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Predictions using a landscape-scale individual-based model

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Data sheet

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Abstract: The impact of pesticide usage reduction scenarios on skylarks was evaluated using a landscape-scale individual-based model. The results of the scenarios indicated that the general reductions in pesticides scenarios would have a negative impact on skylarks due to side-effects of altered farm management, despite the positive influence of having less pesticide in the environment. Technical scenarios indicated that the greatest benefit to skylarks is by altering the structure of the crop such that they have access for nesting and feeding. Of the scenarios investigated the greatest benefit was obtained from the use of unsprayed field margins. Large benefits could also be achieved using unsprayed margins even if they were not added to all fields. Unsprayed field margins will also have other significant benefits to wildlife by protecting the non-cultivated areas from spray drift.

Keywords: Skylarks, pesticide usage, ALMaSS, scenario modelling

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1 Foreword

This report covers the scenarios commissioned by The Danish Economic Council in support of their project on the effect of agricultural use of pesticides. The scenarios presented are a combination of scenarios of different tax measures, and a set of technical scenarios designed to highlight the response of the model to specific variables to help to quantify specific effects of specific parameters. Due to time constraints it was not possible to carry out a more comprehensive sensitivity analysis, nor to increase the number of replicates used, however, the current level of replicates seems to be satisfactory to demonstrate the differences between the scenarios.

2 Summary

Five scenarios of potential ways of implementing reductions in pesticide usage were evaluated against a baseline scenario for the impact that they would have on skylark populations. These scenarios were a general decrease in all pesticides (P), a larger (H) and smaller (DH) decrease in herbicides used, a 5m unsprayed margin around all fields (UM), and the impact of increasing the current area of organic farming by 25% (O). In addition 14 technical scenarios were constructed designed to illustrate the effect of assumptions and parameter inputs to the model. All scenarios were run using a derivative of NERI's ALMaSS model which is designed to integrate animal ecology with landscape structure and management. The results of the scenarios indicated that the general reductions in pesticides scenarios (P, H, DH) would have a negative impact on skylarks. Scenario O had no significant impact since the area altered was very small in percentage terms. Scenario UM had the largest positive impact.

The cause of the decline under decreased pesticide was two-fold. Firstly the response of the farmer was predicted to be to increase the area of winter cropping, which is typically detrimental to skylarks. Secondly, the reduction in number of times the farmer opens the tramlines in the crops leads to decreased accessibility for the birds, and therefore reduced foraging possibilities. The increased food biomass as a result of reduced pesticide applications did not outweigh these negative effects because access to the food was not improved and may be decreased. The technical scenarios indicated that the greatest benefit to skylarks is by altering the structure of the crop such that they have access for nesting and feeding. Large benefits could also be achieved using unsprayed margins even if they were not added to all fields. Unsprayed field margins will also have other significant benefits to wildlife by protecting the non-cultivated areas from spray drift.

A crucial assumption in the modelling work is that given the limited reduction in pesticide usage, there will not be a significant increase in weeds or a decrease in the impenetrability of crops. Further simulations could be carried out in collaboration with agronomists to improve the basis for this assumption.

3 Dansk sammendrag

Effekter på antallet af lærker i et agerlandskab er belyst ved fem modeller (scenarier) for at gennemføre en reduktion i pesticidforbruget. Disse fem modeller er sammenlignet med antallet af lærker ved et uændret pesticidforbrug. De fem modeller er 1) en generel reduktion af alle pesticider (P), 2) et større forbrug af herbicider (H), 3) et mindre forbrug af herbicider (DH), 4) en 5 m usprøjtet randzone omkring alle marker (UM), og 5) forøgelse af et økologisk dyrkningsareal med 25% (O). Yderligere er der gennemført 14 tekniske scenarier for at belyse effekten af de forudsætninger og parametre som modellen bruger som input. Alle scenarier er kørt i en videreudvikling af DMU's ALMaSS model, som er designet til at analysere de økologiske parametre af udvalgte dyr i et landskab i forhold til landskabets struktur og udnyttelse. Resultaterne af scenarierne indikerer, at de generelle scenarier for reduktion i pesticid- og herbicidforbrug (P, H, DH) vil have en negativ effekt på bestande af lærker. Økologiscenariet (O) har ingen signifikant effekt, fordi det øgede økologisk dyrkede areal udgør en meget begrænset del af det samlede landskab. Scenariet for usprøjtede randzoner (UM) havde den største positive effekt på lærkebestandene.

Der er to hovedårsager til faldet i lærkebestande ved generelt reduceret pesticidforbrug (P, H, DH). For det første forudsættes, at landmandens respons på reduceret forbrug vil være at øge arealet med vinterafgrøder, som typisk har negativ indflydelse på lærkebestanden. For det andet fordi færre kørsler med sprøjten vil medføre mere lukkede plejespor. Det vil gøre markerne mere utilgængelige for lærker og reducere mulighederne for at de kan søge føde i marken. Den øgede mængde føde for lærkerne, der forventes som følge af reduceret pesticidforbrug kan ikke opveje disse negative effekter, da føden bliver mindre tilgængelig. De tekniske scenarier indikerer, at den største positive effekt for lærker kan opnås ved at ændre på afgrødens struktur (mindre biomasse, mere åben afgrøde) i randzonerne, så der bliver bedre adgang til at etablere reder og søge føde dér. Der kan også opnås klar positiv effekt på lærkebestandene, hvis der etableres usprøjtede randzoner på en del af markerne. Usprøjtede randzoner vil derudover have positiv effekt for planter og dyr i landskabet ved at beskytte udyrkede markkanter og hegn mod pesticidafdrift.

En nøgleforudsætning i modellen er, at under de begrænsede reduktioner i pesticidforbruget (P, H, DH), vil der ikke komme en markant stigning i ukrudtsmængden eller en øget åbenhed i afgrøden. Yderligere simuleringer i samarbejde med agronomer kunne forbedre grundlaget for denne forudsætning.

4 Introduction

This report considers a set of scenarios for the reduction of pesticide usage in Denmark developed by the Danish Economic Council. The scenarios encompassed general pesticide reductions as well as more targeted measures. The aim of the aspect of these scenarios reported here was to evaluate the impact of tax measures on agricultural wildlife. In order to achieve this the skylark was chosen as a representative species with the underlying assumption being that effects on this species are mirrored by other wildlife species which use the field surface. In this regard the skylark is an excellent choice, since it uses the cultivated areas for breeding and for feeding. Its food is primarily arthropod based in the breeding season, which means that it is indirectly affected by changes in insect and vegetation abundance, rather than directly poisoned by pesticides. In addition, this species is sensitive to the structural state of the vegetation, requiring short, open or patchy vegetation for nesting and breeding (Schläpfer, 1988; Wilson et al, 1997). These conditions are also similar to those required by most non-pest animal species on the field surface, and a requirement for many of the arable weeds, which have been in serious decline over the past 50 years. Since, patchy crops with weedy areas create suitable micro-climates for a range of arthropod species, and these provide food for the skylark, the link between skylark success and general benefit for wildlife on the cultivated areas is likely to be strong.

The result of the agricultural intensification of modern agriculture (via increased pesticide use, improved crop cultivars, improved fertiliser regimes, changes in crops grown, and generally improved agricultural efficiency), is a situation where the agricultural landscape is largely a mosaic of dense monocultures that out-compete weeds for light and are generally poor habitats for wildlife. It is even suggested that animals as large as hares have difficulty in penetrating modern crops to find food (Rühe, 1999). This change has occurred over the past 30 years and has resulted in a general decrease in skylark abundance from an index of 100 to its current level of approximately 60 (Jacobsen, 1997). This decline is in line with those of other farmland birds such as corn bunting, although this is probably not as steep as the decline in farmland weeds. The skylark can therefore be described as a typical, rather than sensitive species, in terms of its responses to agricultural intensification.

