature review indicated that there are both direct and indirect benefits of mixed farming on farmland birds. Mixed farming results in a variety of habitats (arable fields, leys, grazed pastures) that provide complementary food to some farmland birds and food to a larger variety of farmland birds, because of the effect of farm land use. In addition, for some farmland birds a direct effect of the presence of cattle (and maybe horses) has been shown, which means that an increased spatial concentration of animal husbandry may result in an overall decline of the FBI.

The trend analysis demonstrated that the indicators have declined most in northern Sweden, which is increasingly dominated by leys. This suggests a negative effect of loss of crop production on farmland birds. However, this effect is difficult to disentangle from the effect of farmland area loss as such.

Our spatial modelling could potentially have captured these specific effects, but would require combining crops from LPIS differently, adding other information such as spatially explicit livestock numbers, and including higher-order interactions and/or non-linear effects in the model. However, model complexity would then increase dramatically and quite far-reaching assumptions on what such a set of predictors actually measures would need to be made. Circumstantial evidence on effects of mixed farming may be extracted from our results (albeit still under restrictive assumptions). Crop diversity in northern Sweden rarely consists of more than two crops and one of them is generally ley (Fig. A1.1). Low crop diversity may indicate a focus on livestock farming (where fields are used to produce fodder in terms of hay and one cereal). We found, for all species, a more positive effect of crop diversity towards the north indicating that more crops (i.e. crops other than ley) and/or a more even mix of crops would especially benefit the abundance of farmland birds there (Fig. 13, Latitude:Crop diversity). Thus, under the assumption that a low crop diversity is an indication of a focus on livestock farming (and the reverse, that a high crop diversity indicate arable farming), farmland birds would benefit from the transition towards more arable farming in northern livestock farming systems and vice versa.

It is beyond the scope of this report to suggest how to promote mixed farming, but we note that some of the policy instruments to thwart agricultural abandonment may inadvertently result in increased regional specialization in the north (see above). Furthermore, not only the presence of animal husbandry in arable landscapes is important, but animals needs to be raised in a way that results in benefits to biodiversity in general and farmland birds in particular by barns being accessible and animals grazing outdoors (most preferably on more or less permanent grasslands).

Promote set-asides (of various kinds)

Fallows and set-aside may contribute to farmland biodiversity by offering a relatively undisturbed habitat where plant and animal populations temporarily can escape agricultural disturbance for nesting and foraging, but still benefit from the open and resource-rich habitats they provide.

Our literature review showed fallows to be attractive to farmland birds, but with different consequences of different types of set-aside. Rotational set-aside were shown to provide both nesting places and winter foraging for farmland birds, and non-rotational set-aside have been shown to be attractive as breeding habitat. Some authors argue that different types of set-asides differ in quality for farmland birds (Vickery et al. 2004, Henderson et al. 2000). Rotational set-asides where over-winter stubble from the previous crop is followed by summer fallow were the most preferred, having "a much more patchy, species rich and complex sward than non-rotational set-aside" (Henderson et al. 2000). Key features defining the quality of set-asides as nesting and feeding habitats for farmland birds are hence the presence of both structurally and compositionally heterogeneous vegetation (e.g. Vickery & Arlettaz 2012) that is present both during summer and winter. Hence, set-asides should preferentially be rotated around the farm land and preceded by over-winter stubble of the previous crop. Non-rotational set-aside maintained for more than one year are also very valuable but actions should be taken to maintain earlier successional stages, that is, avoiding the development of too dense swards. It is then important that such management actions take place outside the birds' breeding season (i.e. in late summer).

Current Swedish regulations (http://www.jordbruksverket.se/download/18.3687637f15a0c73d8495a60f/1486390074643/Det+h%C3%A4r+g%C3%A4ller+f%C3%B6r+tr%C3%A4da+2016.pdf) for set-asides do include prescriptions for late management (cutting no earlier than 30 June), although exceptions exist in some regions where management is allowed during many species' breeding (mid-June). Sowing of beneficial crops (flowering and seed-producing broad-leaved plants) upon set-aside establishment is also encouraged. However, fallows without vegetation ("svartträdor") and where mechanical or chemical vegetation control is applied are allowed and this type of fallows do not benefit birds. Hence, adjustments to these regulations to better fit requirements for biodiversity in general and farmland birds in particular might be warranted.

Even though evidence from the literature suggest that the quality of set-asides may be important, some results where no differentiation between set-aside qualities have been made do suggest a generally beneficial effect. Previous analysis of farmland bird trends demonstrated that a period of high levels of fallow in Sweden was a period of less decline in FBI (Wretenberg et al. 2006). In our spatial modelling, we had to pool semi-natural grasslands and fallow, so it is subsumed in our general demonstration of the value of semi-natural habitats. Several species responded positively to these habitats and some of these (e.g. Yellowhammer) are known to utilize fallows to a large extent (e.g. Henderson et al. 2000, Gillings et al. 2010) indicating that this habitat contributed to the response. Given the clearly positive effects that set-asides in general have been shown to have on many farmland bird species, we suggest that they could be promoted as a way to improve FBI. To the extent possible, we also encourage management prescriptions that increase vegetation complexity and food resources, e.g. promoting early successional stages, applying management outside the breeding period, keeping vegetation over winter, sowing of flower and seed rich plants and avoiding chemical treatments.

Our literature review also demonstrated that some measures specifically directed towards farmland birds may fulfil the same effect as fallows (and winter stubble), i.e. wild bird cover (“fågelåkrar”), skylark plots (“lärkrutor”), buffer strips (“skyddszoner”) and appropriately managed ecological focus areas (“ekologiska fokusområden”). Although the effect of these measures at the population level remains to be shown, they likely have strong effects on the farmland birds targeted (winter-resident seed-eaters and Skylarks). In addition they are easy to motivate and probably relatively easy to implement. We see the possibility to link these measures to the ongoing greening of the CAP.

Promote wetlands in the agricultural landscape

Ponds, open ditches, and temporarily flooded meadows provide habitat and food to farmland birds, but have declined dramatically in Swedish agricultural landscapes as a result of lowering of water tables, field drainage and filling of small water bodies to benefit farm operations.

Our literature review showed good evidence that farmland birds benefit from wetlands since wetlands and the vegetation associated with them provide nesting places and foraging ground. However, except for the effect on wetland birds, evidence on their general effects on farmland birds is scant. Neither our trend analysis, nor our habitat modelling, could contribute evidence due to lack of data. That said, the circumstantial evidence on the positive effect of farmland wetlands is strong, e.g. as suggested by some recent studies on the effect of created wetlands.

Wetland creation can benefit farmland birds and the FBI, but some evidence suggest that the type of wetland created have consequences for the extent to which farmland birds benefit. However, more research is needed to determine the consequences for farmland bird populations.

Promote crop diversity

A diversity of crops may benefit individual farmland bird species, by providing complementary habitats and benefit the local diversity of farmland birds by benefitting farmland bird species with different habitat requirements. The first mechanism will have a positive effect on the total number of farmland birds and thus the FBI, while the second mechanism may or may not benefit the total number of farmland birds.

Our literature review found very limited evidence of the effect of crop diversity on farmland birds. Some farmland birds may benefit from a structural variety of crops, e.g. a mixture of spring and autumn sown crops. Our trend analysis do not provide any evidence concerning the effect of crop diversity. Our spatial modelling gave however some support for the benefit of crop diversity. In particular, there was a clear pattern for species that are known to utilize arable fields to a larger extent to have stronger positive responses than other species.

Crop diversity was more important in the north where diversity is lower perhaps indicating a non-linear relationship, i.e. crop diversity is less important once a certain threshold level is reached.

Without further research into how structural crop diversity affects farmland birds at multiple spatial scales, we cannot safely conclude that the promotion of crop diversity would benefit the FBI in Sweden, at least above the level of the three crops already set by current CAP greening rules.

Decrease the use of pesticides and inorganic fertilizers

The direct and indirect effects of increased use of pesticides and inorganic fertilizers are the main reason for the loss of farmland birds, by changing the requirement for linked animal husbandry and crop production and negatively affecting food availability.

Variation in farmland bird trends between European countries are partly explained by variation in general agricultural intensification which is closely linked to the use of inorganic fertilizers and pesticides. Historically, pesticides had a dramatic effect on farmland birds (Carlson 1962), but our literature review suggest that indirect effects of pesticides are far more important in contemporary agriculture by directly affecting availability of plant food and both directly and indirectly affecting availability of invertebrate food. We found that high nitrogen use may be detrimental to birds through its effect on vegetation and crops, but also beneficial to grazers and birds preying on soil invertebrates. Most scientific information stems from investigations of organic farming, demonstrating that the prohibition of pesticides and inorganic fertilizers with the associated changes in farming practices often results in positive effects on birds, particularly in areas with intensive farming. However, there is also some evidence that locally restricting use of inputs in conventional agriculture in the form of conservation headlands ("sprutfria kantzoner") may benefit farmland birds. Our trend analyses and spatial modelling lacks the instruments to analyse these aspects of agricultural intensification. In summary, measures that result in reduced use of pesticides (including herbicides) and inorganic fertilizers will very likely benefit farmland birds, but the independent effect of different measures is poorly evaluated scientifically.

Discussions regarding the biodiversity consequences of reducing agricultural intensification are often framed as land-sharing vs. land-sparing (Green et al. 2005, Fischer et al. 2008). According to some, reduced agricultural intensity (by e.g. reducing the use of pesticides and inorganic fertilizers) will require expansion of agricultural land at the expense of biodiversity (Phalan et al. 2011), while others maintain that integration of conservation in farmland is a way to combine preservation of ecosystem services and sustainable agriculture with conservation (Tscharnkte et al. 2012). This debate is based on an overly simplified view of the relationship between agricultural intensification and expansion, but also suffers from lack of quantitative information on biodiversity consequences of alternative pathways for agriculture (Fischer et al. 2014). In particular, the consequences of conservation in agriculture on ecosystem services benefitting crops are insufficiently known (Ekroos et al. 2014). In Sweden, biodiversity is to a large extent connected to farmland, thus the framework of land-sparing vs. land-sharing may be ill suited to discuss biodiversity conservation.

Delay mowing of leys

Earlier mowing of leys because of increased use of fertilizers and silage, is detrimental to some farmland birds such as Curlew, Corncrake, and Whinchat, as evidenced by our literature review. A delay of mowing dates and a decrease in fertilizer application on some leys, is a measure that would most likely have positive effects on several ground nesting bird species. However, this conclusion is partly speculative, as no studies on the topic have been performed in Sweden.

Promote spring-sown crops in the plains and create "bird fields"

Spring-sown fields provide breeding (and feeding) sites in early spring with no or very short vegetation, preferred by many farmland birds. In addition, spring-sown crops most often result in stubble fields that are left in autumn and over winter. The stubble fields often contain large amounts of seed-spills, to the benefit of seed-eating birds.

Our literature review showed that the shift from spring-sown to autumn sown crops is regarded as a major reason for the decline of farmland birds, not the least seed eating birds. In particular, this has been a main argument in the UK where demographic analyses have linked farmland bird declines to winter mortality (Siriwardena et al. 1998). Also in Sweden there has been a large loss of spring-sown crops, farmland birds seems to suffer from this change according to studies that compared different agricultural landscapes. In our trend analyses the decline of spring-sown crops is another farming measure that parallels the long-term decline in farmland birds (in addition to total farmland loss and the proportional increase of ley). This does not prove that there is a functional relationship, although it is highly likely given the many case studies showing the importance of spring-sown crops in bird species tightly or loosely connected to farmland, in both Sweden and elsewhere. Our spatial modelling suggested that spring-sowing elicited the weakest response among the factors studied. Nevertheless, the species exhibiting a positive response were among those expected to be affected, i.e. breeding and/or foraging in more sparsely vegetated open fields. Importantly, our bird-habitat modelling do not capture effects of spring-sown crops on the winter food availability.

Some of the specific measures listed under fallow above (wild bird cover, skylark plots, ecological focus areas) may be used to compensate for the loss of spring-sown crop, given appropriate management.

Minimum tillage and No-till "direct drilling"

Minimum tillage has the potential of benefitting farmland birds by not burying seeds during ploughing, and allowing weeds and soil fauna to thrive. Some of these benefits may be countered by the more frequent use of herbicides.

Our literature review found some evidence that this benefitted farmland birds, but there is a need for additional research. In particular, we found no studies of this in Sweden. Lack of data means that neither our trend analysis nor our spatial modelling can be used to evaluate the consequences of the increasing use of low tillage regimes in Sweden. Hence, while there may not be sufficient evidence that increased use of low tillage will benefit the FBI, this is an area or urgent need of studies since there is a potential for multiple benefits to both agricultural sustainability in general and farmland birds in particular.

4.3.1 Expected effect at the species level

	Lapwing	Eurasian Curlew	Skylark	Barn Swallow	Meadow Pipit	Yellow Wagtail	Wheatear	Whinchat	Common Whitethroat	Red-backed Shrike	Rook	European Starling	Tree Sparrow	Linnet	Ortolan Bunting	Yellowhammer
Stop the loss of farmland in Sweden	Green	Green	Green	Green	Green	Green	Green	Green	Green	Green	Green	Green	Green	Green	Green	Green
Stop the loss of, and create new, semi-natural habitats	Yellow	Green	Yellow	Green	Green	Yellow	Green	Green	Green	Green	Green	Green	Green	Green	Green	Green
Promote mixed farming (crops AND husbandry)	Green	Yellow	Yellow	Yellow	Yellow	Green	Yellow	Yellow	Yellow	Yellow	Yellow	Green	Yellow	Green	Yellow	Yellow
Promote set-asides (of various kinds)	Green	Green	Green	Green	Green	Green	Green	Green	Green	Green	Green	Green	Green	Green	Green	Green
Promote wetlands in the agricultural landscape	Green ?	Green ?	Yellow ?	Green ?	Green ?	Green ?	Green ?	Green ?	Green ?	Green ?	Green ?	Green ?	Green ?	Green ?	Green ?	Green ?
Promote higher crop diversity	Yellow	Yellow	Yellow	Yellow	White	White	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow
Decrease the use of pesticides and inorganic fertilizers	Green ?	Green ?	Green ?	Green ?	Green ?	Green ?	Green ?	Green ?	Green ?	Green ?	Green ?	Green ?	Green ?	Green ?	Green ?	Green ?
Delay the mowing of leys	Green	Green	Green	White	Green	Green	Yellow	Green	White	White	White	White	White	White	Green	White
Promote spring-sown crops	Green	Green	Green	White	Green	Green	Green	Yellow	White	White	Green	Yellow	Green	Green	Green	Green
Create "bird fields"	Yellow	Yellow	Green	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Green	Yellow	Green	Green	Green	Green
Minimum tillage and No-till "direct drilling"	Yellow ?	Yellow ?	Yellow ?	Yellow ?	Yellow ?	Yellow ?	Yellow ?	Yellow ?	Yellow ?	Yellow ?	Yellow ?	Yellow ?	Yellow ?	Yellow ?	Yellow ?	Yellow ?

Figure 16. The matrix shows the potential effects the different suggested measures may have on the 16 different focal farmland bird species. Green colours indicate that the measure most probably will be beneficial, and strong. Yellow colour means that the measure is likely to be positive, and if so will be moderate. White colour means that we expect no positive effect. A question mark in a square suggest that the effects are particularly difficult to assess, normally due to lack of empirical evidence.

