Tempo-Spatial Patterns of Foraging by Birds in Mosaic Agricultural Landscapes

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Cover illustration: Spring-staging waterfowl in the Ume River Delta area. (Photo: Kjell Sjöberg)

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Abstract

Many farmland breeding bird populations decline, while large herbivorous bird species, which forage on farmland outside the breeding period, increase their numbers. Intensification of agriculture causes both processes. Foraging habitat choice was studied in farmland breeding Eurasian Curlews and spring-staging waterfowl, through repeated counts of birds on fields.

Foraging Eurasian Curlews shifted from grasslands to tilled, newly sown cereal fields in June, while non-foraging birds did not. The conclusion is that earthworms in dry untilled grassland soils become gradually harder to access for probing birds, while tilled soil remain easy to penetrate. Eurasian Curlews benefit from mosaic landscapes with a mixture of crops, and which offer ample foraging conditions throughout the season.

During spring-staging, geese and swans commute between the roost and agricultural fields. Variable selection in hurdle models revealed that field size, distance to the roost and agricultural treatments ley, stubble and unharvested cereal were important for foraging habitat choice, while other agricultural treatments and disturbance were not. Fields with unharvested cereal were, by far, the most attractive. The dataset had high levels of zero-inflation and aggregation, and hurdle models did not fit the data very well. Instead, we created the ADJUN model, which performed better than the hurdle model. ADJUN and hurdle models were used to estimate the coefficients of the important variables. Based on the estimates, we present mathematical formula to calculate the probabilities for presence, and the expected numbers of the four studied waterfowl species on agricultural fields of staging sites similar to the Ume River Delta area.

From these studies, I conclude that agricultural treatment is the most important determinant of the quality of a field for foraging birds, and also, that landscape-wide planning of treatment of farmed fields can be an effective tool for bird conservation, and for the reduction of crop damage by birds.

Keywords: Eurasian Curlew, farmland bird, soil-penetrability, waterfowl, staging site, zero-inflation, modelling, hurdle model, AIC, generalized linear model, true zero observation

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Dedication

This thesis is dedicated to this little grain of doubt, that lingers in the back of my mind when all the question marks appear to have been straightened out.

Contents

List of Publications

This thesis is based on the work contained in the following papers, referred to by Roman numerals in the text:

I de Jong, A. **Seasonal shift of foraging habitat choice in farmland breeding Eurasian Curlew**. Submitted manuscript.

II de Jong, A., Sjöberg, K. and Yu, J. **Modelling foraging habitat use by spring-staging waterfowl**. Manuscript.

1 Introduction

When agriculture started to develop during terminal Pleistocene, Scandinavia was still completely covered by the Weichselian ice-sheet (Grosswald 1980, Roberts 1998). When the ice-sheet withdrew 11,000 BP, hunter-gatherers immigrated into the deglaciated parts of Scandinavia. Agriculture spread over Europe during the first half of the Holocene and reached the southern parts of Sweden 6,000 BP. However, it took another 3,000 years to become firmly established in coastal northern Sweden (Harris 1990, Welinder *et al.* 1998). In the inland of northern Sweden, finally, sedentary farming was introduced as recently as four hundred years ago (Welinder *et al.* 1998).

During the hunter-gatherer period, man influenced the landscape mainly by decreasing the population densities of large herbivorous mammals, including the post-glacial megafauna. In south-central Sweden, this resulted in the closing of the forest canopy (Emanuelsson 2009). Early sedentary farming, on the other hand, led to a re-opening of the landscape due to grazing livestock and extensive collection of winter feed (mainly hay, leaves and branches) away from the farmed fields. The introduction of fertilizers and motorized equipment at the beginning of the 20th century resulted in a sharp increase of the productivity of arable land. Consequently, the production of food, feed, and pasture became concentrated to easily-managed, high-yielding fields near human settlements; while forests, wetlands and remote fields were no longer needed for agriculture. Again, the forests grew denser, and previously farmed lands were abandoned. In this process, a large proportion of (semi-)natural grasslands used for hay-making or grazing were either turned into arable land or forest (Morell 2001, Flygare & Isacson 2003, Emanuelsson 2009).

