Bilagsrapport i projektet EUs landbrugsordninger og pesticidpolitikken

Report on the wildlife impacts of unsprayed margin and quota scenarios as modelled in ALMaSS

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Indholdsfortegnelse

Introduction

This report forms a part of the overall evaluation of the impacts of two scenarios for reducing pesticide usage in Danish agriculture, and specifically deals with the predicted impacts on six indicator species modelled in the ALMaSS system (Topping et al, 2003). These species were chosen as being common species in the agricultural system for which a great deal of information is available to build detailed behavioural and ecological models. They are all either typically used in pesticide risk assessments for non-target organisms or considered species sensitive to pesticide usage.

The project work package reported here relied on input from other sections and models in the project which dealt with the area coverage and farm type, and expected changes in farm management. These outputs form the input to the ALMaSS scenarios and were therefore externally fixed.

The report is divided into a general methods description and two sections related to two phases of the work carried out under this project. The general methods description details the ALMaSS model used for all modelling in the following sections and includes a general introduction to testing this type of model. Section I details the development of a relatively simple impact index designed to summarise impacts of scenarios on each species in a way more easily communicated to non-ecologists. Section II describes the application of this index to ALMaSS analysis of the two policy scenarios, namely an unsprayed margin scenario, and a pesticide quota scenario.

General Methods

ALMaSS (http://www.dmu.dk/International/AnimalsPlants/ALMaSS/)

The Animal Landscape & Man Simulation System (Topping et al, 2003a) has a long pedigree. ALMaSS was designed as a system to evaluate the impact of human management of landscapes on key species of animals in the Danish landscape, and has been developed over a period of 10 years. It was not created with a clearly focused goal in mind but to be a highly flexible system capable of simulating a wide range of interactions between landscape structure, management and animal ecology. Thus, ALMaSS is a flexible system for implementing agent-based models[1] of selected species, with the aim of predicting the impact of changes in management of the Danish landscape.

ALMaSS can be separated into two main components, the landscape and animal models. The landscape comprises a topographical map, together with strategies of human management, primarily farming but also other management such as mowing of roadside verges; traffic and road networks; weather; sub-models for calculating arthropod bio-

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[1] Agent-based models are models consisting of autonomous agents, each obtaining information from their local environment in order to achieve some purpose. In our case the purpose for animals is survival and reproduction

mass; models for general vegetation and crop growth; and also models of the environmental fate of pesticides. These sub-models and processes are updated on a daily basis during the simulation and provide the potential to model factors such as farm and crop management in great detail. The farm management modules permit the definition of different farm types each with their specific crop choices and type of management (e.g. conventional pig, arable, and dairy production, organic variants of these).

Each farm mapped in the landscape is allotted a farm type and the farm manager, also an agent, applies management to his fields in terms of sowing crops and subsequent crop husbandry whilst reacting to weather and soil conditions. Crop husbandry is highly detailed (see Topping & Odderskær, 2004) and simulates all farming activities that would be carried out on that crop (e.g. ploughing, harrowing, sowing, fertilizer applications, pesticide applications, harvest, and post harvest operations). Applications of pesticides and fertilizers can be allocated specific characteristics (e.g. amount and type), and may result in changes in the vegetation growth, arthropod biomass, and provide field specific information for animal models such as the type and amount of toxicant present.

The topographic map utilized by the landscape has a resolution of 1 m^2 and typically covers an area of 100 km^2. Combining this map with the management information, weather and vegetation growth information creates a virtual reality into which the animal models are placed. The animal models are agents designed to simulate the ecology and behaviour of individual animals as closely as possible. Each agent moves around in its virtual world in much the same way that a real animal would move in the real world, picking up information from its surroundings as it goes and acting upon this in order to feed, and ultimately reproduce. Changes to the agent's environment occur on a daily basis as weather changes, vegetation grows, or the farmer manages a field.