We have, upon request, produced a matrix suggesting how the 16 different focal farmland bird species may be affected by the different suggested measures (Fig. 16). To some extent, the matrix is based on empirical evidence. However, lack of studies of the effect of specific measures on many of the species results in much of it being "best professional judgements", i.e. based on our knowledge of the ecology of the different species. Positive effects may be direct and obvious, for example, where large amounts of seeds in a bird field lead to increased survival of seed-eating species. Many effects may be more subtle, such as wetlands benefitting farmland birds by generally supporting insect production in the area. Some effects may be both positive and negative for a species, such as wetlands for Skylarks; the presence of water, for drinking and for insect production, may be positive, but the surrounding edge zone that often include higher vegetation that Skylarks dislike, may be negative. Given the great uncertainty and complexity in the species-specific effects of some of the measures suggested, the suggestions in the matrix should be treated accordingly.

4.4 The difficulty of giving quantitative advice

Our task was to propose measures to reverse the decline in farmland birds. In many respects it would be desirable to provide quantitative recommendations, in terms of what measures and in which quantity are needed to ensure that future farmland bird populations are larger than today. Unfortunately, there are several impediments to this.

First, farmland bird populations are declining for a multitude of reasons, which means that it is inherently difficult to predict the future changes of farmland bird populations. For example, the statistical modelling reveals a relationship between the farmland bird index (or the population size of a particular farmland bird species) and the availability of some critical habitat, such as semi-natural grasslands. However, we do not know which changes, caused by other variables, which an increase in semi-natural habitat should offset to increase the farmland bird index.

Second, while we know the consequence of marginal change in a particular habitat, land use per se cannot be changed directly, but only through policy changes. Models such as SASM or Capri handle land-use change as a result of policy change at regional scales, but that is not a sufficient spatial detail to make precise prediction about population changes of farmland birds.

Third, the available data on birds is mostly from the national monitoring programs. These are designed to pick up temporal trends in bird populations, at a spatially representative manner. They can be used to assess general habitat associations, but have limitations for finer scale relations. Thus, as mentioned above, it is not possible to evaluate the direct effect of measures that do not have large spatial extent, precluding evaluation of measures such as "bird fields" and even organic farming. In order to be able to make finer quantitative assessments a denser survey scheme, specifically in farmland, would be required.

Fourth, and related to the above, the predictors we have used in the habitat modelling are the areas of land uses covered by different crops or managements as classified for agricultural or control purposes in the LPIS. That is, the available data is not collected to be relevant for farmland bird ecology, and can at best be used as proxies. Therefore, it is quite likely that our statistical models is not closely linked to the actual mechanisms behind the population changes. In addition to the available data, it would be useful with a separate monitoring scheme to measure relevant habitat parameters. This could include, e.g. separation between grazed and mowed leys, sward heights and livestock kind and density in pastures and leys, mowing regimes in leys, sward density in leys and crop fields, manure, fertilizer and herbicide/pesticide application, shrub and tree cover along field border and in pastures. Increased ability to capture these – and possibly other – variables through improved monitoring and/or remote sensing techniques would aid the possibility to make predictive modelling of bird populations.

By using an approach combining a literature review, trend analysis and spatial modelling, we have been able to capture many different aspects of agricultural change. Some aspects of change were by necessity better captured by one of the approaches than by the others; while detailed scientific studies may reveal mechanisms behind change, only the modelling captures large-scale population consequences. However, it would have been much more satisfying if the approaches were more complementary, so that for example detailed studies of the effect of incidental habitats could be supported by spatial modelling. However, although there is a quest for more systematic compilation of evidence (Pullin et al. 2009), the fragmented status of evidence forces us to rely on a combination of evidence from different sources to draw conclusions (Ekroos et al. 2017). We are confident that basing policy decision on this approach will yield more positive effect on farmland birds than ignoring the available science, but are well aware of the large uncertainties and need of more research.

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Appendix 1 - Habitat association modelling

Introduction

The dependence of farmland birds on farmland land-use was modelled using joint species modelling (Ovaskainen et al. 2010, Clark et al. 2014, Pollock et al. 2014). In this modelling, all species' association with land-use is analysed simultaneously in one model. This has many advantages. One is that covariation between species can be explicitly modelled and estimated. This covariation can stem either from species interactions and facilitation or from factors influencing farmland birds but which are not included in the model. Another is that the joint modelling allows analysis of more uncommon species than what would have been possible if independent analyses where performed separately for each species. The rarer species will "borrow information" from the more common ones by the modelling of covariance between species. Yet, due to their construction, joint models give species specific estimates of land-use dependence and hence the ability to make separate inferences about habitat dependence for each species. Thus, in one model common to all species we can get detailed information both about each species separately and about species co-occurrence patterns. In short, we analyse how a set of farmland characteristics affect the abundance of a set of farmland birds (16 species) while accounting for any residual covariation among them.

Methods

Model specifics

Although the general approach used in Ovaskainen et al. (2010) and Pollock et al. (2014) was followed, that is, we modelled all species responses to a set of predictors together in one model while simultaneously accounting for the variance-covariance among sites between them, our model is a modified version in several respects. The most obvious difference to the other studies is that while their species data consisted of presence/absence data, ours are abundances. Thus, while they used logit or probit regressions, we used negative binomial regression as the basic underlying model. Hence, each species' abundance was modelled as a negative binomial distributed response variable related to the independent variables by a linear relationship on the log scale (log link). The negative binomial is a generalization of the Poisson distribution allowing for aggregated counts (a form of over-dispersion). In short, a modelled aggregation factor allows for inflated variation compared to the Poisson distribution (a low aggregation factor means more aggregated counts). The species included in these analyses are likely to vary in aggregation (e.g. some occur in flocks) and we therefore modelled separate aggregation factors for each species. Similar to previous studies, the association between species abundances among sites (species covariance) was modelled by letting the species' mean abundance (the mean of each species negative binomially distributed abundance) follow a multivariate normal distribution with a (log) mean determined by the linear predictor (linear combination of land use predictors) and an estimated variance/covariance matrix. As these kinds of models are difficult to specify in "traditional" maximum likelihood frameworks, we instead used a Bayesian analysis approach in which prior distributions and maximum likelihoods are combined into posterior distributions of model parameters. These, in turn, are sampled from using Markov chain Monte Carlo (MCMC) algorithms. Apart from providing a more flexible and easy way of describing the model, a Bayesian approach also allows a fairly simple and straightforward way of propagating parameter uncertainties. Basically, the MCMC sampling gives for each parameter a posterior distribution from which any kind of variance/uncertainty measure can be calculated. We used the program Stan as run from R to fit the model (R Development Core Team 2009, Stan Development Team 2016a). We used non-informative priors for all parameters in the model and in other respects adjusted the code for optimal performance following recommendations in the Stan manual (Stan Development Team 2016b).

Data

The "joint habitat association modelling" can broadly be described as relating a set of predictors to a set of responses. The predictors are descriptors of the habitat (the farmland landscape) and will in the following be variably and interchangeably referred to as predictors, variables and factors and their relationship to the responses as effects, dependencies or coefficients. The responses are species-specific counts of farmland birds and may be referred to as counts, abundances or responses.

The predictors – Land-use

The variables used as predictors in our modelling came exclusively from the LPIS (Land Parcel Information System, LPIS, "Blockdatabasen"). This means that in these analyses we were limited to studying variables that can be readily extracted from the database. This is crucial to have in mind, because although these variables are likely to be important, they are not necessarily the most important predictors of farmland bird abundances.

We were also limited by the fact that despite using an extensive data set on bird abundances (the Fixed route monitoring scheme, see above), the total area covered by this scheme is low. Given that farmland constitutes only 7-8% of total land area in Sweden, the farmland area covered by the scheme is even lower. In the Fixed routes farmland birds are indeed counted in a truly representative sample of the farmland habitats, but the variables we want to study the effect of needs to be relatively common throughout Swedish farmland. As an example, we cannot study the effect of "bird fields" (fågelåkrar) as these are so rare that they do not show up in the routes. Even the effects of organic farming cannot easily be studied within the Fixed route scheme due to its low proportion among farmland habitats in Sweden, in particular in agriculture-dominated parts of Sweden.

The variables we selected are represented in routes more or less throughout Sweden and are intended to measure various aspects of agricultural change that might be important for recent farmland bird declines. Our intension was to reflect these under the constraints mentioned above. The land-use variables are as follows:

Farmland area. This variable is included to measure the importance of farmland per se. It might seem trivial to include farmland area as a predictor of farmland birds but for one thing it is necessary to include it such that effects that in reality is due to farmland area are not attributed to other variables slightly correlated with farmland area. And even if all farmland birds depend on farmland they may exhibit different pattern in dependence that can give important information about the nature of the relationship. Farmland area is measured as the area of all farmed land as reported in LPIS, excluding land-uses that can be considered as forest and those not considered relevant or where the coding is unclear or variable over years. Excluded land-uses are: parts of semi-natural pastures and meadows with high density of trees (more than 60 trees/ha), mountain pastures, forest pastures, game grazing, reed canary for the years 1999-2000, custom buffer strips, non-approved crop on arable field or pasture respectively, wetland, Christmas-tree plantation, forest plantation, unused pasture, flooded area and missing crop.

Proportion semi-natural habitat. This measures the importance of semi-natural habitat in the farmed landscape. Habitats for farmland birds in the agricultural landscape can take many forms, most of which are not represented in LPIS. We chose two land-use classes from LPIS: semi-natural pastures (including meadows) and fallow. Both provide feeding and nesting habitat for farmland bird species although some species prefer one over the other. One other potential habitat might be available in LPIS: field borders. These interstitial habitats are important for many species, but are only represented in LPIS as borders between blocks and there is currently no way of differentiating borders of different quality. The quality difference may be large however with some block borders having a clear delineation in reality often consisting of a stone-wall with more or less bushy vegetation and others barely visible where the crops on both sides basically are not separated at all. Recent developments of the LPIS have also resulted in that there are borders between blocks that are merely administrative with no visible border at all. Furthermore, the amount of field borders is closely correlated with amount of pasture in Sweden and including both will hamper the analysis by introducing collinearities between predictors. The strong correlation means that one of the variables measure about the same thing as the other and it will therefore suffice to include only one of them. It should be acknowledged that there might be rather significant quality differences in fallows and pastures as well but we assume here that these are much less that for field borders Proportion semi-natural habitat is calculated as the proportion of areas of fallow and pasture in total farmland area.

Proportion extensive crop. This measures the importance of extensive management (leys) and is calculated as the proportion of ley and buffer strips on arable land where arable land is farmland area, *excluding* fallows and pastures. That is, it is intended to measure the role of extensification by inclusion of ley on otherwise annually cultivated arable land. Such inclusion should constitute an extensification of farming on arable fields with less disturbance and less application of inputs (at least pesticides). We included buffer strips since these are similar in these respects although by definition linear and placed along watercourses. We did not differentiate between leys of different qualities as reflected by the crop codes in LPIS. Hence, leys may be both short-rotation, intensively managed leys maintained for hay and silage production and longer laying extensive leys mainly used for grazing.

Crop diversity. This variable measures the diversity of crops on arable fields per route. Diversity is the Shannon diversity (= the exponentiated Shannon index, $e^{\text{Shannon index}}$) and can hence be viewed as the number of effective crops in the arable fields. The number of effective crops is the translation of the actual relative proportions of crops into a number of equally common crops, e.g. a route with two crops where one of the crops is clearly dominating will have a Shannon diversity close to 1 while a route with two equally common crops will have a Shannon diversity of about 2. Crops from LPIS are grouped into 17 groups according their structural and temporal appearance. That is, consideration is taken both to what the crop looks like (from a bird's perspective, i.e. differentiating between cereals, oil-seed rape, vegetables, root crops etc.) and time of sowing (autumn vs spring sown). Leys are also included as one of these structural crops.

Proportion spring sown crops. This is a measure of the importance of timing of sowing. The timing and type of management (ploughing, sowing, or over-winter stubble) as well as the development of the swards are features that differ between these two types and should hence be of importance for farmland birds. It is calculated as the proportion of crops sown in spring among all annual crops grown on arable fields (e.g. excluding ley).

We included the five land-use variables described above, plus a latitudinal gradient (the Y coordinate of the starting point of the survey route in projection RT90 2.5 gon V) as main effects in the model. We also wanted to study whether land-use dependence varied along the latitudinal gradient and therefore included all two-way interactions between land-use variables and latitude under the assumption that interactions with latitude reflect regional differences in land-use dependence. Thus, in total we had 12 predictors (5 land-uses, latitude, 5 interactions and an intercept) in the model. We also included a random effect of route to handle the repeated sampling of routes. Similarly, to control for yearly variation in counts due to phenology and/or general population trends we included also year as a random effect.

Table A1.1. Summary of variables used in the model. Note that this is based on the dataset used, i.e. due to repeated surveys each route can be represented more than once.

Variable	Unit	Mean	Standard deviation	Range
Farmland area	hectare	51.2	62.8	0 – 296.4
Prop. semi-natural	proportion	0.290	0.274	0 – 1
Prop. Extensive	proportion	0.609	0.371	0 – 1
Crop diversity	number of effective crops	2.05	1.45	0 – 8.28
Prop. spring sown	proportion	0.528	0.443	0 – 1
Latitude	meter	6576021	289171	6161000 – 7436000

All 5 land-use variables plus latitude were standardized prior to analysis (centred at their mean and scaled by their standard deviation, see table A1.1). Hence, the unit of estimated coefficients are standard deviations and since we let latitude interact with all other variables, the main effects of these variables are estimated at mean standardized latitude of zero which translated into non-standardized latitude 6576021 (RT90 2.5 gon V), just south of Stockholm. We will refer to this latitude as south central Sweden. Further, coefficients of the interactions can be interpreted as the change in main effect when moving 1 standard deviation (≈290 km) northwards or southwards. The geographical centre of Sweden is much further north than Stockholm, but our analysis only included routes with farmland (see below), and farming in Sweden is skewed towards the south, hence the southern skew of the mean of the coordinates.

There were overall low correlations between predictors with the exception of a correlation of 0.8 between crop diversity and farmland area (Fig. A1.1). However, variance inflation factors can be considered low (Quinn and Keough 2002) with a maximum of around 2.76 for crop diversity and farmland area. Hence, collinearity should not pose significant problems in the analyses.