Like in history in general, our knowledge of birds in the agricultural landscape degrades when moving from the present to ancient times. This may be an important reason why our biological conservation concern is mainly based on the development over the last 50-100 years, and the conservation target (base-line) set accordingly (Emanuelsson 2009, Vera 2009). Recently, our current base-line for biological conservation has been challenged (Donlan et al. 2005, Svenning 2007, Emanuelsson 2009), and e.g. Vera (2009) argues that sustained biodiversity demands the restoration of landscapes once shaped by large, herbivorous mammals. For many species of farmland breeding birds, the re-opening of the landscape should be beneficial, especially if it were combined with re-wetting of the landscape and with extensification of agriculture (Toogood and Joyce 2009).

Despite our lack detailed historical knowledge, we have good reason to believe that early sedentary farming improved conditions for many of today's farmland breeding birds, especially the ones that breed and forage on (semi-)natural grasslands and arable land. Livestock and scythe replaced the ungulate populations that hunting humans had decimated. In northern Sweden, agricultural regimes based on a small area of infields, nutritionally supported by the surrounding landscape, dominated well into the first half of the 20th century (Emanuelsson 2009). Meanwhile, the area of arable land started to increase during the second half of the 19th century, through the cultivation of natural grasslands and wetlands. Initially this led to a further improvement of the conditions for farmland bird species, of which several increased their numbers and range.

Since the middle of the 20th century, agricultural intensification and, on the other hand, the abandonment of marginal farmland have led to a decline of many other farmland breeding species in Western Europe, especially the ones that feed on invertebrates and seeds of weeds (Fuller *et al.* 2004, Siriwardena *et al.* 2008, Butler *et al.* 2010). In northern Sweden, the decline of farmland breeding birds started more recently, and has not been as dramatic as in southern-central Sweden or in Western Europe (Hagemeijer and Blair 1997, de Jong & Berg 2001, Ottvall *et al*. 2009).

Unlike farmland breeding birds, large herbivorous birds have gained from the industrialization of agriculture (van Eerden *et al*. 1996). These birds use farmland during the winter and during migration, and have benefitted from new crops, increased yield and more spill. Species like Whooper Swan (*Cygnus cygnus*), Bean Goose (*Anser fabalis*), Greylag Goose (*Anser anser*) and Canada Goose (*Branta canadensis*) rely heavily on agricultural crops outside the breeding season, and all but the Bean

Goose have increased their numbers and range dramatically over the last decades (Madsen *et al.* 1999). These increasing waterfowl populations pose new management challenges, because of increasing crop damages and carry-over effects on vegetation and other bird species in their breeding habitat (Jepsen 1991, Madsen *et al.* 1999, Jefferies *et al.* 2003, Gauthier *et al.* 2005, Klaassen *et al.* 2008).

The agricultural landscapes of northern Sweden offer excellent conditions for investigations of the avian fauna. In this region, the decline of farmland breeding birds has only recently begun, and its history and causes could be studied effectively, both locally and in comparison with other places in Sweden and internationally (e.g. Wretenberg *et al.* 2006). Also, the role for migratory birds on their way to and from boreal, arctic and alpine breeding grounds played by the agricultural landscapes of northern Sweden is largely unexplored. In addition, damage to agricultural crops caused by birds is a fairly new, but growing, problem in the region. Thus, there are unique opportunities to study, empirically and experimentally, the development of the interactions between bird populations and the agricultural landscapes of northern Sweden.

2 Objectives

This thesis assesses deterministic aspects of tempo-spatial foraging behaviour of birds in the agricultural landscape. Because of their high mobility, birds seek to be where the current cost-benefit ratio is optimal and, thus, their presence expresses the quality of an agricultural field for them. By repeatedly counting birds on agricultural fields, the tempo-spatial process of foraging habitat use can be studied.