The tax measures which form the basis for the scenarios presented here are designed to reduce pesticide usage. In this regard it is important to recognise that these products are not thought to have direct toxicity for the skylark, but function indirectly by removal of arthropod food directly (insecticides) or indirectly by removing weeds that form habitat for arthropods (herbicides). In determining the effect of these changes it is essential to be aware that when one factor is altered in the real world, other factors almost always also change as a result. In this case it is impossible to envisage a significant reduction in pesticide usage without concomitant alterations in other farming practices. To date when a risk assessment is required for pesticides (usually as part of the pesticide registration procedure), these other factors are not considered. The result is a potentially serious inaccuracy in predictions, which are proliferated by the EU regulatory process. The scenarios presented here avoid this problem by utilising a new modelling approach, namely agent-based landscape modelling, which integrates landscape structure, farm management and ecological and behavioural models of animals into a single entity. These models are specifically designed to integrate different factors for risk assessment and overcome many of the issues raised by multiple stressors and complex management systems. Specifically with respect to the modelling of skylark, Schläpfer (1988) has described the temporal aspects of timing of crops and vegetation structures required for nesting, and Wilson et al (1997) have documented the spatial aspects of resource requirements. The ALMaSS-based system (Topping et al, 2003) used here is the only currently available system which can integrate these aspects with real landscape structures and management changes.

5 Methods

An extension of the ALMaSS system (Topping et al., 2003), ToxImpact, together with a modified version of the skylark model described by Topping & Odderskær (2004) were used for these simulations. The properties of the model system are briefly described below, with the extensions in ToxImpact described in more detail.

5.1 Model Description

The model consists of two separate but interacting models, a landscape simulation and the skylark model. The skylark model is an agent-based model describing skylark behavior as a set of states linked by transitions, requiring the landscape simulation to act as a data server. The full model is described by Topping & Odderskær (2004) and unless noted below the values for parameters in the model are taken from Topping & Odderskær (2004). Hence only the key differences between the agent-based model and the implementations of more traditional models are briefly described here:

- The model is spatially explicit with a spatial resolution of $1m^2$ and a total landscape of 10 x 10 km^2 is modelled.

- Each vegetated landscape element is modelled separately with vegetation height, green- and total-biomass, and insect biomass sub-models, each driven by day-degree relationships.

- A landscape element may be subject to management by man. Fields, and linear habitats are managed in this way by mowing or other agricultural activities. These activities interact with the vegetation and insect models altering their values (e.g. insecticide spraying reduces insect abundance by 80% on the field where it is sprayed, insect abundance recovers back to pre-spray levels over a three-week period).

- Individual farms manage crop rotations, and all fields are assigned to farm units. Fields are managed following crop husbandry plans designed to closely simulate the real management of each crop modelled in terms of logical and temporal relationships between agricultural operations. Any agricultural activity on a field is recorded and this information is available to any skylark in the simulation. These managements include the use of normal insecticides, herbicides, fungicides and growth regulators as the default.

- Breeding skylarks are spatially located within the landscape and have a 250m-radius home range from which to find food. The location is dependent upon territory quality, which is expressed in terms of vegetation structure.

- Development of chicks and eggs utilises the ambient temperature and the period of time the female spends incubating to determine the development rate of the eggs. Incubation time is determined by the time required for the female to fulfil her daily energy budget, which in turn depends on food availability and accessibility within the home range of the bird. Likewise, nestling growth and survival is determined by the rate of food supply by both parents. The energy balance of the nestlings determines their growth, and birds with negative growth rates for two consecutive days are assumed to die. The time to nest leaving is determined by the size of the nestling, and hence slower developing birds will leave the nest later. Nestlings that do not reach fledging weight after 14 days are assumed to die. Fledglings follow the same rules as nestlings, but gradually become self-sufficient, finding a linearly increasing proportion of their own food daily until total independency at 30 days old.

- The spatial nature of the model permits explicit foraging behaviour to be modelled. Insect biomass is modelled explicitly for each vegetated element in the landscape, and the availability of insects is determined by the structure of the vegetation (see ToxImpact extensions below).

- Over-wintering mortality is modelled as a probabilistic mortality for the individual varying each year and being evenly distributed between 0.3 to 0.7.

- Other mortalities modelled explicitly are a daily probability of predation for all stages during the breeding season, estimated from Odderskær et al, (1997), and estimates of direct mortalities resulting from agricultural operations such as mechanical weeding.

5.2 Extensions included in ToxImpact

5.2.1 Pesticide Simulation:

In order to be able to handle the application of a pesticide to local areas at different times of the year and to model its fate, the landscape model was extended by the incorporation of a pesticide module. The pesticide module is responsible for ensuring that when a pesticide is sprayed in a landscape element, each 1 m^2 unit of that element has a pre-determined amount of pesticide residue deposited upon it. Twenty-fours hours after application, the concentration of each 1-m^2 area is re-evaluated based on an estimated rate of decline (DT_{50}). If a subsequent application were to occur in the same landscape element, the pesticide concentration is the sum of the new application residue and that remaining from the previous application. Once the concentration of residue is below 0.00001 mg kg^{-1} m^{-2}, it is assumed to be zero to avoid infinitesimal calculations.

The pesticide module is also capable of simulating drift into neighbouring elements assuming any specified relationship relating the proportion of applied rate deposited to the distance from source using the relationship: $P = 2.7538 ((d + 1.8698)^{-2.12156})$, where P is the insecticide deposited and d is the distance from source in metres. These constant values were obtained from FOCUS (2001) for an arbitrary pesticide. The minimum grid size for resolution of drift in the model was 4m, hence the amount applied to each grid cell was determined by taking the mean proportion for the whole grid cell.

5.2.2 Skylark Behaviour

Nest location is a critical part of the skylark's behaviour since the availability of nesting locations will determine the suitability of a territory. ALMaSS used vegetation height alone to determine nest site quality (Topping & Odderskær, 2004), however this has since been extended to use a combination of height and vegetation density to reflect the fact that skylarks can nest in relatively tall, but open crops. Hence a nest location is valid if the following logical equation holds true:

$(0.03\text{m}<H<1.10\text{m AND } D<50) \text{ AND NOT}(H<15 \text{ AND } D<9) \text{ AND NOT}(H>70 \text{ AND } D>10) \text{ AND NOT}(H>30 \text{ AND } D>15)$

where H is the height of the vegetation and D is $B/(H+1)$, where B is the vegetation biomass in g dry matter m^{-2}

Similarly the evaluation of an area by the male skylark for its suitability as territory also incorporates a density measure applied to vegetation between 0.03 and 1.1 m tall:

Territory Assessment Score = $S - (1.1^{D-15} - 1) + P$

where S is the maximum score possible for non-patch vegetation, D is $B/(H+1)$, where B is the vegetation biomass in g dry matter m^{-2}, and P is zero unless the habitat is patchy. This relationship has the property of penalising habitats with dense uniform vegetation.

D is also used in addition to height to determine the hindrance factor associated with foraging in tall dense vegetation. Vegetation is assumed totally accessible if less than 30cm tall and with a D or 15 or less, above this the hindrance factor is calculated as $114.3D^{-1.75}$, where D is calculated as for eq.1. This function rapidly decreases accessibility for vegetation with a D above 15. The hindrance factor calculated in this way is multiplied by the insect food biomass present at that location to determine the effective available biomass for the skylark.