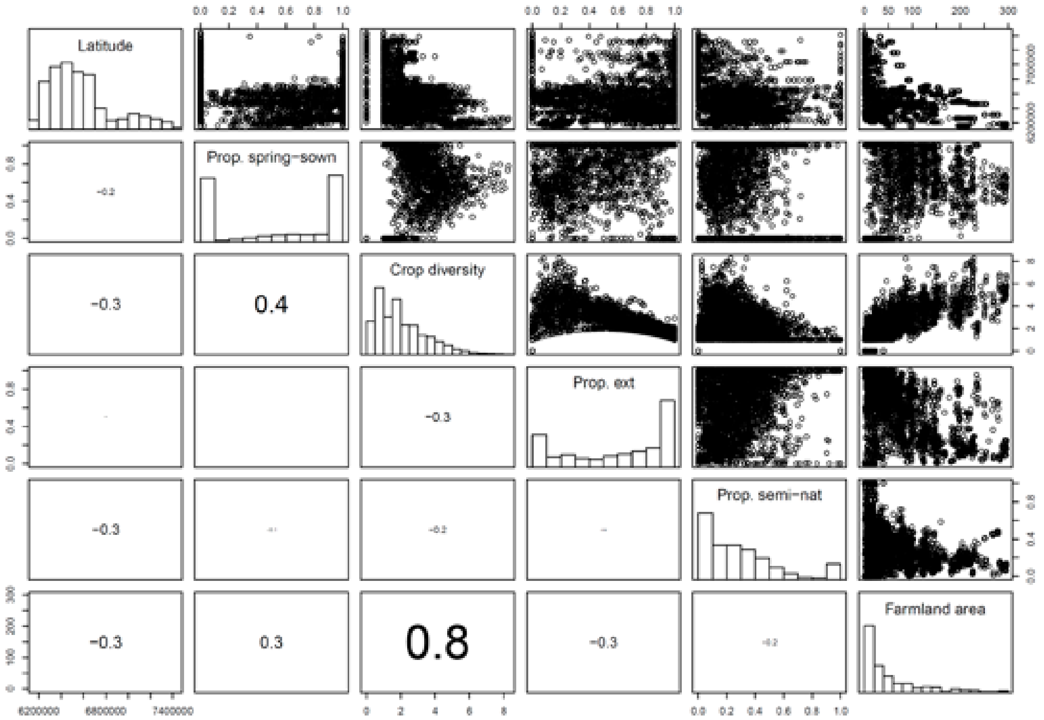

Figure A1.1. The distributions of, and pairwise correlations among, the predictors included in the model. Above the diagonal are scatterplots, below the correlation coefficients (with size indicating absolute strength). Along the diagonal are the histograms of each variable.

The response – Bird counts

Routes

Bird count data came from line transect counts in the Fixed routes scheme (see above). Out of a total of 716 routes, we included the 327 routes that were surveyed during the period 1999-2014 and had farmland (LPIS) within 200 m from the line transect at any point during this period (Fig. A1.2). Not all routes were surveyed all of these 16 years; the mean (and median) number of years surveyed was 11 (range 4–16).

Bird species

We included all 14 species within FBI plus the two species that are part of the index for the Swedish Environmental Objective no 13 "A varied agricultural landscape". Thus, in total we had 16 farmland bird species (Table A1.1). The routes in which each of the species have been counted at least once during the period 1999-2014 can be found in figure A1.3.

Post-modelling processing – correlations in species abundance

In the previous sections we have mainly referred to associations in species abundances among sites as covariance between species, but co-variances can easily be converted into correlations (Pollock et al. 2014). We will in the following use correlations rather than co-variances.

Pollock et al. (2014) present an equation (eqn 4 in the paper) for converting the estimated coefficients (habitat dependences) into a species correlation (covariation) matrix. This matrix describes the correlation in species abundance that is due to "the environment" and will henceforth be referred to as environmental correlation. In our case "the environment" is the predictors in the model. Compared to the correlation matrix estimated in the joint model, which measures the residual correlation between species after controlling for effects of predictors, the environmental correlation matrix measures the correlation between species *due to* the predictors and can thus be viewed as complementary to the residual correlation matrix.

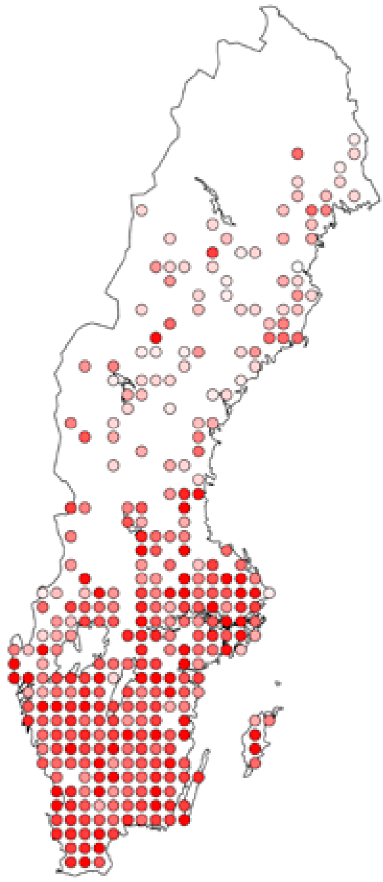

Figure A1.2. Map of all 327 Fixed routes included in the analysis (i.e. being surveyed at least once during 1999-2014 and having farmland). The darker the red the more years a route was surveyed (white = 4 years, red = 16 years).

Both provide important information (Pollock et al. 2014); large absolute values of residual correlations between species may indicate that species interact through, for example, competition but they may also be due to unmeasured factors affecting species in similar, or opposite, ways. Strong environmental correlations in relation to the residual correlations suggest that the predictors included in the model are in fact influential enough to cause correlational patterns in abundance. The environmental correlations can also be used to group species with common associations to the predictors. By looking at trait characteristics of species that are grouped together and trying to discern patterns of how they respond to predictors, we might find further clues about what drives the association between farmland birds and land-use (see further below).The main effect of latitude was not included among predictors when calculating environmental correlations. We are not interested in how birds co-vary due to latitude as this is mainly a result of general distributional patterns. Rather, our focus is on how birds co-vary due to land management. However, we do include the interactions between latitude and the other predictors in this analysis since we are also interested in how effects of land management change along latitude.

As mentioned, to help interpreting the results of habitat dependence we could use the environmental correlations to group species according to their land-use dependence. This was done using cluster analysis based on the environmental correlation matrix. We translated the environmental correlation matrix into a dissimilarity matrix by taking 1 - the correlations and dividing the result by 2 to get it on a 0 – 1 scale. Hierarchical agglomerative clustering with complete linkage was then performed based on this dissimilarity matrix using function hclust in R (R Development Core Team 2009). We set the cut-off dissimilarity value for delimiting clusters to 0.125 which corresponds to a positive correlation of 0.75, i.e. (groups of) species having a correlation of less than 0.75 with other (groups of) species where considered distinct clusters.

Figure A1.3. The maps show from which routes each species have been registered in 1999-2014. Strength of red in filling is a relative measure of abundance between 0 (white) and 1 (red) calculated by dividing all abundances with maximum abundance, where abundance is the mean over the survey years.

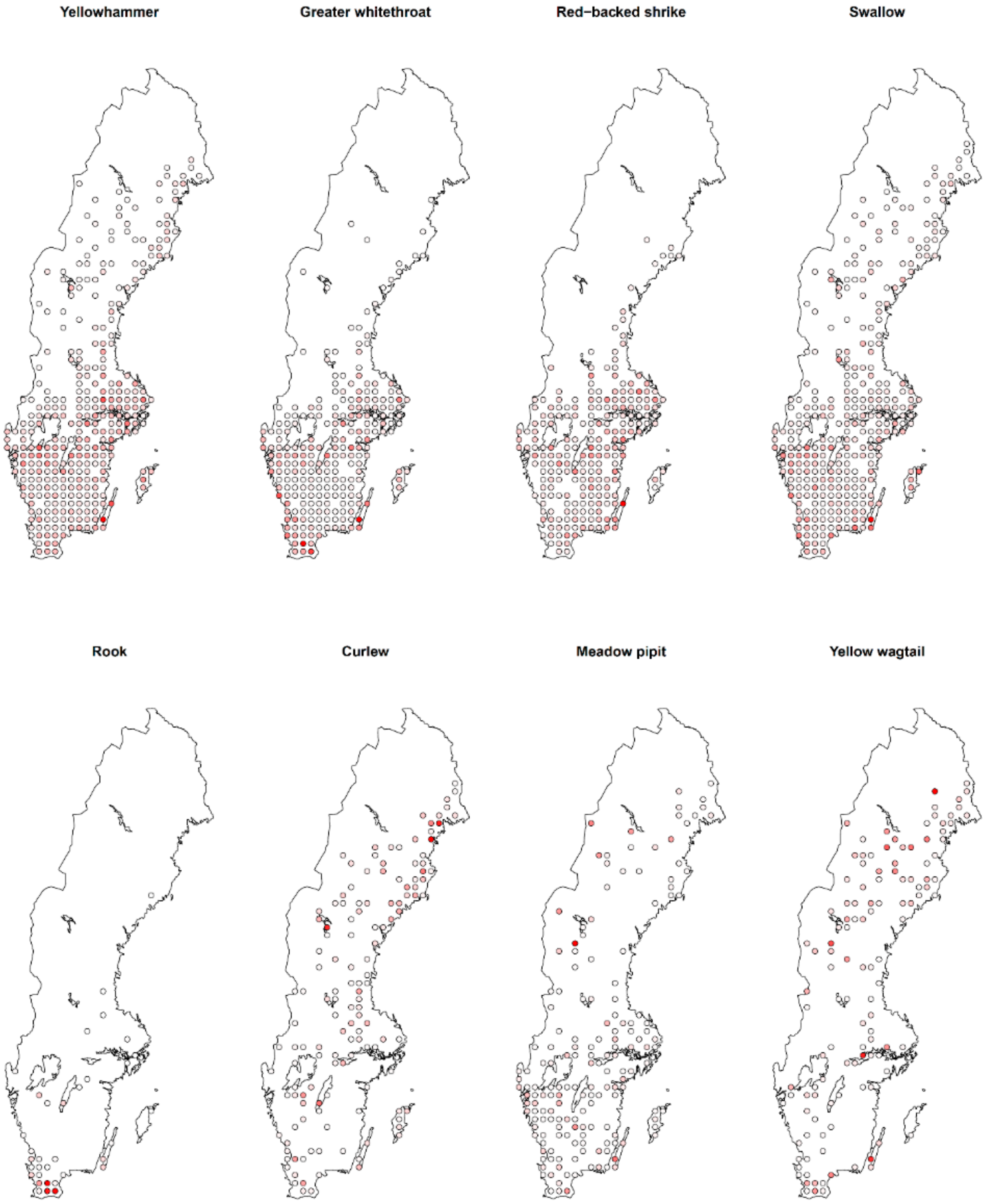

Figure A1.3. *(Continued)*

Reduced dataset

When analysing large and spatially extensive datasets, hidden collinearities or other spurious patterns may cause interpretational problems. Whether collinearities are a problem using our data is not clear, since variance inflation was rather low. Nevertheless, there might still be associations between measured and non-measured variables or other hidden patterns. For example, for some of the variables used, proportions that could not be calculated because the denominator is zero were set to zero. This was e.g. the case for proportion spring-sown crops, where 35% of the dataset had no annual crops at all. This treatment of the non-calculable cases might affect our measure of collinearities as well as our interpretation of the results. We therefore decided to also run the model on a reduced dataset where we as much as possible tried to minimize collinearities between predictors (cf. Fahrig et al. 2011). The following sub-setting of the original dataset was performed to arrive at a reduced dataset:

First, only routes south of latitude (RT90 Y-coordinate) 6736000 and with at least 10% farmland was included. Several species (Yellow Wagtail, Meadow Pipit) have a significant part of the population outside farmland particularly in the northern part of the country such that spurious correlations between these habitats and small areas of farmland in northern routes might influence the analysis. Including only routes with at least 10% farmland (32 ha) will allow more combinations among land-use variables. For example, it is difficult to have more than one or two crops in a smaller area of farmland. This step resulted in a dataset of 117 routes and 1469 observations. Second, we removed routes with less than 2 effective crops (Shannon diversity<2), resulting in 108 routes with 1145 observations. The second step also meant that all routes with no annual crop was removed allowing calculation of not only proportion spring-sown crops but also the other land-use proportions for all remaining routes. Finally, we removed 5 routes with less than 3 yearly visits resulting in a final reduced dataset of 103 routes and 1137 observations to improve our ability to estimate route variability (Fig. A1.4). Variance inflation among predictors were in this dataset reduced to a maximum of 2.00 (proportion extensive crop; Fig. A1.5). All results from the analysis of the reduced dataset will not be explicitly presented in the text, but comparisons between results from the full and reduced dataset will be presented for each land-use predictor below. Clearly, results where similar and strongly correlated between the two analyses.

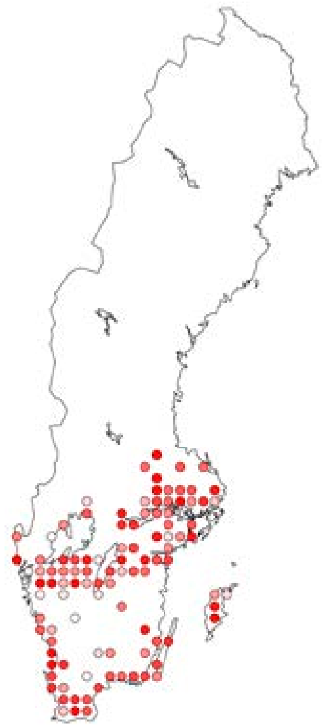

Figure A1.4. Map of the 103 Fixed routes included in the analysis of the reduced dataset. The darker the red the more years a route was surveyed (white = 3 years, red = 16 years).

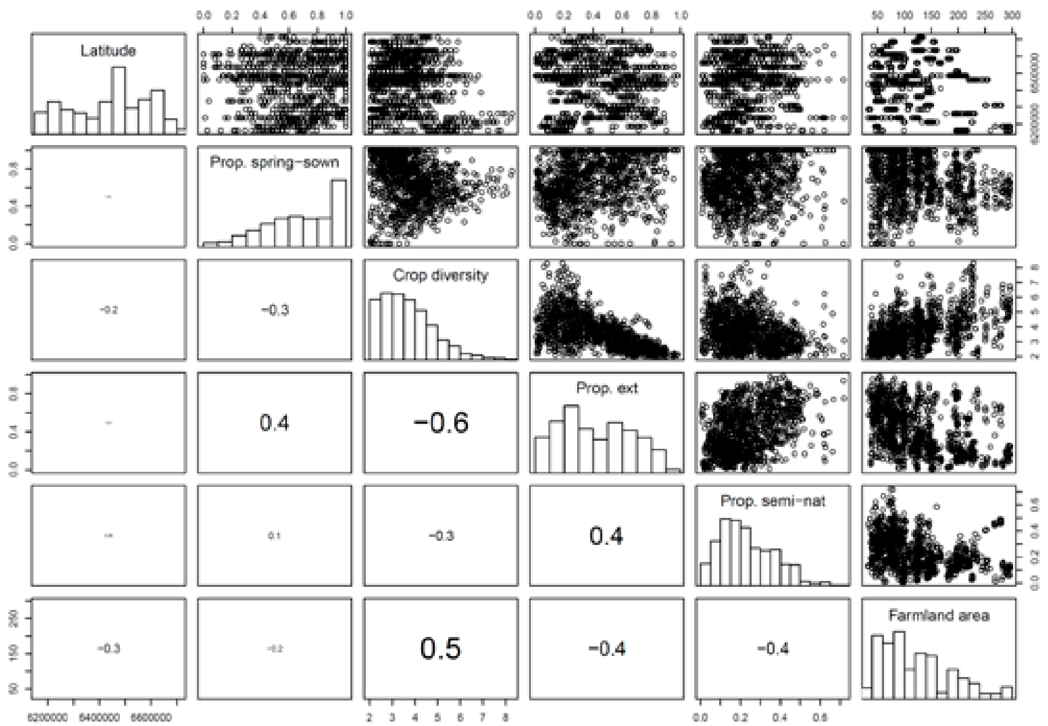

Figure A1.5. The distributions of, and pairwise correlations among, the predictors included in the model using the reduced dataset. Above the diagonal are scatterplots, below the correlation coefficients (with size indicating absolute strength). Along the diagonal are the histograms of each variable.