The hypotheses were:

- Foraging and non-foraging Eurasian Curlews shift preference for agricultural treatment classes over the breeding season differently. (Paper I)
- In the process of deciding where to forage, swans and geese use field characteristics in the order of priority: (1) density and quality of accessible food resources and (2) flight distance from the roost. (Paper II)
- Numbers of spring-staging swans and geese on individual agricultural fields can be modelled (and thus predicted) from field characteristics; field size, agricultural treatment and distance to the roost. (Paper II)

3 Methods

3.1 Study area

The investigations presented in this thesis were carried out in a rural landscape in the vicinity of the city of Umeå (63.8^{o}N, 20.3^{o}E) in the county of Västerbotten, northern Sweden. Here, farmed land on sediment soils, forests, lakes, settlements and infrastructure create a mosaic landscape. Agricultural production is dominated by dairy production and the main crops are ley and spring-sown barley. Farmland is divided into fields, the long term management units for farming. Fields are easily recognized by vegetation cover, surrounding ditches and forest edges. Due to variation in treatment of fields, the farmed land also has a mosaic structure.

The study on Eurasian Curlews (Paper I) was made in the agricultural landscape south of the Ume River within 20 km from of the city of Umeå. A total of 298 fields (509 ha) along ten road/track sections were included in the study. These roads or tracks were accessible throughout the study period and allowed for a complete view over the investigated fields.

The waterfowl study (Paper II) was conducted in the agricultural landscape of the Ume River Delta area (west of the river downstream the city of Umeå). This area is an important staging site for waterfowl during spring migration. In this landscape, the vast majority of agricultural fields (90% = 1700 ha), were included in the study. The studied species feed on agricultural fields during daytime and spend the night (and regularly even part of the day) on a system of roosts, usually located on river arms or bays in the river delta. However, when flooding occurs, pools on farmland are also used for roosting.

3.2 Study species

The Eurasian Curlew *Numenius arquata* (Linnaeus, 1758) breeds on wetlands (bogs and mires) and on farmland (Svensson et al. 1999). Eurasian Curlews nest on the ground and feed on invertebrates taken from the soil surface and up to over 25 cm depth. In Sweden at least half of the population breeds on agricultural land (Arvidsson et al. 1992, de Jong & Berg 2001). The Swedish breeding population, which winters in Western Europe, has declined at an average annual rate of 1.8% since 1975 and 2.9% since 1998 (Lindström *et al*. 2009), and the species is redlisted as Near Threatened (NT). The Eurasian Curlew is a very popular bird and could play an important role as a flagship species in biodiversity conservation in the agricultural landscape (Home *et al*. 2009).

Whooper Swan *Cygnus cygnus* (Linnaeus 1758), Bean Goose *Anser fabalis ssp*. (Brisson 1760), Greylag Goose *Anser anser* (Linnaeus 1758) and Canada Goose *Branta canadiensis* (Linnaeus 1758) were the studied spring-staging waterfowl species. These birds breed in wetlands, lakes and coastal habitats of the northern boreal zone of Fennoscandia and western Russia (del Hoyo *et al.* 1992, Gjershaug *et al.* 1994, Hagemeijer & Blair 1997, Väisänen *et al.* 1998, Svensson *et al.* 1999). The breeding populations of the Whooper Swan, Greylag Goose and Canada Goose in Sweden and Finland have increased dramatically over the last three decades (Väisänen *et al.* 1998, Svensson *et al.* 1999, Ottvall et al. 2009), but the population trend for the Bean Goose in these countries is stable, at best (Madsen *et al.* 1999, Thomas Heinicke pers.com.). Among birds, these species belong to the large herbivores and, outside the breeding season, they forage mainly on agricultural fields where they eat harvest spill (potatoes, sugar beets, maize, grain, etc.) or grasses (Jefferies *et al.* 2003, Fox *et al.* 2005). These agricultural fields are within “commuting-distance” (usually less than 10 km) from a roost, where they rest, bath, drink, preen and socialize, mainly during the night, but often even part of the day. During spring migration, swans and geese, especially those that breed in the Arctic, store energy reserves to be used during the breeding season, and, consequently, their demands on the quantity and quality of available food resources are high (Drent and Daan 1980, Drent *et al.* 2006). In places where geese are hunted, they are easily disturbed by human activities and are considered “shy”, but they readily habituate to human presence when they feel safe (Béchet *et al*. 2003, Béchet *et al*. 2004, Tombre *et al* 2005). Spring-staging geese cause substantial crop damage in Denmark and Norway, but not in Sweden, so far (Jepsen 1991, Klaassen *et al.* 2006, Viltskadecenter 2010).