There are a number of other constraints to nest location, also present in the original model. These are that the nest may not be within 50m of very tall structures (>3m), and must be inside the territory (not the home range). The search pattern determining the placement of the nest is a spiral search pattern starting at the centre of the territory and spiralling outwards. Hence, if suitable nest locations occur closer to the territory centre they will be selected over those in the periphery.

It should also be remembered that this selection will be time-specific. This is because the vegetation structure is changing on a daily basis, hence what would be a viable selection in May (e.g. in winter wheat), may no longer be viable in June. In this way the breeding window of Schläpfer (1988) is explicitly incorporated in the model.

5.3 Scenario Definition

All scenarios were run on a 10 x 10 km landscape map from central Jutland, Denmark (56° 22′ N, 9° 40′ E, Fig. 1). For each scenario conducted, 10 replicate runs of 55 years duration were run. In all cases the scenarios utilised the same historical weather pattern from the landscape from 1989-2000, which was looped five times to provide 55 years of weather.

Data concerning the area of the landscape covered by different farming types and the crops grown were supplied by the project as output from the ESMERALDA model (Jensen et. al, 2000). These data represent estimates of the national averages for Denmark projected to 2015, and predictions of changes in crops grown and pesticide applications under a range of scenarios:

The scenarios considered were:

- Baseline (B) – the projected conditions in 2015 assuming no changes in pesticide use.
- Pesticide (P) – a scenario describing the impact of a general tax on pesticide usage
- Herbicide (H) – a scenario describing the impact of a specific herbicide tax
- Differentiated Herbicide (DH) – in this scenario the taxes imposed were heavier for clay soils.

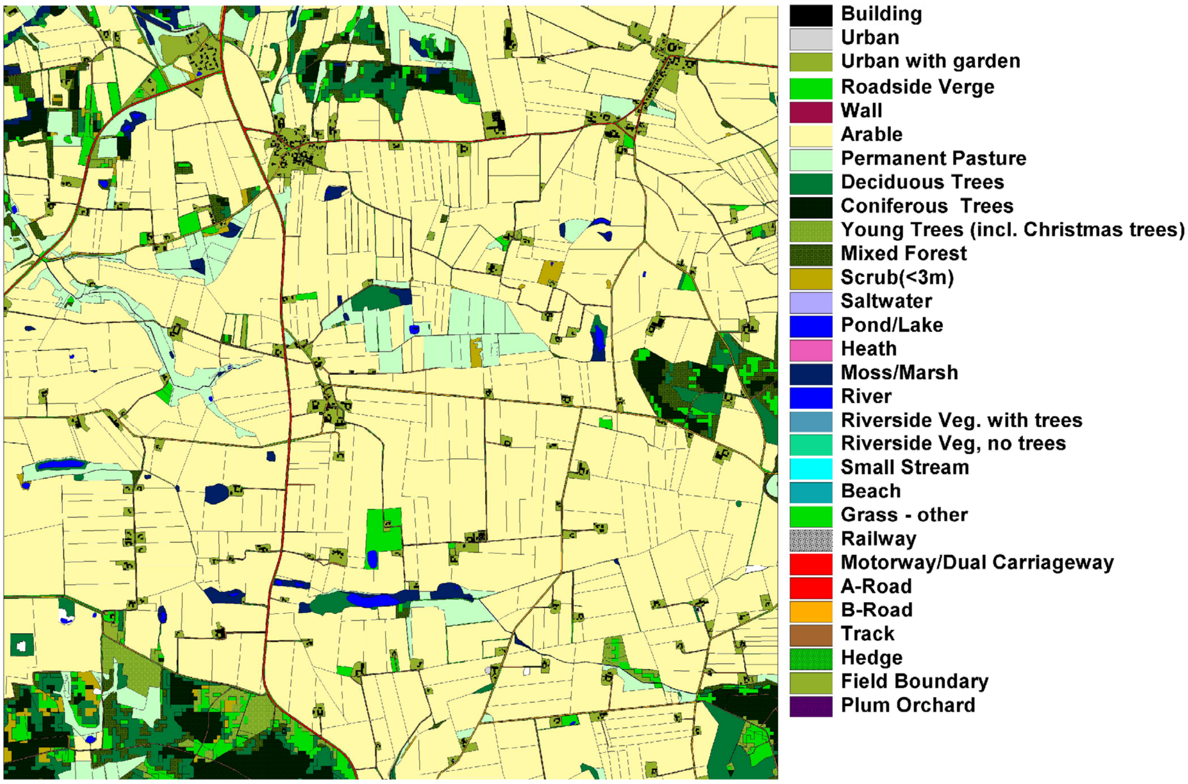

Figure 1: A 5 x 5 km section of the 10 x 10 km landscape used for these simulations. Yellow areas indicate arable fields. The key indicates those habitats that can be represented, but only a proportion is present on the map shown.

- Unsprayed Field Margins (UM) – in this scenario 11% of the arable land was converted to unsprayed field margins by allocation of a 5m margin to 100% of all crop boundaries. It was assumed that these margins were also unfertilised.
- Organic Farming (O) – the area of organic farming in the landscape was increased by 25% of it original value.

Farm type allocation – Nine farm types were defined in ESMERALDA, arable on clay, arable on sand, pig on clay, pig on sand, cattle on clay, cattle on sand, organic on clay, organic cattle on sand, organic others on sand. The percentage coverage by area for each farm type in each scenario is listed in Table 1. Most scenarios were largely unchanged from the baseline scenario, but the organic scenario was somewhat different. These proportions were allocated to the model landscape in terms of area covered.

Table 1 The percentage coverage by area for 9 farm types at national scale as predicted by ESMERELDA

Farm Types	Organic	All other scenarios
Arable, clay	13.9	14.2
Arable, sand	16.9	17.3
Cattle, clay	3.4	3.5
Cattle, sand	22.6	23.1
Pigs, clay	9.3	9.5
Pigs, sand	22.0	22.4
Organic, clay	1.1	0.9
Organic cattle, sand	4.4	3.7
Organic others, sand	6.4	5.4

There were larger differences in terms of the area covered by each crop between scenarios. Table 2 lists the crops that were modelled and their percentage coverage for the baseline scenario. Table 3 shows the number of fields each crop has covered after 50 subsequent crop rotations using the percentage crop coverage by farm type listed in Table 2. Tables 4-7 list the alterations in crop coverage for the scenarios P to UM, there was no change for the scenario O, but a larger area was covered with organic farms. In some cases rounding caused a crop to disappear from the rotation, but in these cases unless the percentage area covered was very small, this crop has been retained. Many small deviations of less than 1% have not been incorporated into the tables.

Table 2 The percentage area covered by each crop type for each farm type in the baseline scenario (B) as predicted by ESMERALDA

Crop	Arable, clay	Arable, sand	Cattle, clay	Cattle, sand	Pigs, clay	Pigs, sand	Organic, clay	Organic cattle, sand	Organic others, sand
Spring barley	27.5	40.3	12.6	16.1	21.4	28.1	12.3	6.4	11.7
Winter barley	3.8	4.2	1.2	1.3	8.4	7.8	0.2	0.0	0.0
Winter wheat	36.9	23.5	12.5	7.4	49.5	40.8	15.7	1.7	2.2
Rye	0.8	4.3	0.2	0.7	1.2	3.3	3.3	1.7	3.2
Oats	0.9	2.7	0.2	0.5	1.2	2.7	4.0	2.3	2.4
Other cereals	0.0	0.3	0.1	0.1	0.0	0.8	0.7	0.6	0.2
Peas	0.8	0.3	0.0	0.0	0.0	0.3	1.0	0.1	0.5
Rape	1.2	0.2	1.1	0.0	0.0	0.8	0.3	0.0	0.0
Grass and clover seed	8.6	3.0	1.3	0.3	3.6	2.2	7.7	0.3	0.9
Potatoes	0.1	1.5	0.0	0.1	0.1	0.3	0.0	0.0	0.1
Sugar beet	9.3	1.3	11.4	0.0	4.4	0.5	2.7	0.0	0.0
Other crops for sale	1.0	0.8	0.2	0.2	0.7	0.2	1.2	0.2	0.8
Beets for feed	0.0	0.1	0.7	1.1	0.0	0.2	0.3	0.0	0.0
Grass in rotation	0.3	2.2	13.7	17.1	0.2	0.9	15.5	31.4	30.6
Permanent grass	1.7	4.3	15.4	17.8	0.9	1.7	15.0	22.3	3.2
Silage cereals and maize	0.2	2.9	23.9	31.9	0.2	0.7	13.2	25.5	34.0
Setaside	6.8	8.2	5.3	5.6	7.9	8.7	7.0	7.4	10.3
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