Results and interpretations

How to interpret model parameters

To help understanding the outputted estimates of parameters from the model (e.g. as presented in figure A1.7), we here provide a short tutorial. Two aspects of the modelling are central for this understanding.

First, abundance is modelled on the log scale which means that the parameters from the model are also on the log scale. On this scale the model tells us that the effects of predictors are additive, that is, they are added together to explain species abundance. A model that is additive on the log scale becomes multiplicative when transformed (back) to the data scale. So, if we back transform our parameters by exponentiation using the natural number *e* as base (we have used the natural logarithm in the models so back transforming means taking *e* raised to the power of the parameter, $e^{\text{parameter}}$), we will get the *proportional* effect of the predictor. For example, if we get an estimated parameter as 0.5 it corresponds to a proportional effect of $e^{0.5} \approx 1.65$ which in turn can be translated to a percentage change of (1 – 1.65) * 100 = 65% increase. A parameter of zero means a proportional change of $e^{0} = 1$ (i.e. no change or (1 – 1) * 100 = 0% change) and negative values translates to proportional decreases, e.g. a negative value of -0.5 translates to $e^{-0.5} \approx 0.61$, (1-0.61) * 100 = 39% decrease. Interactions should similarly be interpreted as multiplicative (proportionate) changes to the main effects when moving 1 standard deviation along the latitudinal gradient, e.g. an interaction between latitude and farmland area estimated to 0.5 means that if moving approximately 289 km (the standard deviation of latitude, Table A1.1) northwards the (main) effect of farmland area should be multiplied by $e^{0.5} = 1.65$.

Second, the predictors in the model were standardized prior to analysis by, for each predictor, subtracting values with their mean and dividing by their standard deviation. The means and standard deviations are calculated on the dataset used, that is, on the land use of the included 327 routes. This means that the predictor values in the modelling are expressed in the unit of standard deviations, and concomitantly, the coefficients describe how abundance change if the respective predictor is changed one standard deviation. For example, the standard deviation of farmland area among included routes was approximately 63 ha (see Table A1.1). Thus, the coefficient for farmland area describes how much abundance change if farmland area is increased by 63 ha. One advantage of the standardization is that the size of the estimated coefficients can be compared between predictors and tell us something about their relative importance. Each coefficients describe how much abundance change if we change the predictor by one unit of how much it varies in the routes included. This is of course a slight simplification as predictors are expressed on different scales to begin with (hectares vs. proportions vs. effective number of crops) and changes will therefore express different things. Further, they cannot be changed independently of each other. Nevertheless, with these caveats in mind, the magnitude of the coefficients tell us something about its importance.

The predictors of farmland bird abundance

The importance of the different land-use variables on farmland bird abundance is shown in figure A1.7 and discussed below. Figures of the full samples from posterior distributions of all species' land-use dependence can be found in Appendix 2 (Figs A2.2-A2.6.). We will not discuss the main effect of latitude as it is not the focus of our analyses but we do discuss the latitudinal gradient in effects (i.e. how effects change along latitude) of the other variables where applicable as regional differences in effects are of interest.

First, however, we will discuss the estimates of correlations between species abundances. We found several significant positive and negative *residual* correlations among species (i.e. co-variation among species that is not directly due to the predictors in the model, Fig. A1.6A). A majority of these were positive with a total average pairwise residual correlation of 0.13 (CI = 0.09 – 0.18). As already described, these correlations result from either direct interactions between species through facilitation (if positive) or competition (if negative) or from common responses to factors that were not modelled. We cannot separate these effects with the current modelling but both probably contribute in our case. Routes apparently differ in important aspects not measured, as suggested by the variance in total abundance on routes. The standard deviation (on log-scale) of route total farmland bird abundance was 0.53 (CI = 0.46–0.59), a value almost on par with the effect of farmland area (see hatched green vertical line in Fig. A1.7), indicating that route characteristics not included in the statistical model, some of which may be related to farmland quality, play an important role for farmland bird abundances.

Variation among years was lower (log-scale mean = 0.06, CI = 0.03–0.08, hatched red vertical line in Fig. A1.7) and part of its variation will be due to the trend in farmland bird abundance discussed above.

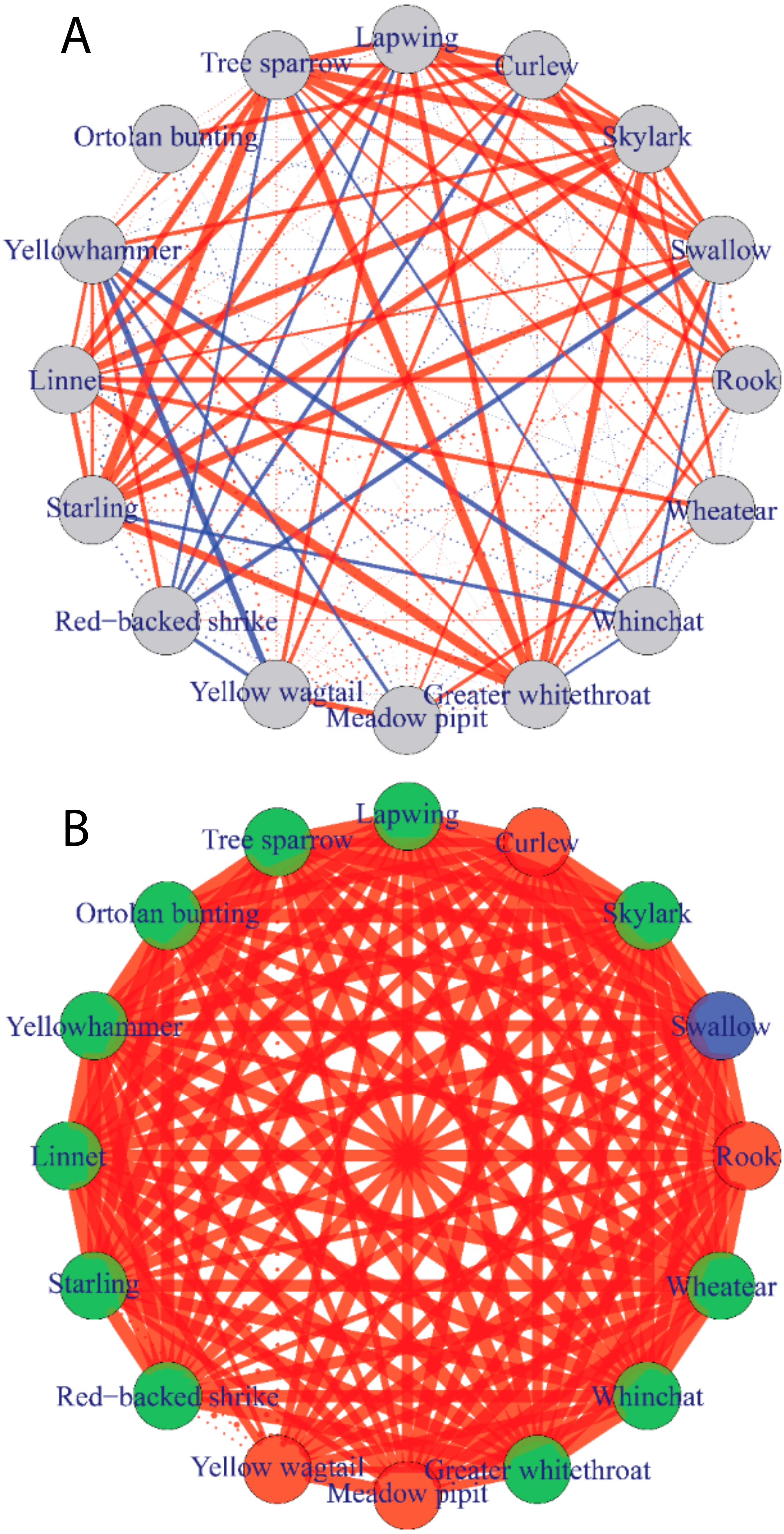

Figure A1.6. These network diagrams show how the different farmland bird species relate to each other in terms of A) residual correlations i.e. correla¬tions left after controlling for predictors and B) environmental correlations i.e. correlations due to predictors. Red lines show positive correlations, blue show negative. Line thickness shows the strength of the between-species correlations. The dotted lines show non-signifi-cant correlations. In B) the colouring shows group membership from the cluster analysis (Fig. 18).

Even though there clearly are factors affecting farmland birds that we were unable to capture in our model, the estimated environmental correlations (i.e. co-variation due to the included predictors except main effect of latitude) indicate that included factors explained a relatively large amount of the covariation between species (log-scale mean environmental correlation = 0.78, CI = 0.70–0.85), Fig. A1.6B). We shall see below, however, that the contributions to the environmental correlation are not equally shared by these factors.

Farmland areas is most important

Farmland area stands out as the most important predictor with estimates vastly exceeding the other variables (Fig. A1.7, note, the figure does not show the predictor latitude, which also showed large effects on abundances). The effect of farmland area also exhibited the largest uncertainties, likely due to a) that the importance of farmland depends on what other land-uses are also present on routes and this may vary over other gradients than latitude (variation along the latitudinal gradient are covered by the Latitude:Farmland area interaction) and b) the variation in quality of farmland may not be covered by the other land-use variables included in the model.

The farmland effect is strongest for Skylark, a true farmland specialist, and other species rarely found outside farmland (e.g. Linnet and Rook) are also among the top farmland dependents. Weakest relationship to farmland area is shown by Barn Swallow, possibly reflecting this species' nesting requirements (need buildings and other man-made structures, including horse farms). Farms with animals may disproportionally be located in areas with less farmed area than in the plains dominated by plant production.

Due to its strong influence on abundance of farmland birds, farmland area is also the most influential predictor in the clustering of species (Fig. A1.8). In fact, the three distinct groups identified in the cluster analysis had most dissimilar responses to the latitudinal gradient in farmland dependence (Latitude:Farmland area interaction, Fig. A1.7) indicating that this interaction was the main driver in the clustering. A large group topped by Tree sparrow, European Starling and Skylark, and with Whinchat and Wheatear at the bottom, showed the strongest positive latitudinal gradient. Possibly, species with stronger positive latitudinal gradients have fewer alternative habitats in the forest-dominated farmland routes in the north.

Barn Swallow constitutes a group of its own. European Swallow was the species showing least farmland dependence (discussed above) and the dependence does basically not change along latitude.

The most distinct cluster is formed by Rook, Meadow Pipit, Eurasian Curlew and Yellow Wagtail. These four species showed quite the opposite pattern in latitudinal gradient as they seem less dependent on the amount of farmland further to the north. For the Rook, this might be explained by its very restricted distribution to the south. There is basically no information available to estimate the interaction; this is also shown by the large uncertainties around the estimate. For the other species in this group the most plausible explanation should be that they are mostly found in alternative habitats in the north. Curlews, Yellow Wagtails and Meadow Pipits to a varying extent occur also on mires, bogs and forest clear-cuts. Even if we only included routes with farmland in our analyses, a large proportion of routes in northern Sweden have plenty of these alternative habitats. Similar, arguments can be put forward for the two species in the first group (Wheatear and Whinchat) having the lowest positive latitudinal gradient. These live in similar habitats in the north but the gradient is still positive since they have also a significant proportion of their population in

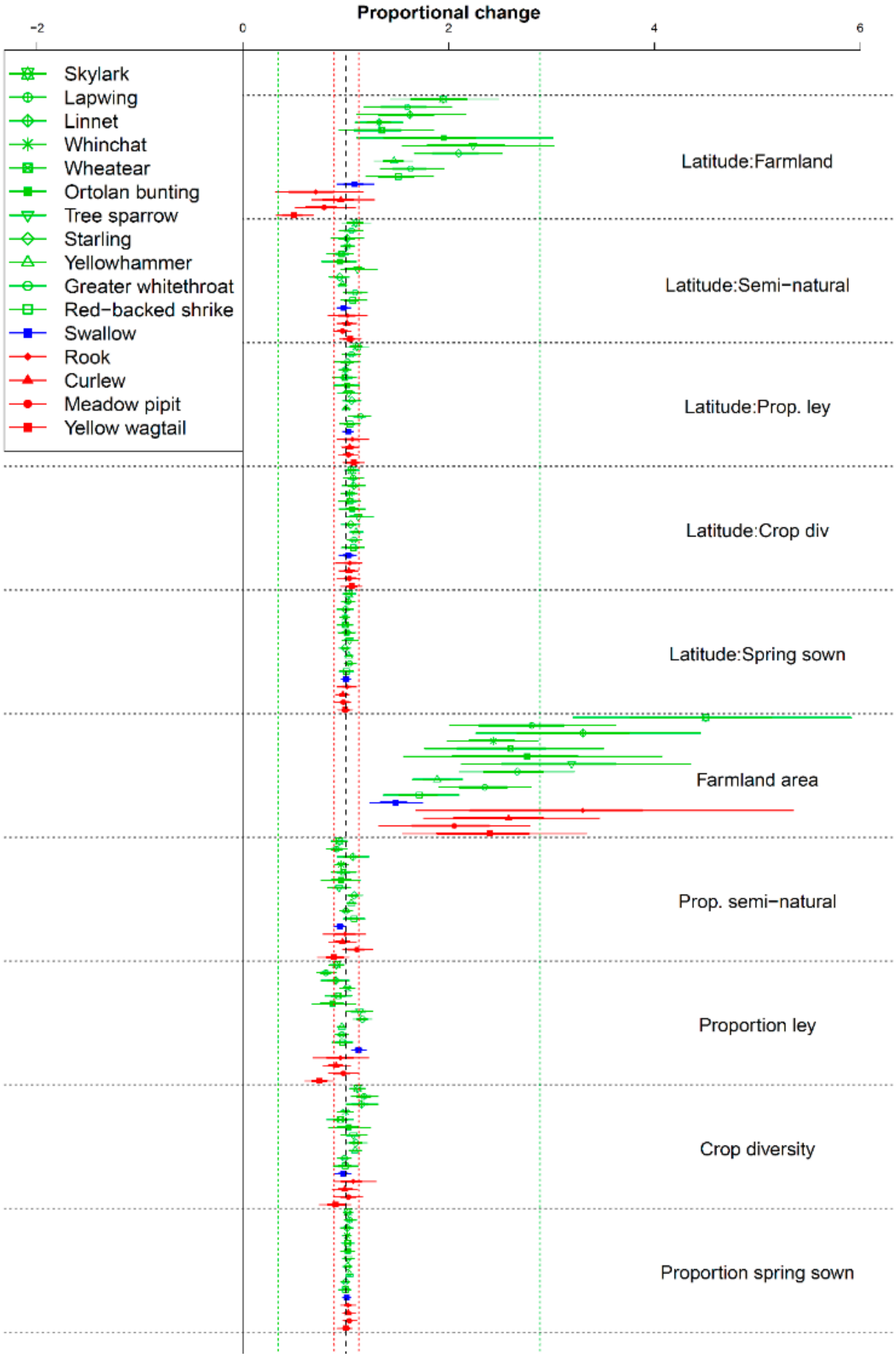

Figure A1.7. Coefficient estimates for predictors in the model (main effect of latitude is excluded for clarity). Coefficients are expressed as proportional change and the black vertical hatched line show a proportional change of 1 (i.e. no change). Colon (:) in effect names indicate interaction. The coefficient values (points) also include 68% (thick lines) and 95% (thin lines) CI. The symbol colours show group membership from the cluster analysis (Fig. 18). The vertical red and green lines show the 95% interval of year and route variation respectively (expressed as twice the estimated standard deviation on the proportional scale).

the south. One exception to this general pattern might be the Ortolan Bunting which to a large extent uses clear-cuts as an important alternative habitat but still exhibit a strong positive latitudinal gradient. In this case, the pattern is probably driven by the fact that in the southern half of Sweden the Ortolan Bunting is extremely rare irrespective of the amount of farmland (i.e. there is no relationship between farmland area and counts of Ortolan Bunting). In the north, the few routes with relatively high counts of Ortolan Bunting have large areas of clear-cuts where most of the buntings are found and these happen to also have reasonably large areas of farmland. We should, however, be careful not to over-interpret the results for the Ortolan Bunting as data for this species is scant.