3.3 Data collection and analysis

For paper I, numbers and behaviour of Eurasian Curlews on 298 fields were documented twice during each of four periods between 2 May and 9 July 2007. These periods represent: (a) the egg-laying phase before farming activities start, (b) incubation period and tilling and sowing of cereal fields, (c) early chick-rearing and harvest of grasslands, and, finally, (d) guarding of the young and sporadic hay-making. The agricultural treatment of the investigated fields was classified as (1) ley, (2) recently cut ley, (3) stubble field, (4) tilled, (5) newly sown cereal, (6) cereal, (7) pasture and (8) set-aside. To minimize observer-caused disturbance, all observations were made from a car using binoculars (10 times magnifications) and, if needed, a telescope (30 times magnification). The behaviour of each individual bird was classified as foraging or non-foraging (= resting, preening, guarding or nesting). These two classes were distinct and mutually exclusive. After the fields had been scanned for Eurasian Curlews, a selection of fields was patrolled on foot to control for undetected birds. These controls showed that only two Eurasian Curlews (0.4% of the observed birds) had been overlooked using this observation method.

Assuming random spatial distribution, 90, 95 and 99% confidence intervals (CI's) of expected numbers of foraging and non-foraging Eurasian Curlews were calculated from area per treatment and total number of birds. These calculations, based on binomial distribution, were made per treatment class and period. Observed numbers were compared with the CI's of the expected numbers.

Paper II is based on numbers of swans and geese on 738-765 agricultural fields in the Ume River Delta area from weekly counts during the spring-staging period of 2005-2009. The counts were made during daytime from 50 fixed positions. In all, 33 counts were included in the analysis. Agricultural treatment of the fields was assessed by ground surveys of the entire study area during the year prior to each counting season (summer and late autumn). Agricultural treatment classes used in this study were (1) ley, (2) stubble, (3) tilled, (4) unharvested cereal, (5) pasture, (6) set-aside and (7) "other".

A Geographic Information System (GIS) was used to map fields, agricultural treatment and observed numbers of the study species. From this digital map, the field characteristics field area, distance to the roost and the amount of settlements, roads and forest edges within a 100 m buffer around the field were extracted.

Version 2.10.1 of R, including the MASS and pscl libraries, was used for statistical analysis and modelling. Hurdle models fitted the data structure and the number of explanatory variables and were used for variable selection, but produced unsatisfactory predictions. Instead, we developed a novel model class “ADJUN” that produced models, which fitted the data better than hurdle models did. Finally, we used both hurdle and ADJUN models to find and evaluate estimates for explanatory variable coefficients, and to propose computational functions that predict presence/absence and abundance of foraging waterfowl on agricultural fields during spring-staging in the Ume River Delta area and similar sites.

4 Results and discussion

4.1 Paper I

The main result of this study was that foraging Eurasian Curlews preferred fields of ley in May, but shifted to newly sown cereal fields in June, while this shift in habitat choice did not occur among non-foraging birds (Fig. 1). The difference between these behaviour classes points at food as the driving force.