Table 3 The number of fields each crop has covered after 50 subsequent crop rotations using the percentage crop coverage by farm type listed in Table 2. Note that some crops have been combined or removed where there was no suitable crop model available in the model system, or where it was impossible to predict what type of crop was grown (Grass in rotation includes Grass and Clover Seed; Sugar Beet includes Fodder Beet; Other Crops for Sale and Other Cereals were removed). In some cases an arbitrary crop entry has been rounded up or down to maintain a list of 50 crops in each rotation.

Crop	Arable, clay	Arable, sand	Cattle, clay	Cattle, sand	Pigs, clay	Pigs, sand	Org., clay	Org. cattle, sand	Org. others, sand
Spring barley	14	21	8	10	11	14	8	4	6
Winter barley	2	2	1	1	4	4	0	0	0
Winter wheat	19	12	7	5	25	21	9	1	1
Rye	0	2	0	0	1	2	2	2	2
Oats	1	2	0	0	1	1	2	1	1
Peas	0	0	0	0	0	0	1	0	0
Rape	1	0	1	0	0	1	0	0	0
Grass in rotation	5	3	9	11	2	2	14	20	17
Potatoes	0	1	0	0	0	0	0	0	0
Sugar beet	5	1	7	1	2	0	2	0	0
Silage cereals and maize	0	2	14	19	0	0	8	17	18
Setaside	3	4	3	3	4	5	4	5	5
Total	50	50	50	50	50	50	50	50	50

Table 4 Deviations to the proportion of crops grown by different farm types under the Pesticide scenario (P).

Crop	Arable, clay	Arable, sand	Cattle, clay	Cattle, sand	Pigs, clay	Pigs, sand	Org. clay	Org. cattle, sand	Org. others, sand
Spring barley	0	1	0	0	-1	-3	0	0	0
Winter barley	0	0	0	0	0	0	0	0	0
Winter wheat	0	0	0	1	1	4	0	0	0
Rye	0	0	0	0	0	0	0	0	0
Oats	1	1	0	0	0	-1	0	0	0
Peas	0	0	0	0	0	0	0	0	0
Rape	0	0	0	0	0	0	0	0	0
Grass and clover seed	0	0	0	0	0	0	0	0	0
Potatoes	0	-2	0	0	0	0	0	0	0
Sugar beet	0	0	0	0	0	0	0	0	0
Silage cereals and maize	0	0	0	0	0	0	0	0	0
Setaside	-1	0	0	-1	0	0	0	0	0

Table 5 Deviations to the proportion of crops grown by different farm types under the Herbicide scenario (H).

Crop	Arable, clay	Arable, sand	Cattle, clay	Cattle, sand	Pigs, clay	Pigs, sand	Organic, clay	Org. cattle, sand	Org. others, sand
Spring barley	-1	0	-1	-1	-2	-5	0	0	0
Winter barley	0	0	0	0	0	0	0	0	0
Winter wheat	0	0	0	1	2	6	0	0	0
Rye	0	0	0	0	0	-1	0	0	0
Oats	1	0	0	0	0	-1	0	0	0
Peas	0	0	0	0	0	0	0	0	0
Rape	0	0	0	0	0	0	0	0	0
Grass and clover seed	0	0	0	0	0	0	0	0	0
Potatoes	0	0	0	0	0	0	0	0	0
Sugar beet	0	0	1	0	0	0	0	0	0
Silage cereals and maize	0	0	0	0	0	0	0	0	0
Setaside	0	0	0	0	0	1	0	0	0

Table 6 Deviations to the proportion of crops grown by different farm types under the Differentiated Herbicide scenario (DH).

Crop	Arable, clay	Arable, sand	Cattle, clay	Cattle, sand	Pigs, clay	Pigs, sand	Organic, clay	Organic-cattle, sand	Organic others, sand
Spring barley	0	0	0	0	-1	-2	0	0	0
Winter barley	0	0	0	0	0	0	0	0	0
Winter wheat	0	0	-1	1	1	3	0	0	0
Rye	0	0	0	-1	0	0	0	0	0
Oats	1	0	0	0	0	-1	0	0	0
Peas	-1	0	0	0	0	0	0	0	0
Rape	0	0	0	0	0	0	0	0	0
Grass and clover seed	0	0	0	0	0	0	0	0	0
Potatoes	0	0	0	0	0	0	0	0	0
Sugar beet	0	0	1	0	0	0	0	0	0
Silage cereals and maize	0	0	0	0	0	0	0	0	0
Setaside	0	0	0	0	0	0	0	0	0

Table 7 Deviations to the proportion of crops grown by different farm types under the Unsprayed Field Margin scenario (UM).

Crop	Arable, clay	Arable, sand	Cattle, clay	Cattle, sand	Pigs, clay	Pigs, sand	Organic, clay	Organic cattle, sand	Organic others, sand
Spring barley	-1	-1	0	-1	-2	-5	0	0	0
Winter barley	0	0	0	0	0	0	0	0	0
Winter wheat	0	0	0	1	2	6	0	0	0
Rye	0	0	0	0	0	-1	0	0	0
Oats	1	1	0	0	0	-1	0	0	0
Peas	0	0	0	0	0	0	0	0	0
Rape	0	0	0	0	0	0	0	0	0
Grass and clover seed	0	0	0	0	0	0	0	0	0
Potatoes	0	0	0	0	0	0	0	0	0
Sugar beet	0	0	0	0	0	0	0	0	0
Silage cereals and maize	0	0	0	0	0	0	0	0	0
Setaside	0	0	0	0	0	1	0	0	0

The amount of pesticide used was also determined from simulations from ESMERALDA (Table 8). The differences between the Baseline scenario (B) and the general pesticide reduction scenarios (P, H, DH) were determined proportionally and these proportions used to alter pesticide application rates within ToxImpact (Table 9). In the Organic scenario (O), the conventional farms used pesticides according to scenario B, and the organic farms use no pesticides. Similarly, in the unsprayed field margins, pesticides were not used, and the reduction in pesticide usage will be an emergent property of the width of the field margin. In this case the 5m with corresponds to an 11% reduction in the area to which pesticides are applied.

Table 8 The resultant number of standard doses of pesticides of different classes per year within each of the four sets of does scenarios used, as predicted by ESMERALDA

	Baseline	Pesticide (P)	Herbicide (H)	Diff. Herbicide (DH)
Herbicides	0.93	0.64	0.54	0.76
Fungicides	0.59	0.47	0.54	0.56
Insecticides	0.24	0.16	0.25	0.24
Growth regulators	0.18	0.16	0.16	0.17
Total	1.94	1.43	1.49	1.73

Table 9 Changes in likelihood of pesticide application relative to Baseline (B). The implementation within ToxImpact was to alter the chance of a pesticide application occurring from 1.0x to Yx where x is the original likelihood of application for any management plan and application, and Y is the value in this table.