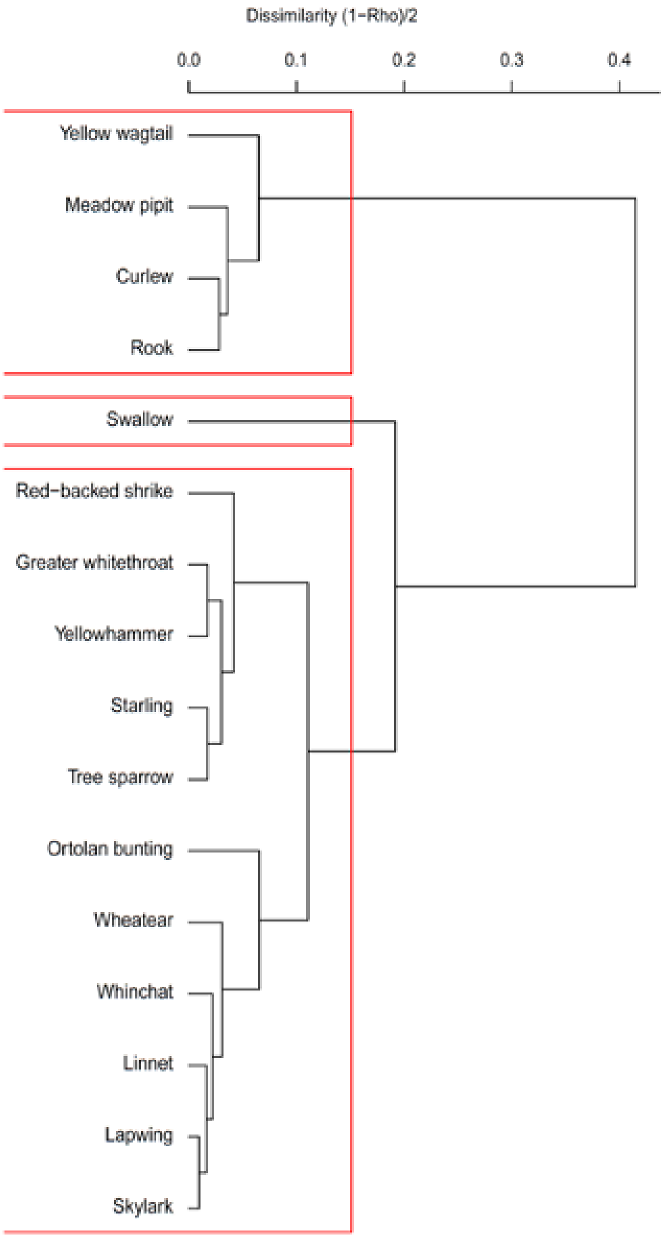

Figure A1.8. The dendrogram illustrates which farmland bird species are most similar to each other in terms of how their abundance is affected by the various farmland variables (based on the cluster analysis of the environmental correlations). Distinct clusters are delineated by red lines.

The patterns shown in the analysis of the full dataset is somewhat changed in the analysis of the reduced dataset (Fig. A1.9). The main effect of farmland area is slightly reduced but still very strong. Notably, the main change is shown by those species known to inhabit alternative habitats further north (Yellow Wagtail, Meadow Pipit, Curlew, Whinchat, Wheatear) whose dependence on farmland area is more positive in the reduced dataset in relation to the other species and this relationship is strengthened rather than reduced along latitude. Thus, the negative latitudinal gradient in farmland dependence exhibited by these species is likely not due to farmland being less valuable in the north but rather due to an artefact of routes in the north having more of these alternative habitats (mires, clear-cuts etc.) where these birds apparently occur and are common. Availability of alternative open habitats (e.g. large mires and clear-cuts) in routes at high latitudes in the reduced dataset is possibly low where non-farmland is mostly forest, hence, the open habitat of farmland is more important at these sites.

In summary, without doubt, the amount of farmland available to farmland birds is of great importance both as strongly affecting species specific abundances and as a driver of covariation among species. Abandonment is hence detrimental to the persistence of the farmland bird community in large parts of Sweden. Alternative habitats exist for some more generalist species, especially in the northern half of Sweden, and this is also reflected in our analyses. Several species showed a reduced farmland area dependence towards the north where they tend to utilize other habitats than farmland (not necessarily due to lower quality of farmland *per se*). Additionally, the Barn Swallow had the lowest farmland dependence and this species find nest sites and suitable foraging grounds in association with farms with animals, which are often found in more extensive areas (low proportion of farmland). Nevertheless, many species are obligate farmland birds and further abandonment and/or deterioration of the farmland habitat, especially in regions with no alternative habitats, are likely to cause further declines in the Farmland Bird Index.

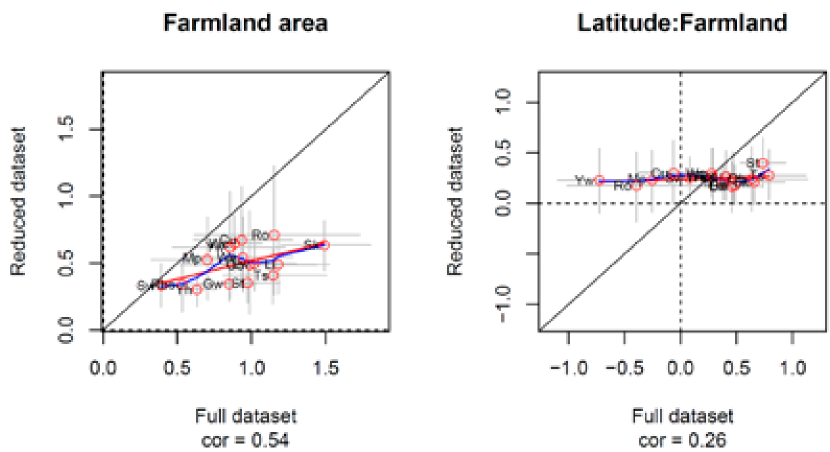

Figure A1.9. Comparison of estimates of dependence of farmland area between analyses using the reduced vs. the full dataset. The correlation between the results from the two datasets are presented below each figure. Red line show fit of a linear regression and blue line the fit of a loess (local polynomial regression). Confidence intervals (HPD) are shown in grey, black solid line show 1:1 relationship. Abbreviated species names are: Sk=Skylark, Lw=Lapwing, Li=Linnet, Wh=Whinchat, We=Wheatear, Ob=Ortolan Bunting, Ts=Tree Sparrow, St=Starling, Yh=Yellowhammer, Gw=Greater Whitethroat, Rbs=Red-backed Shrike, Sw=Barn Swallow, Ro=Rook, Cu=Curlew, Mp=Meadow Pipit, Yw=Yellow Wagtail.

Importance of the other land-uses

The other predictors included in the model had comparatively lower influence on farmland bird abundance. This can be illustrated by recalculating the environmental correlations, but excluding farmland area and its interaction with latitude in the calculations (Fig. A1.10). It is apparent that most of the environmental correlations disappear when farmland area is not included (log-scale mean environmental correlation= 0.14, CI = 0.005–0.28), suggesting that the other predictors (i.e. the particular characteristics of farmland) is of less importance. Once again, the residual correlations indicated that there are factors affecting farmland bird co-occurrence that are not modelled, among which there might well be factors describing other aspects of farmland quality or quantity that we cannot capture using the LPIS.

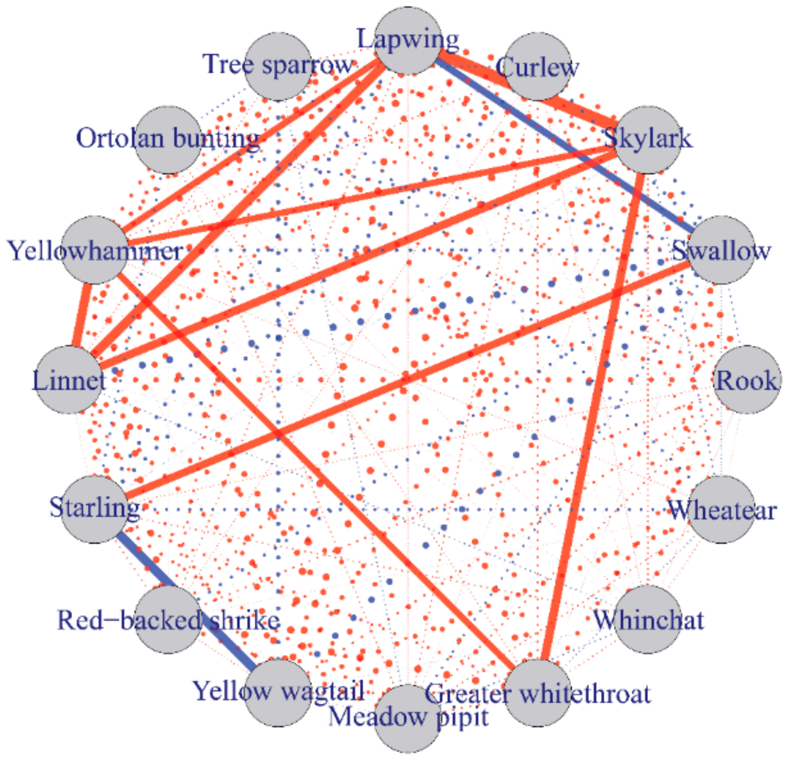

Figure A1.10. This network diagram is similar to the one in Fig. A1.6B, showing how the different farmland bird species relate to each other in terms of environmental correlations i.e. correlations due to predictors. The difference compared to Fig. A1.6B is that effects of farmland area and its interaction with latitude have been excluded when calculating the environmental correlations. Hence, here only the other predictors contribute to environmental correlations and it can be clearly seen that correlations due to these other predictors are much weaker. Red lines show positive correlations, blue show negative. Line thickness shows the strength of the between-species correlations. The dotted lines show non-significant relationships.

Semi-natural habitats

The proportion of semi-natural habitats in the agricultural landscape may be expected to be of significant importance for most farmland birds. Our results showed some support for this hypothesis as species associated with semi-natural pastures (e.g. Red-backed Shrike, Starling, Yellowhammer, Meadow Pipit) showed largely positive relationships to this factor (Fig. A1.7). Also fallows may be important as the two species with the clearest positive signal (Yellowhammer and Starling) are known to readily use these habitats. For many species strongly associated to arable fields (Skylark, Lapwing and Yellow Wagtail), there was generally a negative relationship to the proportion of more natural habitats. Semi-natural pastures in Sweden are for these species probably too densely vegetated with bushes and trees and the potentially positive effect of fallows is probably not strong enough or they do not constitute a large enough part of the semi-natural habitats to overcome this negative effect. In the full dataset proportions semi-natural habitats reach very high proportions in some routes, such that availability of open arable fields is by necessity low. In the reduced dataset, the proportion semi-natural habitats does not exceed 70% giving some room for the presence of some arable fields and open field species did not show negative effects of semi-natural habitats using this dataset (Fig. A1.11). Hence, while semi-natural habitats are generally beneficial, especially for species strongly associated to these habitats, too high proportions in the agricultural landscape might be negative for obligate open habitat species. Somewhat surprisingly, the Barn Swallow showed a negative effect of proportion semi-natural habitat. Once again, this species is strongly dependent on the presence of animals on farms, and specifically the associated buildings and the surprising result may be due to spurious correlations between the proportion of semi-natural habitat and density of buildings in the landscape. The latitudinal gradient in dependence of proportion of semi-natural habitats did not show any general pattern and basically vanished in the reduced dataset.

In summary, semi-natural habitats benefit farmland species specifically associated to such habitats. For species that need large, open habitats (arable fields), too large proportions of semi-natural habitats might be negative as the availability of arable fields where they can nest is by necessity low. The estimated latitudinal gradient did not indicate any major change in dependence of more natural habitats throughout Sweden.

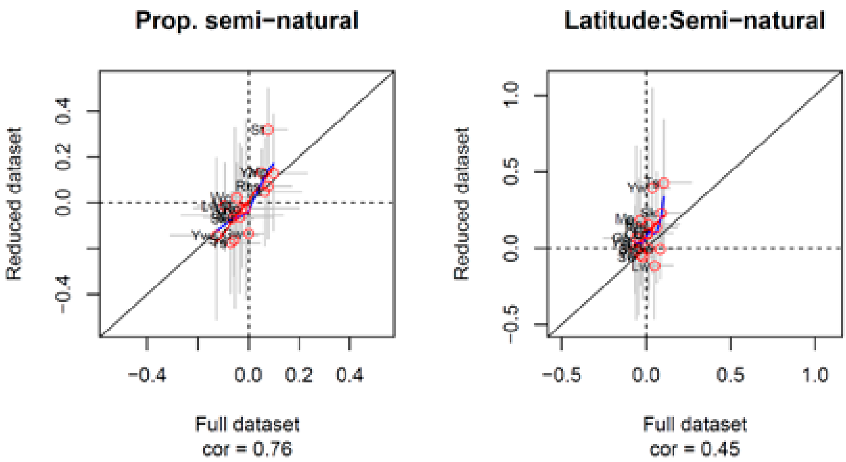

Figure A1.11. Comparison of estimates of dependence of proportion semi-natural habitat (pastures and fallow) between analyses using the reduced vs. the full dataset. The correlation between the results from the two datasets are presented below each figure. Red line show fit of a linear regression and blue line the fit of a loess (local polynomial regression). Confidence intervals (HPD) are shown in grey, black solid line show 1:1 relationship. Abbreviated species names are explained in Fig. A1.9.

Proportion of extensive crops

The proportion of ley on arable fields gave the most variable results in terms of main effects and for many species this pattern was the same throughout Sweden, although across species there was a tendency for more positive/less negative effects further north. Again, Yellow Wagtails stand out as most negatively affected. Other negatively affected species are Skylarks and Lapwings, that is, species common on annually tilled land (at least in the intensive south). European Starlings, Tree Sparrows and Barn Swallows are positively affected by proportion ley. Leys used for grazing are beneficial for European Starlings and these types of leys are probably more common in northern Sweden, possibly explaining the largely positive latitudinal gradient for this species. The Barn Swallow is strongly associated with animal husbandry which use leys for both grazing and fodder production, hence the effect of ley is positive. Although several species in southern to central Sweden seems to be negatively affected by proportion ley, the effect is less negative for many of these in the north where leys may provide the bulk of open field habitats. The same holds for Greater Whitethroat. Estimates of effects of extensive management was quite similar in the reduced dataset although generally less precise (Fig. A1.12). For species common on annually tilled land estimates are still negative and for some almost identical in the reduced data. The interpretation that leys used for grazing are more beneficial for the Starling is supported by the analysis of the reduced dataset. A higher proportion of leys in the more productive agricultural regions is used for fodder production and is more evenly and densely vegetated, possibly of less value for Starlings. Accordingly, in contrast to the analysis of the full dataset where Starling showed strong dependence on leys, in the reduced data this effect was basically zero. The latitudinal gradients in effect may seem on average larger but uncertainties are also larger and hence the pattern is not different from the full dataset. It is still generally positive, a result in line with the idea that leys in the north provide open habitats often associated with animal husbandry to the general benefit to farmland birds.