My interpretation of this shift of foraging habitat choice is that, when soils dry out, probing for soil-living invertebrates in un-tilled soils becomes gradually harder. Tilling loosens up the soil and newly sown (tilled) fields offer easy access to soil-living prey. In grassland dominated landscapes, tilled fields may be essential for adult Eurasian Curlews under dry summer conditions, especially in areas where alternative feeding options (e.g. in ditches and on uncropped patches) have been reduced, as they usually are in today's agricultural landscapes.

The importance of soil-penetrability for foraging behaviour has been shown in several wader species, e.g. Dunlin *Calidris alpina* (Mouritsen & Jensen 1992, Taft *et al.* 2008), Common Snipe *Gallinago gallinago* (Green *et al.* 1990) and Eastern Curlew *Numenius madagascariensis* Congdon & Catterall 1994 and Finn *et al.* 2008). The latter is a close relative to the Eurasian Curlew with similar ecology, but it does not regularly breed on farmland. The issue of soil-penetrability, or probing resistant, also puts focus on the accessibility of available food. Food is only truly available when it is accessible.

Farmland breeding Eurasian Curlews once evolved in natural wetland habitats, where probing resistance was not hampering foraging birds. When they left their shrinking home to settle in expanding man-made habitat, their long bills were probably as efficient as before, but when fields were drained and wet, uncropped habitats disappeared, reaching their main prey became troublesome. Tilled fields solved their problem. Unfortunately, tilled fields alone can not make up an attractive breeding habitat for Eurasian Curlews. Berg (1993) and Valkama *et al*. (1998) showed that grasslands were important in landscapes dominated by tillage (cereal fields). In my study area, the conditions are reversed; the landscape is dominated by grasslands and tilled cereal fields are important during the second half of the breeding period. Consequently, a mixture of grasslands and cereal fields is the landscape of choice for farmland breeding Eurasian Curlews. If wet uncropped habitats are available within the breeding territory, habitat quality improves even further. When agriculture, again, can deliver "smorgasbord" landscapes, the decline of the Eurasian Curlew and other farmland breeding birds is likely to halt and, eventually, reverse.

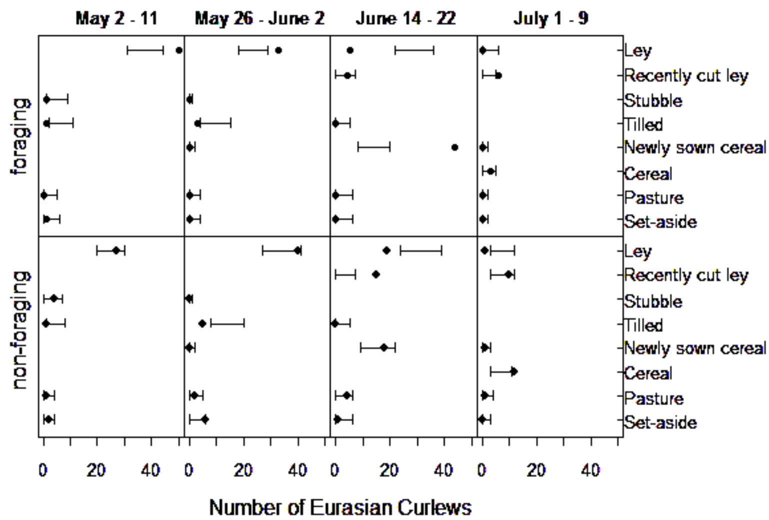

Figure 1. Observed numbers (dots) of foraging and non-foraging Eurasian Curlews over agricultural treatment classes and periods compared with 95% intervals under random spatial (binomial) distribution (bars).

4.2 Paper II

The 38,879 counted waterfowl individuals were very unevenly distributed over the agricultural fields in the study area, and on 76% of the fields (57% of total area) not a single bird was counted. Which fields were used varied between species, between years and within the staging period. Even the numbers per field varied greatly. The results of the counts indicate an opportunistic foraging behaviour and high levels of flexibility in the selection of fields for foraging by swans and geese.