	Baseline	Pesticide (P)	Herbicide (H)	Diff. Herbicide (DH)
Herbicides	1.00	0.69	0.58	0.81
Fungicides	1.00	0.80	0.92	0.96
Insecticides	1.00	0.66	1.04	1.03
Growth regulators	1.00	0.89	0.89	0.95

Further assumptions that were made regarding the five main scenarios:

- Crop growth is assumed to be optimal, following the assumption that all farmers grow their crops optimally following agricultural advisory guidance. This results in uniform stands of crops within the model without significant areas of weedy patches or bare soil.
- A reduction in the herbicide usage is to a large extent counterbalanced by the farmer by reducing dosage, improving application timing, removing unnecessary prophylactic applications, and altered crop choice, such that the result of the herbicide reduction scenarios is not structurally diverse weedy crops, but in fact not significantly differing to the pre-reduction scenario. The extent to which this assumption is important is also investigated in this study (see Technical Scenarios).
- When the farmer applies a pesticide, he opens up the tramlines, which improve the skylarks access to the crop by 45%.
- All unsprayed field margins are assumed to be both unsprayed and unfertilised, resulting in patchy, weedy margins where crop biomass is reduced by 10%. Again this assumption is examined by the technical scenarios.
- The effect of a habitat being patchy is to increase the habitat quality and likelihood for skylark nest selection by 30% (assuming it is not in proximity to trees).
- That organic crops have a lower total biomass and height than their conventional counterparts.

5.4 Technical Scenarios

The purpose of the technical scenarios was to elucidate in importance about assumptions or input parameters on the overall impact of the five main scenarios. Hence, these scenarios are primarily designed to be compared to the baseline scenario B.

Fourteen technical scenarios were defined:

T1) Herbicide Crop Only – this scenario is as scenario H, but with only the changes in crop area incorporated, and no changes in pesticide usage. This scenario indicates the impact of crop changes alone on the assessment. Crops were as scenario H, pesticides as scenario B

T2) Herbicide Chemical Only – This is the counter-part to T1. In this case the crop changes were not incorporated, but changes in chemical usage were. Crops were therefore as for scenario B, but pesticides as scenario H.

T3) Pesticide X2 – This scenario evaluates the impact of a doubling of the pesticide reductions from scenario P. All inputs are as for scenario P, but with the values from Table 9 being reduced further by the same reduction factor used in scenario P (e.g. 0.80 to 0.60, 0.89 to 0.78).

T4) Winter Wheat 1 – this scenario was designed to single out the impact of increasing the area of winter wheat at the expense of spring crops. This is of interest because an increase in winter wheat is one of the factors which is altered in the main scenarios. In this case 90% of spring cereal crops in the arable clay and arable sand farm types were replaced with winter wheat. All other factors were the same as for scenario B.

T5) Winter Wheat 2 – As for T4 above, but in this case the only farm types in the landscape were arable clay and arable sand farms. This scenario therefore simulates a winter wheat dominated arable landscape as is a number of regions in Europe.

T6) Organic 100% - this scenario evaluates the impact assuming that all farms in the landscape were organic farms based on equal proportions of the three organic farm types defined in scenario B.

T7) Unsprayed Field Margins 5m – This scenario is identical to UM, but with using the crop allocation from scenario B. Hence this scenario indicates the effect of the unsprayed margins in the absence of crop changes.

T8) Unsprayed Field Margins 10m – This scenario is identical to T7, but with the width of the margins increased to 10m instead of 5m. The area which is subsequently unsprayed is 21%. All other inputs are as for scenario UM.

T9) Unsprayed Field Margins 20m – This scenario is identical to T7, but with the width of the margins increased to 20m instead of 5m. The area which is subsequently unsprayed is 40%. All other inputs are as for scenario UM.

T10) Field Margin Area 5% - this scenario evaluates the impact of only placing unsprayed 5m margins around 50% of fields, giving an approximate reduction in area sprayed of 5%. Selection of fields to receive margins was random. All other inputs are as for scenario T7.

T11) Field Margin Area 2.5% - as T10, but with only 25% of fields having unsprayed field margins. All other inputs are as for scenario T7.

T12) Unsprayed Margin 50% Patchy – this scenario examines the assumption that the unsprayed margins are assumed to have patchy crops. In this case, only 50% of these margins are designated as patchy. All other inputs are as for scenario T7.

T13) Unsprayed Margin Non-patchy – as for T12, but no margins are considered to be patchy. All other inputs are as for scenario T7.

T14) No weed control – this scenario considers an extreme situation whereby all fields are without weed control and will have weedy and patchy crops leading to greatly improved accessibility for the birds. Crop biomass is also assumed to be reduced by 10%. This represents the best possible structural conditions within the limits of the actual crops that are grown. Crops are as scenario B, but no herbicides are applied. Herbicide applications are not replaced by mechanical weeding.

Resulting Data – in all cases 10 replicates of each scenario were run for 55 years and three statistics were generated based on the last 33 years of simulation. The use of the last 33 years allows time for the simulations to settle down to a stable equilibrium and avoids noise due to random starting conditions:

i) The annual population maximum size (adults plus young of the year), measured after reproduction, but before over-wintering mortality.

ii) The proportion of the adult population not breeding on the 15th May each year (hereafter referred to as the floating population).

iii) The mean number of offspring per breeding female reaching the age of 18 days old. This measure is used because it is approximately the time when a female will stop feeding her chicks and potentially start a new brood cycle. This figure will necessarily be lower than published figures from field results because the empirical data must be taken from birds in the nest and birds of 18 days old have been out of the nest for approximately one week, during which time they will have experienced a certain level of mortality.

In all cases confidence limits were calculated for the mean of the 33 ten-replicate means. This gives a wider confidence limit than would be the case if the raw data were used, so these can be considered a conservative estimate and should be used as a guide to variability only.

6 Results

The Baseline scenario resulted in a stable population of skylarks with an approximately 1:1 sex ratio. The maximum population size was predicted to be approximately 15 birds per square kilometre (including young). Annual variation in population numbers caused by weather was low (Fig 2a). The average size of the floating population was 21%, meaning that in mid-May there was an average of 21% of adults that were not involved in breeding. This figure will also include those birds that have not yet started but will breed, and those which have just abandoned breeding (e.g. in winter crops), so it is likely to be a over-estimate. However, a figure of 21% represents a large buffer against poor breeding years and indicates a healthy population.

In all scenarios, with the exception of T5, a stable population of skylarks was achieved (Fig. 2ab). Within a scenario population levels were relatively constant resulting in narrow confidence limits to the mean population size despite the relatively low number of replicates (Tables 10 & 11).

Of the five main scenarios, two scenarios, Differentiated Herbicide (DH) and Organic (O), did not significantly affect the skylark population. In the case of the organic scenario the reason is clearly that the increase of 25% in organic farming gives less than 2% increase in the total area of land under organic farming, hence with the current level of replication, this difference is not detectable. Similarly for scenario DH, the difference compared to the Baseline is small relative to the other scenarios. In all cases of general pesticide removal scenarios (P, H, DH), the proportion of non-breeders on May 15th decreased, indicating that the average population surplus was lower than Baseline for these scenarios. These impacts are caused by a combination of two factors, namely changes in crops grown and the fact that by not spraying, tramlines are not opened, denying the birds access to food resources in the crop. By contrast, scenario UM had an increased population size, increased floating population and increased number of chicks per female compared to all other scenarios. This is clearly due to the assumptions that these margins have ample food (see Chiverton & Sotherton, 1991) and have a structure which does not impede access for nesting or foraging.