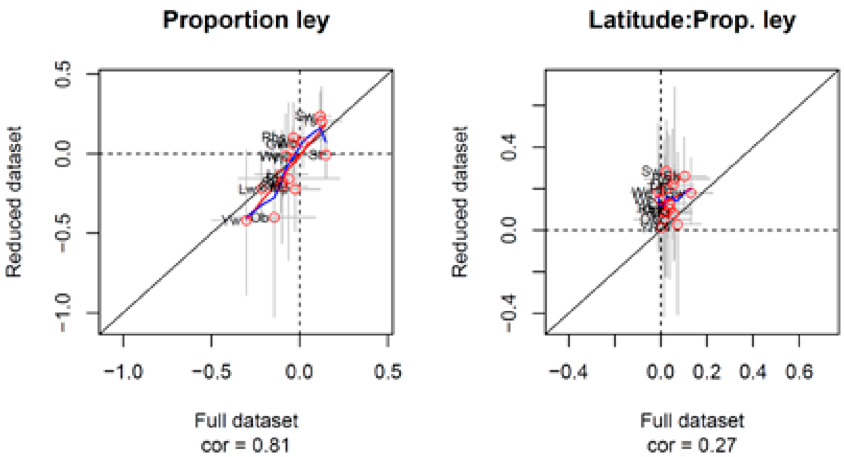

Figure A1.12. Comparison of estimates of dependence of proportion extensive land-use (ley and buffer-zone) between analyses using the reduced vs. the full dataset. The correlation between the results from the two datasets are presented below each figure. Red line show fit of a linear regression and blue line the fit of a loess (local polynomial regression). Confidence intervals (HPD) are shown in grey, black solid line show 1:1 relationship. Abbreviated species names are explained in Fig. A1.9.

In summary, a few species benefit from increased proportions of ley on arable fields in southern as well as in northern Sweden, but for the bulk of species it is largely negative. This pattern is even clearer in the more productive regions of Sweden. The general tendency of leys being more beneficial in the north may be due to it being the only open habitat there, but may also reflect the fact that leys in the north may be of better quality (more extensively managed and associated with grazing livestock).

Crop diversity

Perhaps surprising, considering it being a measure of the character of the arable fields, crop diversity was clearly positive for several species with effects exceeding that of semi-natural habitats (Fig. A1.7). Diversity varied over Sweden where in the northern part the number of effective crops rarely exceeded 2, one of which is likely to be ley. There was a strong correlation between crop diversity and farmland area, a natural consequence of area restriction (there is less room for more than a few crops on a limited area of farmland). Hence, although variance inflation was estimated at reasonable levels, some of these effects may clearly be confounded by other factors. Nevertheless, the species exhibiting significant positive associations with crop diversity are all known to generally use arable fields for foraging and nesting (Skylark, Lapwing, Linnet, Starling and Yellowhammer), suggesting that the effect is at least partly true. Furthermore, there was a strong positive correlation in effects of spring-sown crops between the analyses of the two datasets (Fig. A1.13). Even if effects were weaker, especially Skylark, but also Lapwing and Linnet, showed positive associations to spring-sown crops when the analysis was limited to routes with two effective crops or more (reduced data). There was no latitudinal gradient in effects in the reduced dataset, hence the more positive gradients found in the full dataset indicate that going from having just one crop (often ley) to also include an additional (annual) crop will benefit many farmland species.

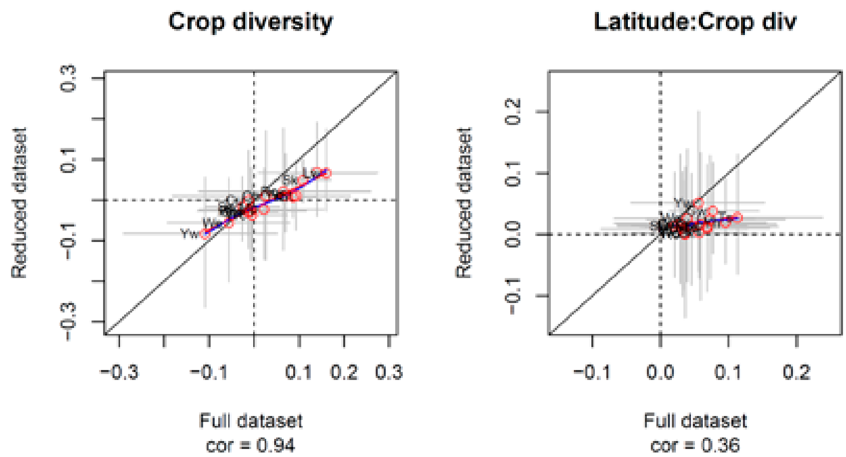

Figure A1.13. Comparison of estimates of dependence of crop diversity between analyses using the reduced vs. the full dataset. The correlation between the results from the two datasets are presented below each figure. Red line show fit of a linear regression and blue line the fit of a loess (local polynomial regression). Confidence intervals (HPD) are shown in grey, black solid line show 1:1 relationship. Abbreviated species names are explained in Fig. A1.9.

In summary, crop diversity is the variable most likely to suffer from collinearity problems in our analyses, however, diagnostics as well as the fact that similar results are found when these problems are minimised suggest that a higher diversity of crops on arable fields may well provide important resources for many farmland birds. A variable structure and composition among crops on the fields may be important by providing alternative habitats for a diverse invertebrate prey community. Arable regions with a high crop diversity hence provide both open areas for finding food and closed ones for shelter. Interestingly, the results suggest that also an increase from one to a few crops may be of value.

Proportion spring sown crops

The proportion spring-sown crops was the least important predictor as judged from our model outcome. The coefficients are low over all and there was basically no latitudinal pattern (Fig. A1.7). One species, the Yellowhammer, did show a clear positive effect. Although this species' habitat requirements may fit well to the characteristics of spring-sown crops, i.e. crops providing sparser swards facilitating feeding and which is often preceded by over-winter stubble with seed resources during winter and early spring, the positive effect was not shown in the reduced dataset (Fig. A1.14). Hence, the positive effect for the Yellowhammer might be due to our handling of proportion spring-sown crops in routes with no annuals crops (setting them to zero). This handling affected routes in less productive (mostly northern) regions more than more productive ones (mostly southern). If any annual crops are present in these less productive regions they are to a large extent spring-sown. Hence, in a non-ignorable part of the full dataset, proportion spring-sown crops is not contrasted against autumn-sown crops but rather against no annual crops at all and, apparently, the Yellowhammer benefit when farmland contain some annual cropping compared to when all land-use is permanent. In the reduced dataset we make sure that annual crops are present and hence the contrast is then more between spring-sown versus autumn-sown and we find no evidence that Yellowhammer prefer spring-sown crops in this dataset. Notably, another species whose habitat requirements should fit well to spring-sown

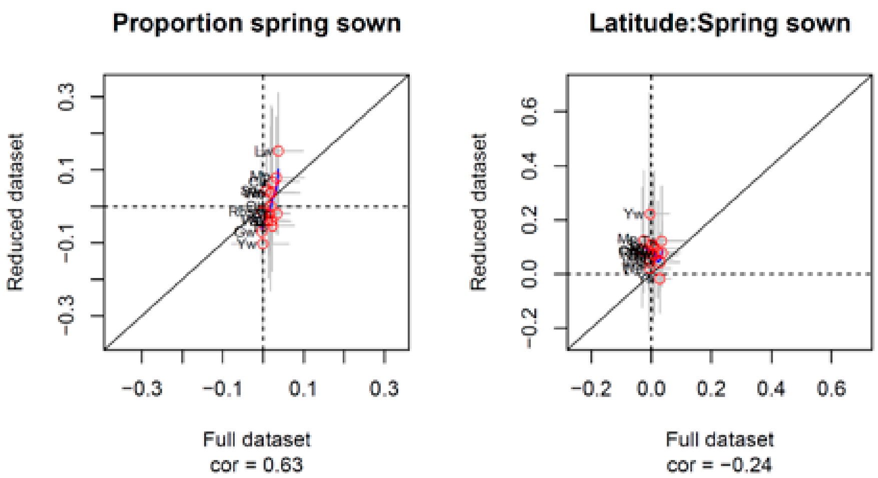

Figure A1.14. Comparison of estimates of dependence of proportion spring-sown crops between analyses using the reduced vs. the full dataset. The correlation between the results from the two datasets are presented below each figure. Red line show fit of a linear regression and blue line the fit of a loess (local polynomial regression). Confidence intervals (HPD) are shown in grey, black solid line show 1:1 relationship. Abbreviated species names are explained in Fig. A1.9.

crops, the Lapwing, showed a tendency for a positive response when using the full dataset and this relationship was strengthened using the reduced data.

In summary, although most species showed small or no effects, spring-sowing might benefit ground nesting arable field species as we found rather clear positive effects on Lapwings. Even though we would also expect that species staying over the winter or arriving early would benefit from the fact that spring-sown fields are generally preceded by over-winter stubble, a species that would conform to this (the Yellowhammer) showed inconclusive results, perhaps due to spurious characteristics of the data. However, we note that some of the benefits from spring sowing accrue during the winter and will not be spatially closely associated with the breeding count data, because resident birds disperse more extensively during the non-breeding season. I.e., there will be aspects of the benefits of spring sowing that we cannot capture using this habitat-association modelling approach.

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Appendix 2

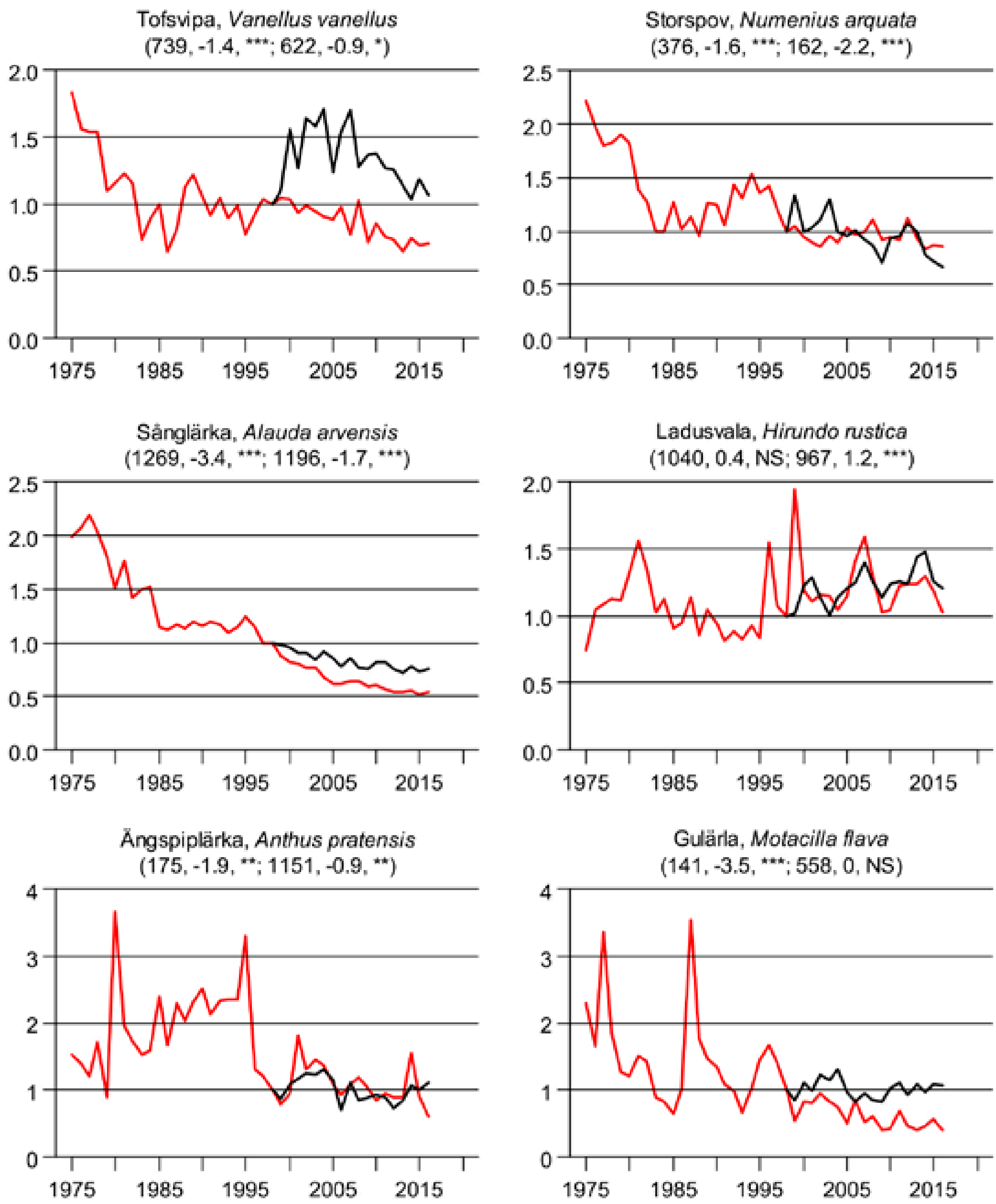

Figure A2.1. Species-specific national trends for the farmland birds included in the two Swedish farmland bird indicators (Table 1, main document). Data come from the Old Scheme (red line) and New Scheme (black line). The population level in 1998 is set at 1. The numbers within brackets are the mean no. of birds observed per year, the average trend (% per year), and level of statistical significance, for the two datasets respectively (separated by semi-colon).