A number of animal models exist for ALMaSS. Those used in this project are ***Alauda arvensis*** (skylark), ***Microtus agrestis*** (field vole), ***Bembidion lampros*** (beetle), ***Erigone atra*** (spider), ***Perdix perdix*** (partridge) and ***Lepus europeaus*** (hare). These range from species with highly detailed behaviour but low numbers (hare) to arthropods with simple behaviour but the necessity to handle millions agents concurrently (beetle simulations reached 25 million concurrent agents in this project). However, all models conform to a basic framework, essentially a state machine, whereby:

- Each animal has an initial state which is a behavioural state.
- There is a set of possible input events.
- Transitions to new behavioural states depend on input events.
- Actions (output events) are determined by behavioural state and environmental opportunities.

Each agent will cycle through this state machine at least once per simulation day, and potentially many times depending upon the inputs and outputs. For example a vole in the state 'explore' may explore his surroundings, resulting in the input that there is no food, and make a transition to the new state ‘dispersal’, this results in the action of dispersal which then triggers a transition to the state ‘explore’. This cycle may repeat itself until the vole finds food, dies, or runs out of time that day (Figure 1). Inputs may also occur as events, not under the control of the animal. For example if our dispersing vole is eaten by a fox it will make an immediate transition to the state ‘dying’. This event driven interaction is also the basis for modelling topical exposure to pesticide applications, meaning that an animal may only be exposed if it is in the location where the pesticide is sprayed at the time it is sprayed.

For further information and model specifics the reader should consult the online documentation, there is also a description in Danish and a description of crop growth modelling in Appendix A and B of Odderskær et al (2006).

Model Testing

Naturally we want to know whether a model used for prediction or understanding is reliable. However, this is rather a difficult and complex concept and there are rarely simple measures of model reliability. Therefore here we present the concept of model testing, often misleadingly referred to as validation. When referred to as validation what is often really being asked is how accurately the model predicts the outcome of the scenarios we are working with. The answer sought is often something like ‘we tested the predictions in ten different landscapes over 10 years and found that the model fit was 99%’. This approach is of course irrelevant since the purpose of developing and using models is precisely because we cannot in fact measure the responses in the real world, usually due to logistical or ethical constraints. What we really want to know is whether the model is fit for the purpose it is intended for. This section has been updated from Odderskær et al (2006) Appendix C, and included here to explain how testing of an agent-based model of this type is done, and why it differs from evaluation of simple mathematical models e.g. Leslie matrix models or differential equation based population growth models.

ALMaSS has been used in a very wide range of applications including pesticide risk assessment (Topping & Odderskær, 2003; Topping et al 2005; Sibly et al, 2005; Topping et al 2009), population genetics (Topping et al, 2003b; Pertoldi & Topping 2004ab), evaluation of land-use strategies (Jepsen et al, 2005), evaluation of landscape structure (Bilde & Topping, 2004; Jepsen et al 2004; Thorbek & Topping, 2005), animal behaviour (Jepsen & Topping 2004), policy analysis (Topping et al, 2005),and theoretical population dynamics (Sibly et al, 2009; Hendrichsen et al 2009; Nielsen et al, 2010). It has also been the subject of the most rigorous testing of any published model of its kind (see Topping et al 2010ab). In addition to the peer reviewed publications and testing ALMaSS has been described using a newly developed protocol for describing large agent-based models (ODdox), which unusually for models of this type provides a detailed commented version of the program code, hence ALMaSS is open to all to review (see http://www.dmu.dk/International/AnimalsPlants/ALMaSS/Documentation/).

ALMaSS is an agent-based model (ABM). It is an entirely different class of model to traditional population models which are usually based upon simple equations and relationships, i.e. a mathematically generated model. Agent-based complex systems such as ALMaSS are dynamic networks of many interacting entities mimicking the processes and interactions we see in the real world. Unlike statistical modelling there is no general framework for designing, testing, and analyzing bottom-up models as yet established, but recent advances in ecological modelling have come together in a general strategy called pattern-oriented modelling (Grimm ***et al***, 2005).

In pattern-oriented modelling the patterns refer to system properties that we see around us, e.g. population growth curves, spatial distribution of organisms, individual developmental rates, or any other measurable characteristic of a system resulting from the interaction of agents. Patterns are therefore the defining characteristics of the system being modelled.