The results from the technical scenarios are presented in Table 11. Scenarios T1 and T2 indicate that the reduction in skylark population size observed in scenario H, was due to both the reduction in spraying intensity and the change in crops which was also a feature of the scenario. The crop change appears to be the more important of the two factors. Scenario T3 indicates that a further doubling of the pesticide reductions did not lead to a doubling of the skylark population decrease, but only a 2% further drop. Scenario T4, examines the impact of a larger switch from spring to winter sown cereals. This scenario effectively equates to a replacement of spring cereals on arable farms, assuming arable farms cover approximately one third of the landscape. The impact is to lower the population size by 25% and to reduce the floating population to one third of the baseline figures. Scenario T5 indicates that if this change is assumed to affect the whole landscape, e.g. in an area where there is no dairy farming, then the population of skylarks is no longer sustainable. This scenario predicts an almost 10% per annum decline in population numbers and a very low mean chick output per breeding female. The floating population is relatively high, but this is caused by birds being forced out of habitats (winter wheat) due to its growth characteristics, before the floating population measure is taken. Hence, in the case of this declining population this is more a measure of the birds that chose poor habitats to breed in rather than an estimate of the reproductive surplus.

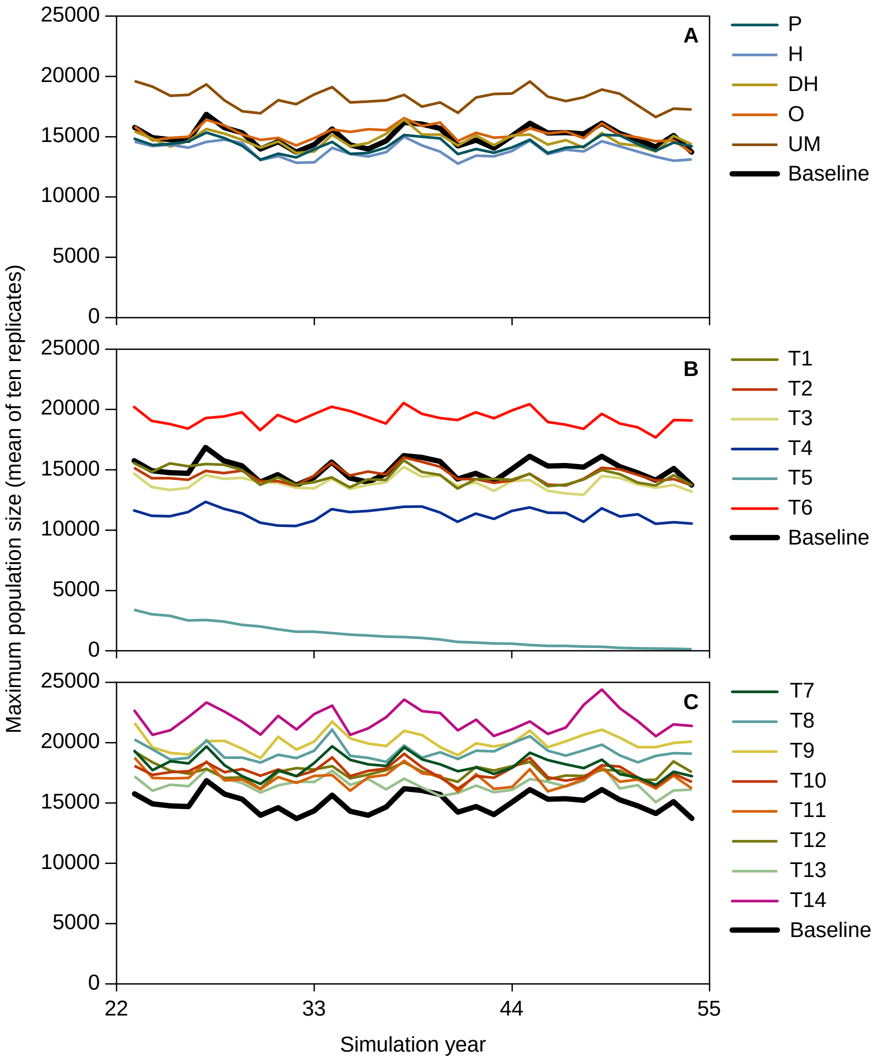

Figure 2 Maximum skylark population sizes as a mean of ten replicates. a) for the five main DØRS tax measure scenarios for 33years of a 55 year simulation. b) as ‘a’ but for the 6 miscellaneous technical scenarios (T1-T6). c) For technical scenarios T7-/14 representing scenarios related to the impact of unsprayed margins.

Table 10 Overall mean statistics for the results of the baseline and five main scenarios. Population size is the overall mean maximum annual population size. Floating population proportion is the mean proportion of adults not breeding on May 15th. No chicks per breeding female is a mean of the total annual output of young surviving to day 18 divided by the number of females which attempted breeding. Difference between baseline and scenario population size is simply dependent on overlap of the 95% confidence limits.

Main Scenario	Population Mean	95% c.i.	Floating Population Proportion	95% c.i.	No. Chicks per breeding female	5% c.i.	Diff. Pop.Size cf Baseline	Population Size Relative Change to Baseline
Baseline (B)	14997	271	0.21	0.022	2.61	0.071	N/A	N/A
Pesticide (P)	14264	199	0.12	0.015	2.37	0.055	Yes	0.95
Herbicide (H)	13814	210	0.11	0.015	2.34	0.057	Yes	0.92
Differentiated Herbicide (DH)	14707	207	0.15	0.015	2.43	0.063	No	0.98
Organic (O)	15236	213	0.17	0.017	2.47	0.064	No	1.02
Unsprayed Field Margins (UM)	18149	256	0.31	0.014	3.01	0.050	Yes	1.21

Table 11 Overall mean statistics for the results of the technical scenarios. Population size is the overall mean maximum annual population size. Floating population proportion is the mean proportion of adults not breeding on May 15th. No chicks per breeding female is a mean of the total annual output of young surviving to day 18 divided by the number of females which attempted breeding.

Technical Scenario	Population Mean	95% c.i.	Floating Population Proportion	95% c.i.	No. Chicks per breeding female	95% c.i.	Sig. Diff Pop.Size cf Baseline	Population Size Relative Change to Baseline
Herbi. Crop Only T1	14430	226	0.15	0.016	2.42	0.064	Yes	0.96
Herbi. Chemical Only T2	14530	202	0.12	0.016	2.36	0.058	No	0.97
Pesticide X2 T3	13874	182	0.11	0.013	2.29	0.052	Yes	0.93
Winter Wheat 1 T4	11264	180	0.07	0.009	2.20	0.061	Yes	0.75
Winter Wheat 2 T5	1213	326	0.13	0.025	1.76	0.068	Yes	0.08
Organic 100% T6	19312	235	0.24	0.010	2.70	0.058	Yes	1.29
UM 5m T7	18098	279	0.34	0.015	3.08	0.057	Yes	1.21
UM 10m T8	19226	221	0.34	0.011	3.15	0.057	Yes	1.28
UM 20m T9	20049	241	0.36	0.013	3.27	0.062	Yes	1.34
UM 5% area T10	17551	219	0.28	0.015	2.89	0.058	Yes	1.17
UM 2.5% area T11	17011	245	0.25	0.015	2.73	0.064	Yes	1.13
UM 50% Patchy T12	17621	211	0.29	0.013	2.95	0.050	Yes	1.17
UM 0% Patchy T13	16555	221	0.25	0.016	2.77	0.046	Yes	1.10
No Weed Control T14	21890	338	0.26	0.020	2.88	0.092	Yes	1.46

Scenario T6 indicates the potential benefit of extensive organic farming over the whole landscape, i.e. total replacement of conventional farms. This scenario resulted in a 29% increase in skylark numbers and a slightly higher floating population.