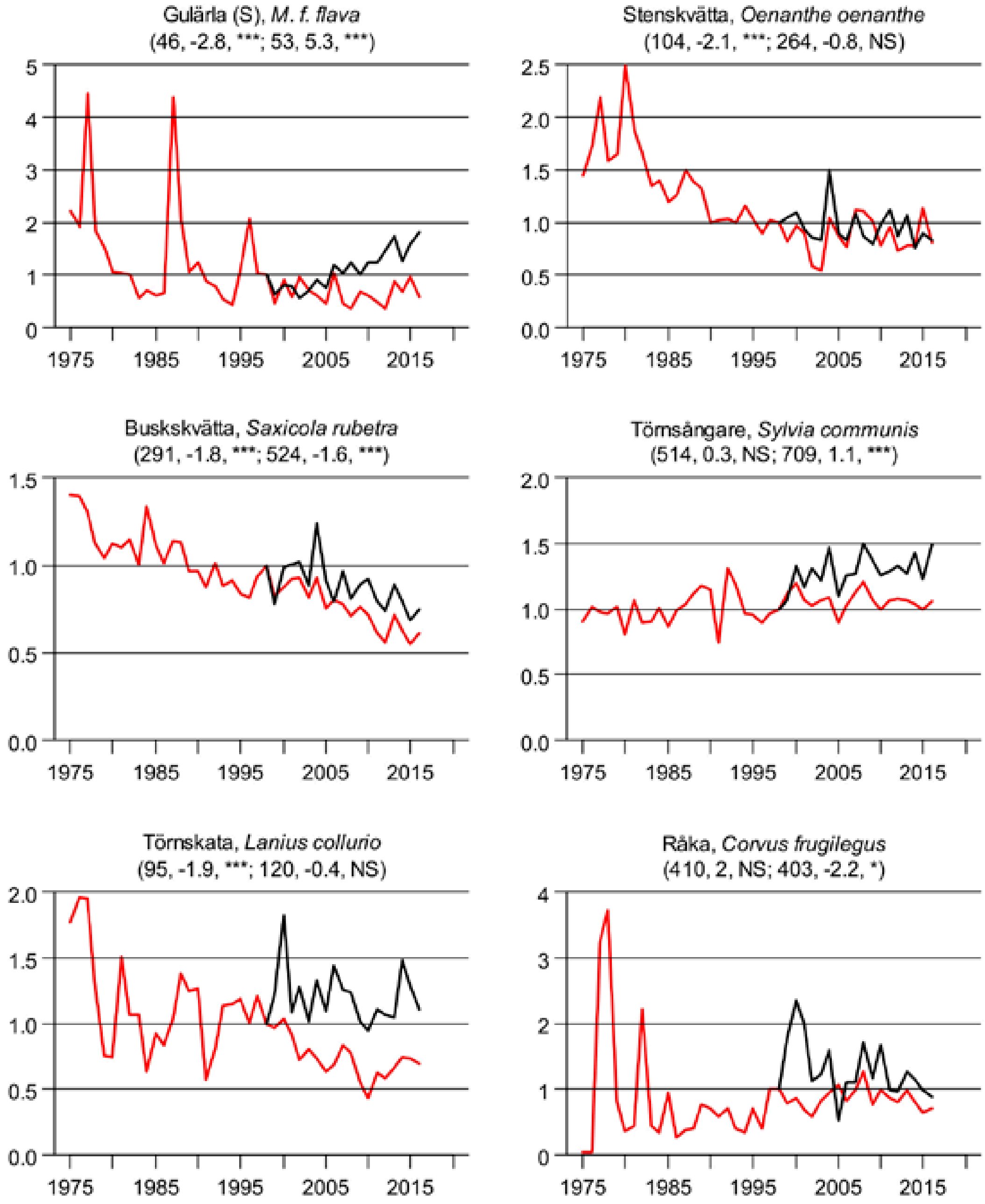

Figure A2.1. *(Continued)*.

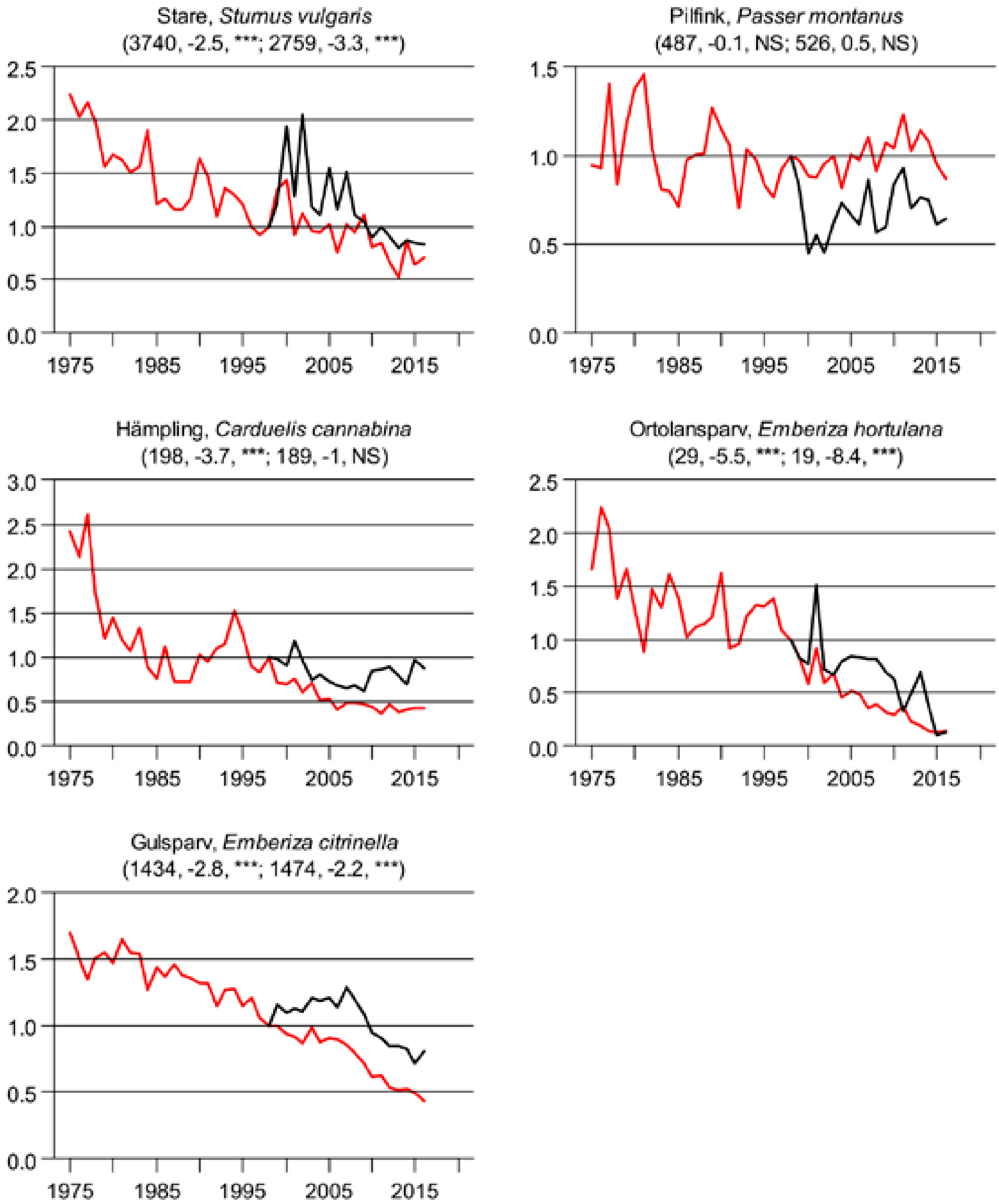

Figure A2.1. *(Continued*).

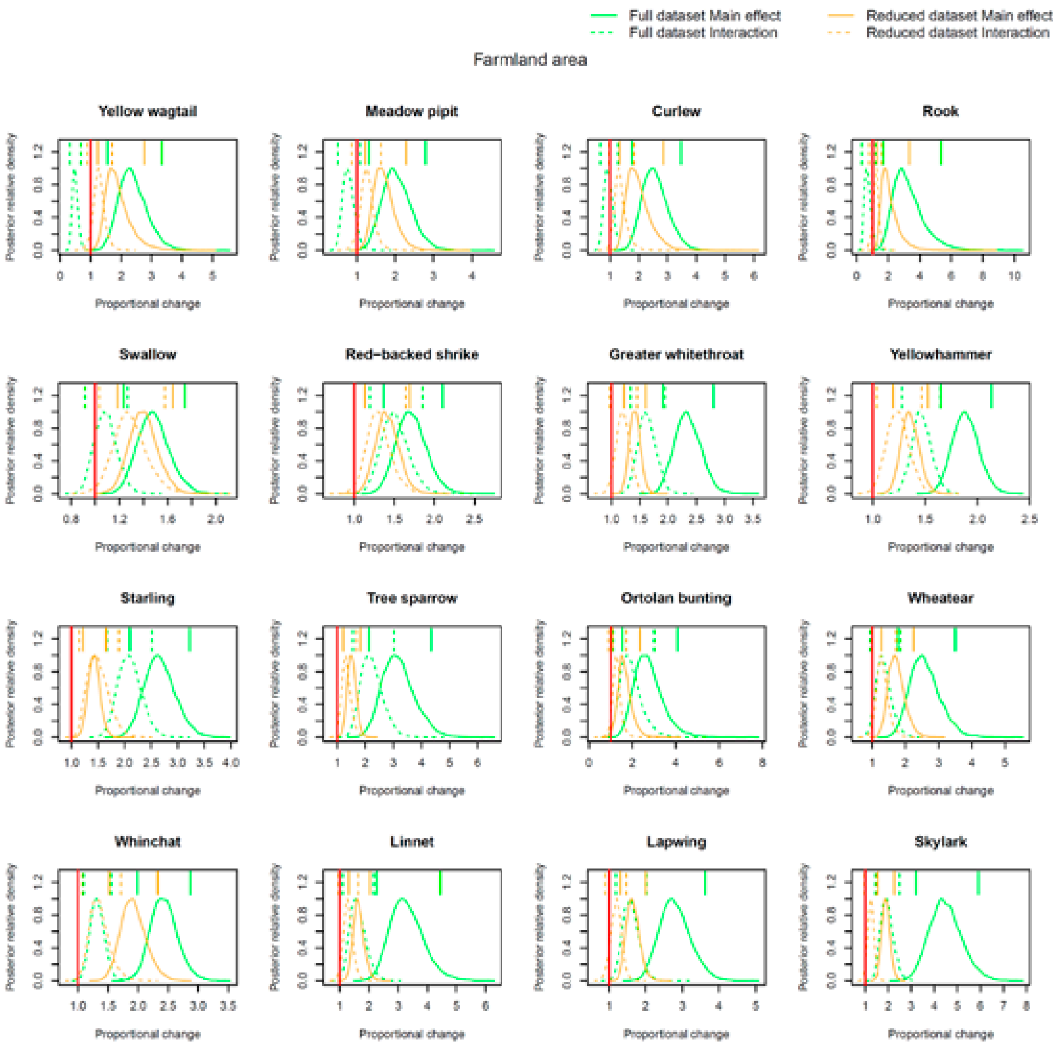

Figure A2.2. Densityplots of samples from the posterior distributions of the effect of farmland area (solid lines) and its interactions with latitude (dashed lines) in the analysis using the full (green lines) and reduced (orange lines) datasets respectively. Samples of effect coefficients from the reduced dataset has been transformed to the same scale as that of the full dataset. Densities have been "normalized" to a maximum of one to facilitate plotting. Red line show a proportional change of one (i.e. no effect). Short lines above the density curves indicate the 95% confidence (credible) interval (HPD).

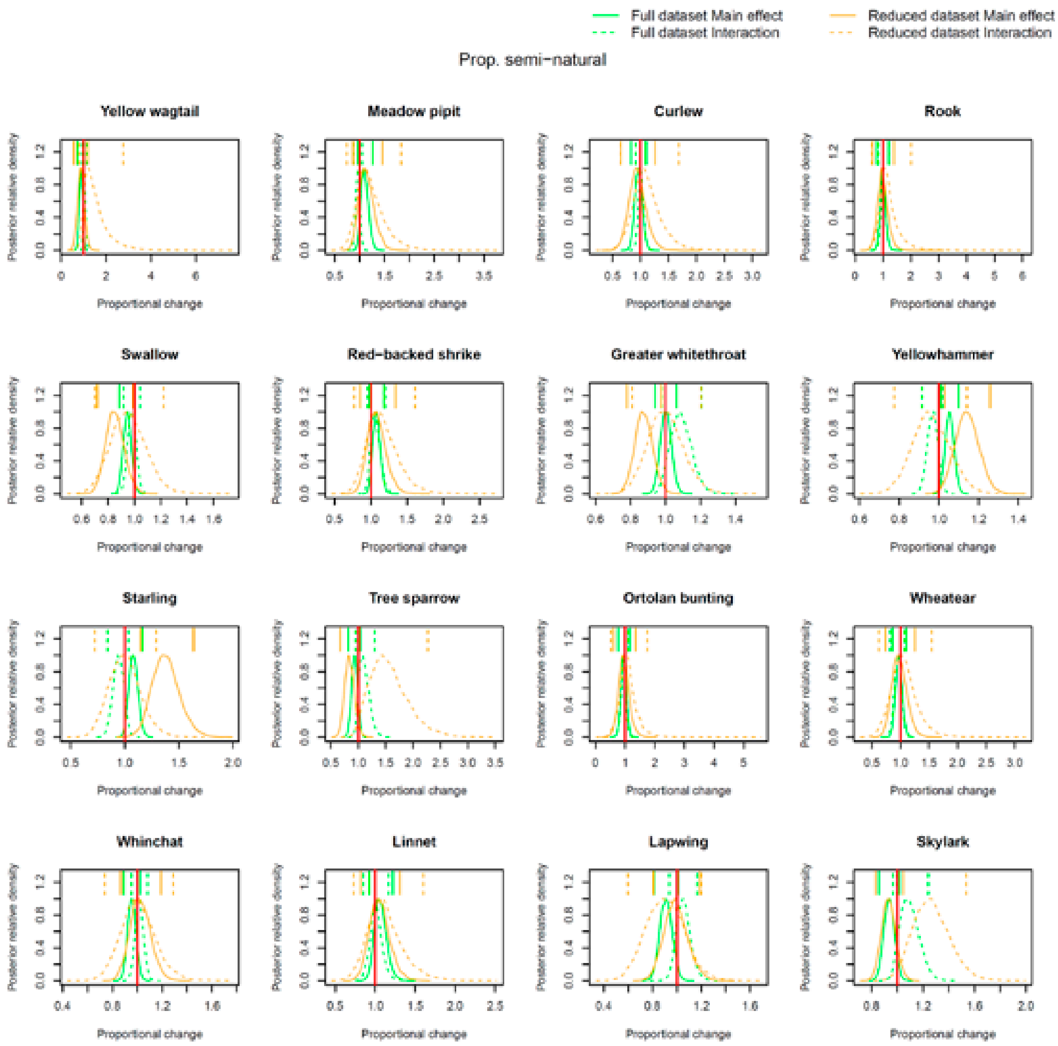

Figure A2.3. Densityplots of samples from the posterior distributions of the effect of proportion semi-natural habitat (solid lines) and its interactions with latitude (dashed lines) in the analysis using the full (green lines) and reduced (orange lines) datasets respectively. Samples of effect coefficients from the reduced dataset has been transformed to the same scale as that of the full dataset. Densities have been "normalized" to a maximum of one to facilitate plotting. Red line show a proportional change of one (i.e. no effect). Short lines above the density curves indicate the 95% confidence (credible) interval (HPD).