The test of whether an ABM model is sufficient to be able to explain the cause of dynamics of the system is whether it can generate enough real world patterns accurately enough for the purpose of the model. If it can do this then the mechanisms that are used to build up the model are considered to be sufficient to generate system behaviour akin to that seen in the real world system. In other words if enough of the basic mechanisms are incorporated so that the overall model system responds to changes like the real world system, then sufficient confidence can be generated in the model to consider its use as a predictive tool. The ability to test the model in this way is partly a function of the rich output signals generated by such a model, unlike mathematical models which typically have very few dimensions to their output signals.

There are two kinds of pattern that must be evaluated, basic patterns and complex patterns. The complex patterns are what are termed ‘emergent properties’ and are the product of interactions between agents in the model. The basic patterns are features of the behaviour of the model that are directly programmed in. Hence checking these requires a range of trivial although laborious tests.

Checking the basic patterns are more or less checks on the system to see that all is functioning as intended. In ALMaSS this includes checks on weather input, landscape structure, vegetation growth, crop allocation, and not least crop or other habitat management. All these basic model parts need to be checked to see that they are producing the correct patterns. The same process is also carried out for the animal models. All kinds of individual behaviours need to be checked to see if they function correctly. These kinds of behaviours are those that are part of the processes directly programmed into the model and are not emergent properties. These basic checks can be thought of as a complex debugging process, i.e. afterwards the individual subcomponents of the model should behave according to expectations (e.g. a farmer should manage his crop following the plan provided).

Once all the basic patterns are correct the interactions between these results in emergent properties, i.e. complex patterns that are not directly programmed responses. Relatively few complex patterns are required for successful analysis since they are a function of the integration of a great many model components or mechanisms, but the more available the better. Probably the simplest and first of these is the plausibility criteria. In ALMaSS where we are simulating animal species this usually consists of an ecologist's evaluation of the behaviour of the model animals, i.e. do they behave like the real thing? Subsequently numerical comparisons with observed patterns are utilized. These patterns, such as changes in animal population numbers with time, are a result of integrating all factors affecting growth, mortality, reproduction and dispersal across spatially and temporally heterogeneous landscapes affected by agricultural management. In ALMaSS testing, the model's detail provides many different patterns for testing. For example in the hare model (Topping et al 2010a) emergent hare weights, sex ratios, survival probabilities, density, and time series patterns we all utilized.

If the model can predict a number of emergent patterns simultaneously from the same set of inputs (e.g. spatial distribution of animals at the same time as their developmental rates, and survival), then confidence in the model grows. As we increase the numbers of patterns that are used to compare model outputs to, we reduce the set of potential input parameter values (parameter space) that can be used. This is because as each new pattern is added it requires a certain specific set of parameter values to achieve a good match, as new patterns are used these new values must be selected from the set of values used to match the preceding patterns. The result is therefore an ever-dwindling range of possible parameter values that can achieve a match to all patterns; hence adding further patterns adds further limitations to the inputs. If sufficient real world data were available to add sufficient new patterns, then the continual reduction in input parameter space will eventually lead to a situation where deviation from a distinct set of parameters leads to failure to simulate all patterns. At this point the model cannot be improved and not only is the model structure (interactions between agents) well tested, but the inputs are also narrowed down, reducing uncertainty and providing a powerful predictive capability. Note that this has very little in common with statistical uncertainty which would assume that the variability in response is a function of the sum of standard errors around the inputs. This statistical approach does not take into account the mechanistic structure of the model nor the fact that biological systems are rich with feedback mechanism invalidating the basis for the statistical approach.

In developing ALMaSS component models this POM approach is seen as part of the modelling cycle as defined by Topping et al, 2010):

- Definition of the question.
- Model construction.
- Identification of performance criteria.

- Iterative testing and reformulation of the model, altering 'A, B & C' as necessary (POM approach).
- Sensitivity analysis of the resulting final model.
- Model documentation.
- Application of the model to the question defined in 'A'.