Scenarios T7-T14 concentrate on various aspects of unsprayed field margins. Scenario T7 does not differ from scenario UM, indicating that the unsprayed margins were able to mitigate the impact of crop changes, at least with the assumption that these margins were patchy and less dense than the sprayed crop. Increasing the width of the field margins increased the positive benefit, but not proportionally to the size increase. A four times increase in width (T9) gave a 34% increase in population size compared to the 21% achieved by the 5m margin. The 10 margin (T8) was intermediate between these two. T10 and T11 evaluate the impact of reducing the area covered by the unsprayed margins, but maintaining the 5m width. T10 approximates to random allocation of margins to 50% of fields, and T11 to 25%. Considering that in T11 only one quarter of the arable area is untreated with pesticides, the impact is still a 13% increase in bird population size. One of the key assumptions made here is that the unsprayed field margin is patchy and therefore, all other things being equal, good nesting and foraging habitat. If this assumption is relaxed, and only a proportion of the margins are considered patchy, then their value as habitat will be decreased. This is a more realistic assumption if the unsprayed margins are fertilised. Scenarios T12 and T13 look at the consequence of 50% and 0% of the margins from the T7 scenario being considered patchy. The increase in skylark population size is predicted to be 17 and 10% compared to 21%. The T13 with many non-patchy margins is therefore worse than the situation where we only have 25% of margins, but these are of high habitat quality.

The no weed control scenario, T14, indicates the maximum possible skylark population size given that crops are still grown. This scenario assumes that crops are accessible for breeding and foraging all year, hence the limits to population growth are food availability and crop husbandry activities (ploughing, harvest etc.). This scenario predicts a 46% increase in population size, which would bring the population size up almost to its 1976 level (Jacobsen, 1997). Note that here output per female is not that much higher than in other scenarios, the difference is therefore in the number of breeding females which is a function of the assumption about the open structure of the crops and would probably not be realistic unless fertiliser applications were also reduced.

7 Discussion

The extent to which the results presented here can be interpreted as applying to wildlife on farmland in general is an important issue to consider. Species will often respond differently to the same factors; hence if we are limited in the number of species we can consider then it is important to use good indicators. The skylark has a diet which is representative of a range of breeding birds in lowland farmland habitats (Wilson et al, 1996), it nests and feeds the field surface and is therefore exposed to farming operations, and must use the crop structure for these processes. Agriculture therefore provides the habitat for these species, but also makes them vulnerable to agricultural impacts on their food and nesting requirements. As a result the skylark has become a flagship species in Europe as an indicator for agricultural wildlife and as an example in the search for the reason for farmland bird declines (Donald, 2004) and has also been used to assess impacts of pesticides (e.g. Topping & Odderskær, 2004). One area where the skylark is not such a good representative is those species which are tightly bound to woody habitats. Bird species such a yellowhammer and whitethroat rely on hedgerows for breeding habitat and generally feed closer to the edge of fields than the skylark. There is little doubt that the direction of influences on these species is the same as for the skylark, but the scale of change is probably different. This suggests that in cases where we are considering protection of the edges of fields using unsprayed margins, then the impact of these measures is likely to be large and positive for these species.

The results that reducing pesticide usage will be bad for the skylark, and by inference other field-living species, seems counter-intuitive. However, it must be remembered that these scenarios are not controlled experiments where we vary only the factor of interest, but predictions of what might happen in the real world, where altering one factor causes changes in others. It is our contention that the models predict realistically what will happen following the implementation of the different scenarios. This includes the farmers response in altering his crop management and crop choice.

Linked to the level of realism is the fact that these results are for a landscape which is representative of the Danish mean situation. However, it is not a typical Danish landscape (e.g. typical landscapes won’t have the mean hedgerow length, mean organic farm area etc.). The results thus indicate effects expected on a national scale, but will vary in landscapes with different structures.

An understanding of the relationships between skylarks and vegetation structure is essential in the interpretation of these results, since in the majority of cases it is these relationships which ultimately govern population size. There are two main aspects to this interaction. The first is that the female skylark requires certain conditions to be met before an area can be used for nesting. These conditions require that she has access to the vegetation and that it is not too high or dense but has a minimum cover (Schläpfer, 1988; Wilson et al, 1997). Skylarks are originally steppe birds, and as a result they prefer open vegetation that provides enough cover to hide the nest, but affords easy access and allows for the detection of predators. Tall structures, e.g. hedges, are avoided because predators such as crows can use them as vantage points to find the nests. Given this description it is easy to see why most crops are potentially suitable nest sites for at least part of the growing season, but equally that dense tall crops are unlikely to be attractive to skylarks as breeding habitat. The second aspect is foraging. Skylarks need access to food in the habitats they use for foraging. This food is often abundant in late summer, but access is restricted in many crops because of the tall and dense nature of the crop itself. Studies have demonstrated that 45% of foraging in tall crops occurs in the tramlines created by the farmer when applying pesticides or other crop husbandry activities (Odderskær et al, 1997), even though these areas are less than 5% of the total field area. Hence removal of tramlines will seriously decrease the ability of the birds to forage in crops. Whilst the birds do have the ability to forage from other areas in a heterogeneous landscape, few field nesting birds will have uninterrupted access to forage throughout their breeding season if they cannot feed from the cropped area. The structure of the crop, whether open and patchy or uniform, tall and dense, plus whether there are tramlines present will therefore have a great impact on the ability of the skylark to forage. Naturally, if there is no food in the crops, due to heavy use of insecticide or lack of suitable conditions for arthropods, then improving the crop structure will not improve the skylark reproductive capacity. But all things being equal, a denser and perhaps taller crop structure will certainly decrease skylark numbers.

When considering the pesticide reduction scenarios, there are two opposing forces at work. One is the reduction in food decreases which would occur if pesticides are not used, and potentially the increase in food availability if weeds increase, leading to increases in arthropods. The other force is the negative change in crop structure caused by a switch to winter cereals, which are denser earlier in the season than spring-sown cereals, and a reduction in the number of fields with tramlines. A further complication is added by the assumption that weeds will increase if herbicides are decreased. This is unlikely to happen given the herbicide reductions considered here for two reasons. The first is that Danish studies (Esbjerg et al, 2002) have shown that reduction down to one quarter of the standard dose is needed before weeds increase significantly. The second is that the farmer will alter his crop choice and management to avoid weedy fields, hence the increase in winter cereals which are easier to maintain weed free. The overall result is that weeds would probably not increase significantly, and even a doubling of the currently very low biomass found would not lead to noticeable increases in food, but changes to crop structure would significantly reduce skylark access to the food that is present, hence giving, on balance, a negative impact. A similar result was obtained by Jepsen et al (2004) when evaluating a total scenario of a total pesticide ban. In this case increasing areas of silage grass led to a small but general decline in skylark numbers. Another interesting factor is that insecticide usage does not always result in obvious negative influences on skylark reproduction. Odderskær et al (1997) demonstrated that pesticide effects are most serious in seasons with average conditions, where they can tip the balance. In years with bad weather or excellent conditions insecticides may not exert a significant influence. A similar result was obtained via modelling using ALMaSS (Topping & Odderskær, 2004). The idea therefore that removing insecticides will be a panacea for the ills of the farmland bird population is not well founded. On the other hand, the effect of pesticides is to remove food sources, and assuming other things do not change, their use has predictably negative consequences for the skylarks food. This is part of the reason for the increase in larks in the 100% organic scenario (T6), where the increase in bird population sizes are a function of different crop structures and total removal of pesticides.