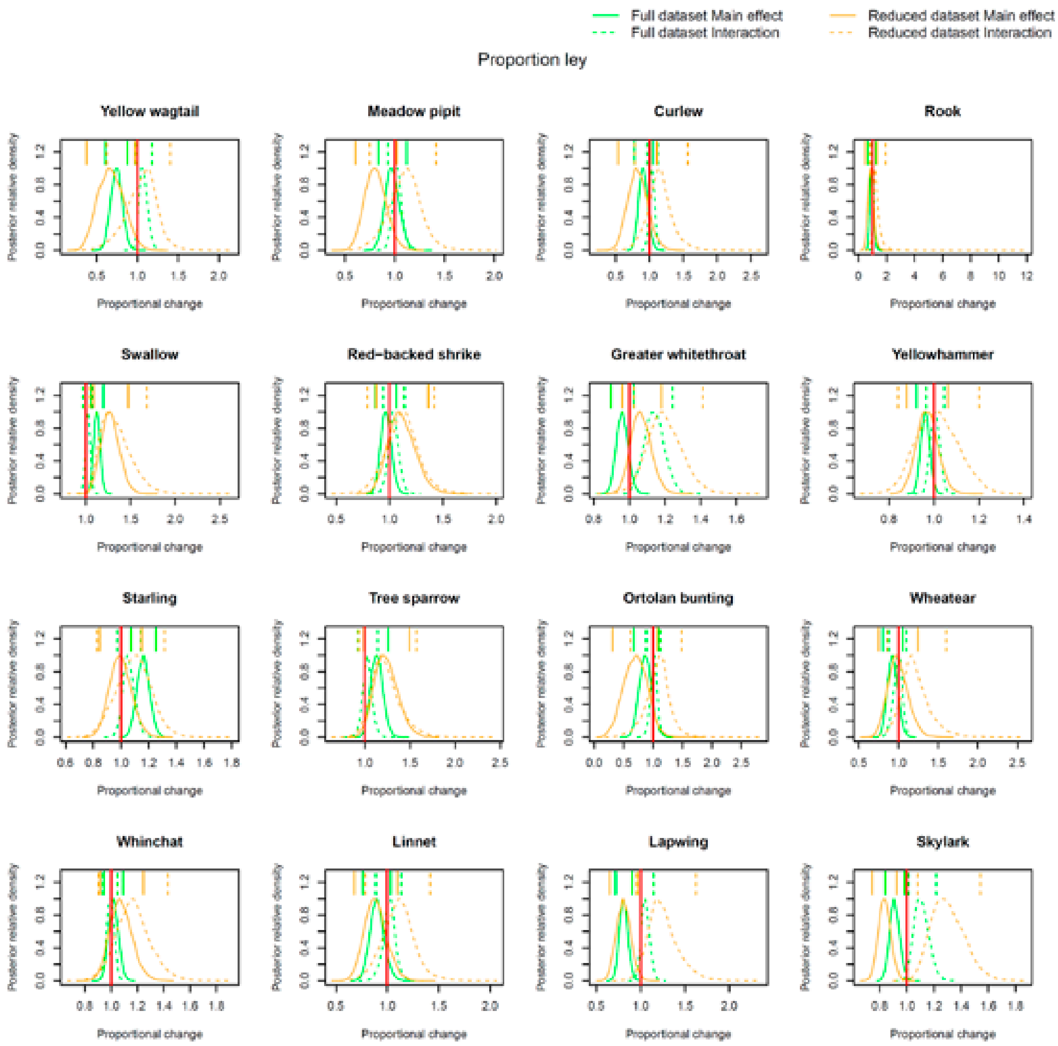

Figure A2.4. Densityplots of samples from the posterior distributions of the effect of proportion extensive crop (solid lines) and its interactions with latitude (dashed lines) in the analysis using the full (green lines) and reduced (orange lines) datasets respectively. Samples of effect coefficients from the reduced dataset has been transformed to the same scale as that of the full dataset. Densities have been "normalized" to a maximum of one to facilitate plotting. Red line show a proportional change of one (i.e. no effect). Short lines above the density curves indicate the 95% confidence (credible) interval (HPD).

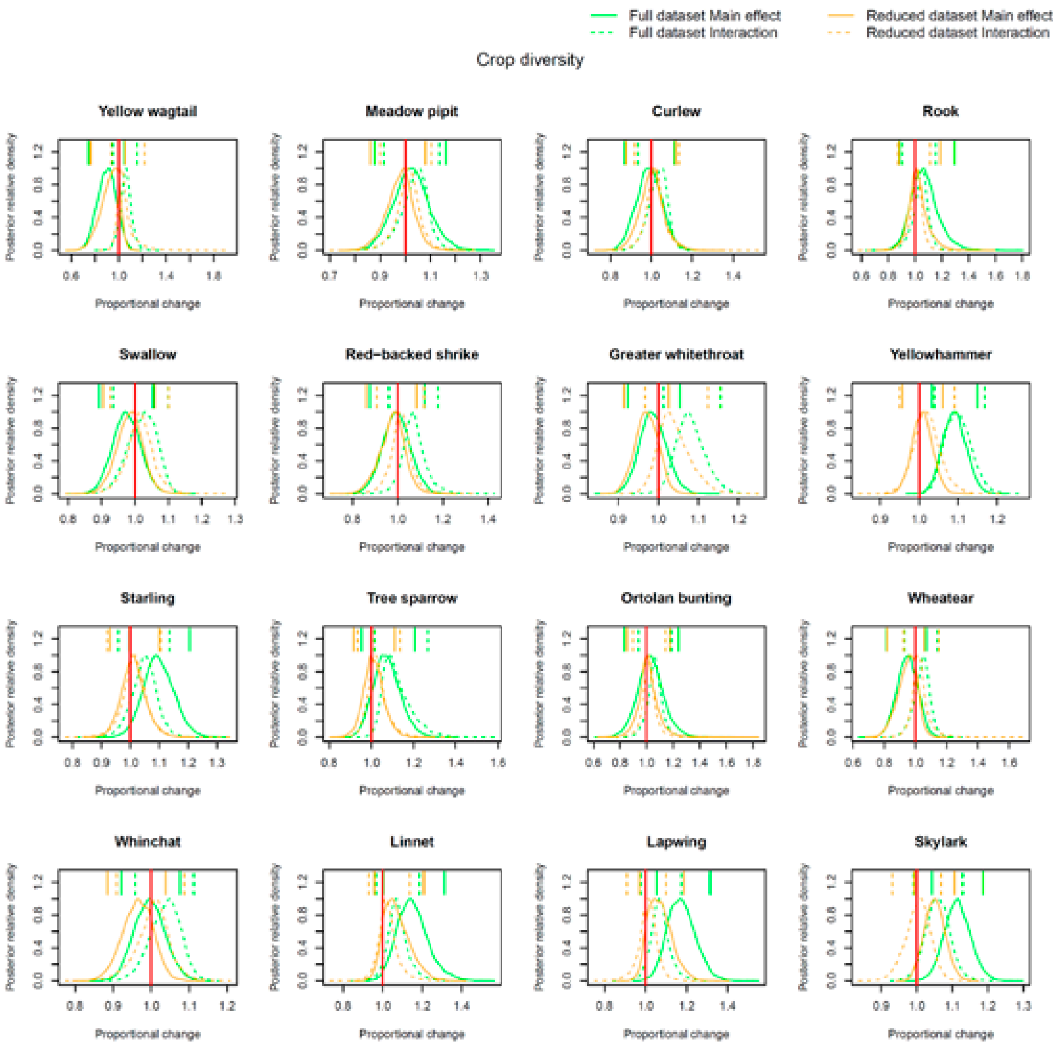

Figure A2.5. Densityplots of samples from the posterior distributions of the effect of crop diversity (solid lines) and its interactions with latitude (dashed lines) in the analysis using the full (green lines) and reduced (orange lines) datasets respectively. Samples of effect coefficients from the reduced dataset has been transformed to the same scale as that of the full dataset. Densities have been "normalized" to a maximum of one to facilitate plotting. Red line show a proportional change of one (i.e. no effect). Short lines above the density curves indicate the 95% confidence (credible) interval (HPD).

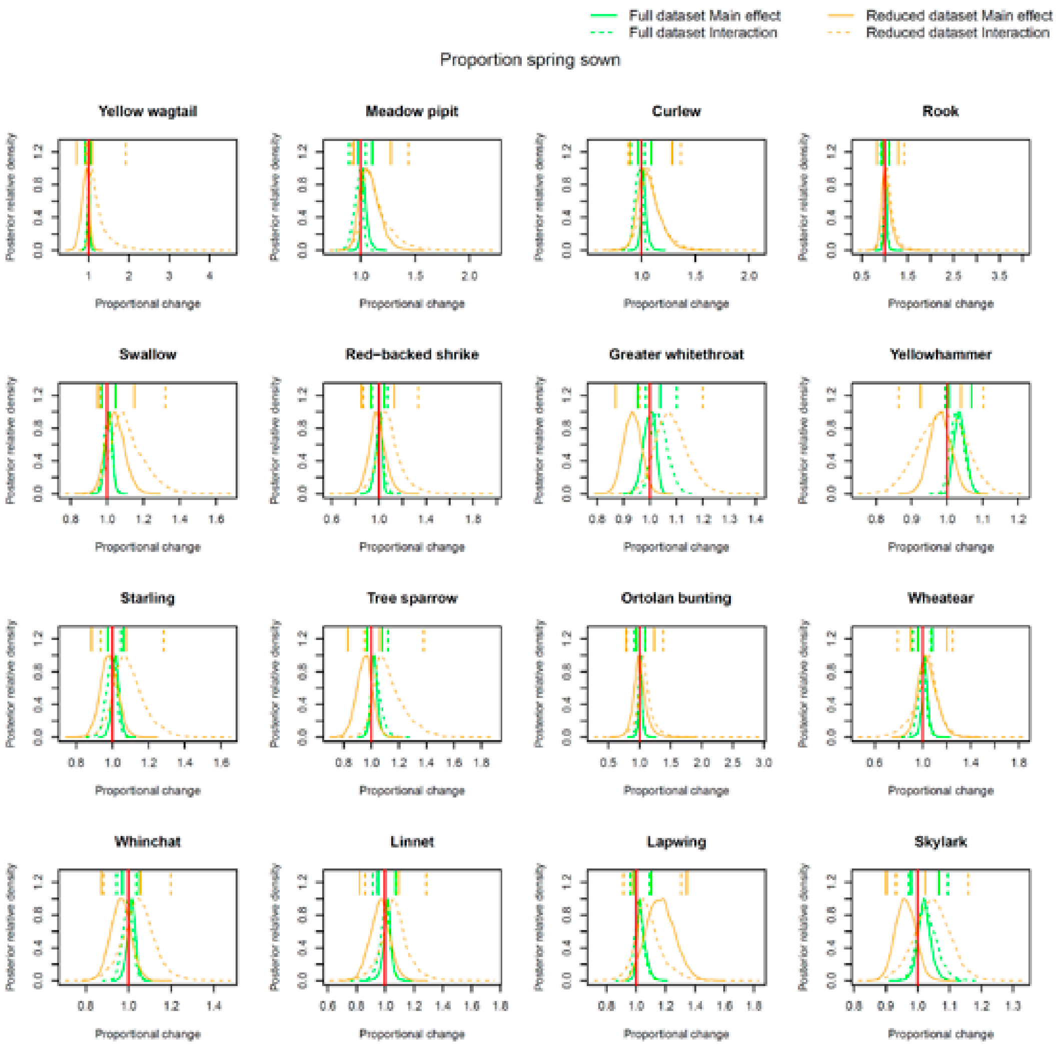

Figure A2.6. Densityplots of samples from the posterior distributions of the effect of proportion spring-sown crop (solid lines) and its interactions with latitude (dashed lines) in the analysis using the full (green lines) and reduced (orange lines) datasets respectively. Samples of effect coefficients from the reduced dataset has been transformed to the same scale as that of the full dataset. Densities have been "normalized" to a maximum of one to facilitate plotting. Red line show a proportional change of one (i.e. no effect). Short lines above the density curves indicate the 95% confidence (credible) interval (HPD).

Reviewers' comments

This report is a thorough discussion of how conditions in agriculture can affect farmland birds and will be useful for anyone wanting an overview of factors influencing farmland birds. The authors have, where possible, used Swedish studies and their own analyses, to highlight their findings and then propose recommendations for improving conditions for farmland birds in Sweden (with focus on Farmland Bird Index (FBI) species). I find no controversy with the suggested recommendations for improving conditions. After the author's research into the subject, it seems that many of the issues regarding farmland-bird relationships that have been studied in Europe during the last few decades have made it into the "recommendations section". So the report is "safe" because most things expected to improve conditions for at least some species are covered. The broad conclusion that conditions for farmland birds will be improved by having variation at multiple scales (from maintaining varied crop structure within fields to keeping mixed farming within farming regions) is probably very true. However, I think improving conditions and reversing population trends are not necessarily synonymous, yet these two terms seem to be used a bit interchangeably as a main focus/objective stated in different places within the report. I was left wondering if the broad and "general" recommendations for improving conditions will lead to reversed trends given the apparent lack of knowledge on specific population limiting factors for the FBI species.

As the authors point out, the recommendations given in the report are very likely to generally improve conditions for species in Swedish farmland. But will that help with addressing the trends of FBI birds (and the wider diversity that the index is hoped to reflect)? To specifically address population declines of birds on the FBI I think more focus on species-specific requirements is required. In addition, there is some evidence that conservation measures in farmland (such as agri-environment schemes) can work well when addressing the needs of specific species. Thus, after my evaluation of the report I asked the authors to provide a table summarising their findings regarding the evidence for the potential roles that stated "recommendations" might have at the species level (rather than at more general biodiversity level). My interpretation from the table and text describing it is that the authors were not completely comfortable with making conclusions on the value of proposed recommendations for each of the species listed in the Swedish FBI. This was surprising as the research community, both professional and otherwise, have been investigating the ecology of farmland birds for two or three decades now. Yet it is apparently still quite difficult to recommend how populations of even relatively few common species from a well-studied organism group will benefit from any proposed conservation actions. Is there a mismatch in the research being funded or published and what we actually need to know for reducing biodiversity loss? I think this is an important question to address in the future.

Throughout the report one gets the impression a main mission was to recommend actions that can reverse negative population trends reflected by the Swedish FBI. To improve conditions that will lead to changed population trends, the main factors that limit populations probably need to be targeted. For birds this is particularly challenging as individuals of many species spend much of their life-cycle outside of Sweden. It is stated in the report that the recommendations are focused on Swedish conditions as this is where The Board of Agriculture can influence land management for conservation purposes. However, and first, if it turns out that major population limiting factors are outside of Sweden's boarders (e.g. hunting, winter food availability or inclement weather along migration routes) then there may be a case for arguing that limited resources for conservation might be better placed elsewhere than further improving conditions for quite common bird species in Sweden. Second, if population limiting factors are suspected to be outside of Sweden's national boarders then surely The Board of Agriculture and Swedish government could put pressure on foreign governments so those countries improve conditions for birds during the non-breeding season. Therefore, I had also hoped that the authors would have further developed the discussion of potential factors limiting populations outside of Swedish farmland a bit more than is present in the report now. I also understand why the authors chose to focus on Swedish conditions. So this is not a criticism of the report per se.

I hope that the authors will try to publish the results of the very ambitious and important habitat association analysis in the peer-reviewed scientific literature. The methods seemed quite complex and the agricultural land-use and bird data used is, to my knowledge, not easy to analyse. While I do not doubt the author's ability to carry-out the analyses, I would prefer it if the methods, results and conclusions are checked by knowledgeable and statistically-minded ecologists during the peer review process.

In summary, I believe that the report is a useful presentation of current knowledge about relationships between agricultural land use practices at multiple spatial scales and farmland birds. An interesting follow up for this report would be to evaluate the feasibility of implementing the proposed recommendations in the context of long-term profitable agriculture. The authors have covered most issues that potentially influence farmland bird populations in Sweden. Now it will be up to decision makers to decide how to prioritize and translate the information given into working conservation actions that will improve conditions for birds in thriving agricultural landscapes.

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