By comparing hurdle models with different combinations of explanatory variables, we found that field size, distance to the roost area and agricultural treatment classes ley, stubble and grain (entered as binary dummy variables) fitted the data best, over the years and over the species. Among these variables, grain (for unharvested cereal) had the strongest effect (positive), followed by stubble (positive) and distance to the roost (negative). Human disturbance (measured by three proxy variables) did not have a strong effect on which field the swans and geese chose to forage on. This lack of impact of human disturbance on swans and, especially, geese may be surprising, but most records of the shyness of these species are from places and times when they were hunted (Göransson and Karlsson 1976, Madsen and Fox 1995). Spring-staging waterfowl in northern Sweden have not been hunted for many decades, and thus, human activities are not perceived as a serious predation risk (Fox and Madsen 1997, Naturvårdsverket 2004). Predation by a growing number of White-tailed Eagles (*Haliaeetus albicilla*, Linnaeus 1758), on the other hand, is likely to play an increasing role for the future distribution of waterfowl in the Ume River Delta area (Wallin and Delin 2010).

Due to the uneven distribution of the counted birds, the dataset was highly zero-inflated and aggregated, and although hurdle models are competent in handling this kind of datasets, their performance was disappointing. As a result, we created the ADJUN model. Like hurdle models, ADJUN models include a binary (binomial) model (step 1) used to fit probabilities for presence (= non-zero counts) and a count model (step 2) to fit abundances (here: numbers of waterfowl per field). The main difference between hurdle and ADJUN models lays in the selection of cases that are used in the count model. In ADJUN models there are two alternative ways to select the cases for the count model (ADJUN A and ADJUN B). In a variant of the ADJUN model (both A and B), fitted values of the count model are <u>not</u> multiplied by the probabilities fitted by the binary model. Measured by standardized Root Mean Square Error, this variant of ADJUN model fitted the data better than hurdle models (Appendix 3 in Paper II).

Finally, we used ADJUN and hurdle models to estimate the coefficients of the relevant explanatory variables (Table 8 in Paper II). These estimates can be used to predict the effect of numeric changes of the explanatory variables. For example, the ADJUN B model for Bean Geese 2009 predicts that the probability that a field is used by foraging Bean Geese decreases with 26% per km from the roost area. Based on these estimates, we present generalized formulas to compute presences/absences and abundances of swans and geese on agricultural fields of staging sites similar to the Ume River Delta area.

5 Conclusions

Eurasian Curlews foraged on grasslands early and on cereal fields later in the breeding season (Paper II). This strongly indicates that this species fares better in landscapes where both field types are available, and that the (re-)creation of mosaic landscapes with a mixture of crops could help to turn the downward trend of the Eurasian Curlew, and other farmland breeding bird species.

Agricultural treatment determines the amount and quality of available food resources, and these food resources are the most important factor behind the presence/absence and abundance of waterfowl on agricultural fields in a spring-staging area (Paper II). Distance to the roost is also important, but disturbance by human activities has a minor impact, when hunting and organized scaring are absent. Agricultural treatment can be used to improve the quality of the staging site for waterfowl, and to “guide” the birds away from places where they are unwanted to places where they cause limited damage. The quality of a field is always measured relative to alternative fields, though, but birds are generally quick to respond to altered conditions. Obviously, it takes a landscape approach and cooperation over the staging area for effective use of agricultural treatment as a tool to rearrange birds in the landscape.

Models derived from large amounts of empirical data can explain processes, highlight important factors and predict responses to changing conditions. The ADJUN model presented in Paper II is competent in modelling presence/absence and abundance from highly zero-inflated and aggregated data. In the future, models for different part of the life-cycle of birds will be linked together, e.g. in flyway-oriented models. Such models will become important tools for sustainable management of e.g. waterfowl populations.

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