The conclusions drawn here at first seem to contradict those drawn by Esbjerg et al (2002), who found more larks visiting low herbicide dosage plots. However, it should be noted that the dosages where these effects were significant were very low (25% of the normal rate used, i.e. less than 25% of the suggested field rate), and at this level there was a significant response in terms of weeds. There was no attempt to link the increased number of birds visiting the plots to their reproductive success, and the increase in visits indicates a preference only, but cannot be taken to mean that the increase was in any way proportional to the increased habitat quality. When viewed in this way, it is clear that the results of Esbjerg et al (2002) support the assumptions made in this modelling exercise, whereby an improved structure to the crop will increase foraging. Unfortunately the study did not include detailed habitat structural measurements, hence the increase in feeding rates cannot be compared to model predicted increases.

The assumption of non-increasing weed biomass in the general pesticide reduction scenarios also means that these scenarios will not be expected to increase weed diversity of the cultivated area. However, if farmers were to allow more weeds in the crop, diversity as well as biomass would probably increase. This is important because there has been a dramatic decline in weed diversity with the intensification of agriculture, and many arable weeds of the past are now plants considered worthy of conservation (Andreasen et al, 1996).

The scenarios concerning unsprayed field margins are of particular interest. Assuming a reasonably large area of land can be managed in this way, and that these areas become structurally suitable for the skylark, then skylark numbers could be dramatically increased by this method. However, it should be noted that over and above the assumption of increased habitat quality, two factors have not been evaluated in these scenarios. The first is that in the skylarks case, unsprayed field margins will not have a beneficial impact if placed along hedgerows, due to the birds avoidance of tall structures. The second is that these scenarios assume random allocation of unsprayed margins to fields. In the cases where not all field had unsprayed margins, this results in a maximised distribution of unsprayed margins through the landscape. Concentration of these margins in a single area would probably not have such an advantageous effect since we can see from the results of increased margin area that we obtain diminishing returns in skylark increases with increasing area. Of the farmland birds expected to benefit from these margins (e.g. partridge & pheasant, Chiverton (1999)), the skylark is probably the only bird to which the former caveat will apply. The latter will probably apply generally, but maximally distributed margins will not lead to population increases in areas where habitat quality is so low that the addition of unsprayed margins does not bring it up to a minimum acceptable level. Note also that if unsprayed margins are managed in such a way that they do not have more weeds or are more open in structure, there will be no increased benefit to the birds. However, they will still retain the advantage of effectively buffering adjacent small biotopes from pesticide drift. This is a significant benefit since herbicide drift into field boundaries is considered to be a serious cause of plant species loss (Aude et al, 2004). Scenarios of general pesticide reduction will also help in this regard, but do not confer the year on year protection that a non-sprayed buffer will afford. If fertiliser free margins are used, leading in time to the patchy margins assumed here, then these benefits will be massively increased by reducing nitrogen inputs to field boundaries.

Another problem with modern agriculture is the more homogenous landscape results in synchronous effects, including pesticide applications which can result in temporal fluctuations in resource availability. For example, if all winter wheat fields are sprayed with insecticide in the same week, and there are no other crops or other habitats in the area, birds with territories there will lack food. Unsprayed margins, or measures ensuring increased crop diversity will therefore be advantageous.

The no weed control scenario suggests that it is possible to reverse the observed decline in the skylark population by radically changing the management of crops. This would generally have very great benefits to wildlife in the agricultural landscape, but at a significant cost to production. A switch to low impact organic farming would provide two-thirds of this increase, but also probably at considerable economic cost. The lesson seems clear, it is hard to maximise wildlife benefits without at the same time losing yields or increasing costs. The reverse situation was demonstrated by the winter wheat scenarios (T4 & T5), where decreasing population and even extinction is possible by an unfortunate change in crops grown. This situation is not so far fetched as it may seem. Skylark, and other farmland bird populations, are still in decline in the UK, which has only a slightly greater proportion of winter cereals than in Denmark, although it has a reduced proportion of beneficial spring cereals. Although not conclusive, it is quite possible that this subtle shift in crop choice is the cause of their populations continual decline. This is further supported by evidence that suggests that it is not the success or failure of individual broods that is limiting population growth, but the number of broods possible (Chamberlain & Crick, 1999; Donald & Vickery, 2000). The number of broods possible in agricultural land is tightly related to the crop structure and therefore the choice of crops.

In general the results presented here, whilst at first seeming to be counter-intuitive are in line with the results of previous studies on single elements of this complex system. Similar results were obtained by Watkinson et al (2000) who looked at the impact GMO crops might have on skylarks and concluded that the impact depended on whether farmers with weedy crops or weed-free crops started to use GMO crops. The point is that the effect is often more related to man’s behaviour and responses than to the direct action of GMOs or in our case pesticides. In our case it is clear that pesticides have a negative influence per se, but their removal may result in the increase in other even more deleterious factors.

8 Conclusions

Crop phenology and structure is the major determinant of the success of the skylarks, since they are dependent on having some vegetation, but not too much for breeding and foraging. Very tall crops (like winter rape) are almost never used for breeding. The DØRS scenarios had little winter rape and therefore were generally more positive for that, but indicate that although the current Danish population is stable, it would not take a dramatic change in cropping systems to start a population decline.

Given this situation it is clear that there is a limit to the improvement that can be made by increasing food resources and access to food resources. Improvements that would give further benefits without the detrimental effects of increasing the area of open habitats by tree removal are in changes in the choice of crops grown, which would increase the number of broods possible.

In summary it is the generally intensive nature of agriculture not the amount of pesticides which are important in limiting skylarks, and other wildlife on the cultivated areas. This includes tightly growing crops out-competing weeds for light, fertiliser usage, a shift to winter cropping and structural changes removing small biotopes and simplifying the agricultural landscape. Pesticides are an integral part of this process, but almost certainly not the most significant aspect. Any measures which decrease the dense uniform structure of the modern day farming landscape will therefore have a positive benefit. If unsprayed field margins, especially fertiliser free margins, could be introduced over a wide area, the benefits of this measure to wildlife would be far greater than any of the general reduction in pesticide usage scenarios considered here.

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10 Addendum

For comparison with the overall DØRS integrated project and their report, it is important to note that the unsprayed margin scenario (UM) differs from the economic scenarios used by DØRS in that the cost of having unsprayed margins also being unfertilised was not considered in DØRS's economic scenarios. In this respect T13 is the correct scenario for comparison to the main DØRS unsprayed margin scenario, since it assumes that none of the margins are patchy.

A final technical scenario T15 was requested by DØRS after completion of the initial report. The details of this scenario and the results are:

T15) Unsprayed Field Margins 15m – This scenario is identical to T7, but with the width of the margins increased to 15m instead of 5m. The area which is subsequently unsprayed is 31%. All other inputs are as for scenario UM.

Results:

Table 12 : The results of the additional technical scenario T15

Technical Scenario	Population Mean	95% c.i.	Floating Population Proportion	95% c.i.	No. Chicks per breeding female	95% c.i.	Different Pop.Size cf Baseline	Population Size Relative Change to Baseline
UM 15m T15	19633	221	0.36	0.012	3.23	0.06	Yes	1.31

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The impact of pesticide usage reduction scenarios on skylarks was evaluated using a landscape- scale individual-based model. The results of the scenarios indicated that the general reductions in pesticides scenarios would have a negative impact on skylarks due to side-effects of altered farm management, despite the positive influence of having less pesticide in the environment. Technical scenarios indicated that the greatest benefit to skylarks is by altering the structure of the crop such that they have access for nesting and feeding. Of the scenarios investigated the greatest benefit was obtained from the use of unsprayed field margins. Large benefits could also be achieved using unsprayed margins even if they were not added to all fields. Unsprayed field margins will also have other significant benefits to wildlife by protecting the non-cultivated areas from spray drift.

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