Developing the formalized testing following this protocol is a huge task and should not be attempted lightly. In the case of the hare and partridge model ALMaSS output was tested using more concurrent patterns than has ever been attempted in any POM study to date (Topping et al 2010ab), however, at a cost of more than four man years of effort in analysis alone. Skylark and vole POM publications are in preparation also based on similarly scaled analytical effort and in the skylark's case additionally a number of detailed field studies carried out over a period of 15 years. The results in all cases have been highly satisfactory, however, they also highlight those areas where more information is required e.g. in the case of the hare it is clear that the interaction between hare behaviour and crop structure is critical to the responses, and that crop structure should be a future focus of improvements in the model.

Section I: Development of the ALMaSS impact index

Background

Human land use is probably the most important driver of change in occurrence and abundance of wildlife in agricultural ecosystems. In many cases, it is clear whether a certain land use change will be beneficial or detrimental to a particular species, but not to what extent and how exactly it will affect populations. In other cases the results are difficult to predict e.g. changes in pesticide regimes which would on the face of it be beneficial to skylarks were predicted to have a net detrimental effects due to confounding behaviour of farmers altering crop choices (Jepsen et al, 2005). Resources for nature conservation are limited and it is often necessary to prioritize among related management actions or scenarios in terms of impact on biodiversity on the basis of limited knowledge. Similarly evaluation of policy impacts will rarely be straightforward and will typically be required quickly, i.e. with timescales that preclude field experimentation. In fact field studies aimed at providing such information (e.g. identifying ecological differences between organic and conventionally grown crops) are most often confined to small-scale inventories or population counts and provide little or no information about the importance of landscape context. Also, field studies rarely provide information about differences in occurrence of individuals between landscapes.

Landscape fragmentation and habitat loss lead to heterogeneous landscapes. The spatial scale at which landscape heterogeneity occurs and the degree of heterogeneity are important for an understanding of species distribution and abundance. However, most work has focused on landscapes consisting of only a few categories. For instance metapopulation theory reduces landscape complexity into simply suitable habitat and unsuitable surrounding matrix. But if we are to obtain realistic patterns of occurrence at a landscape level, then this fine scale detail is important. Likewise, multi-species assessments of land-use changes are important to understand how species with different functional traits, life histories, and trophic relationships respond to the same change to their environment. At the same time, incorporation of detailed species-specific behavioural mechanisms and sensitivity to changes in local environmental conditions is needed for realistic predictions at the species level. Agent-based modelling of real species allows for such integration. Applications of agent-based modelling are developing rapidly in ecology and aided by increased computational capacity are now able to handle simulations of complex systems (Grimm et al, 2005). Agent-based simulations models can handle the spatio-temporal environmental variation dynamics and compute individual responses to local variation in their environment. Knowledge of individual responses can subsequently be aggregated into distributional or density responses at the landscape level, leading to highly descriptive and flexible model systems.

Concurrent with the development of model building technology, new methodological advances in approaches to agent-based modelling are facilitating their development, testing and communication (Topping et al, 2010a), and with the development of increasingly realistic agent-based models their use in applied ecology is also increasing.

While the flexibility of these model systems is widely recognized there are still challenges of communicating the results of such models, particularly when the results of agent-based models are to be used in management. Clear communication of results from agent-based models may facilitate priority-setting among land-use scenarios for legislators (Jepsen et al. 2005), and a simple easily understood metric describing the major responses should help provide this clarity. The aim of this section of the project was therefore to develop an easily understood index of the impact of a scenario change based upon changes in abundance and distribution of animals within the model landscapes of ALMaSS.

Materials and methods

The strategy for developing the impact index was to evaluate response across species to both changes in landscape structure and to landscape composition using a controlled experimental approach to scenario building. Each combination of species, landscape structure and landscape composition was evaluated and the response of population metrics were evaluated.

Choosing the spatial metric:
One obvious method would have been to adopt an exisiting spatial statistic. However, initial testing with spatial statistics indicated that use of these (e.g. Ripleys k) was over complex, and led to the necessity for statistical assumptions the implications of which were not clear. For example to calculate a change in the level of aggregation using Ripley’s k we initially scaled responses to the Poisson expectation, then compared one scenario by subtraction with the other, the result being

an indication of whether the distribution became more even or more aggregated. The result is an arbitrary score comparing aggregations which varies depending upon the radius used to calculate it, but without having any easily understood connection to the real world. There were also doubts as to the statistical importance of the isotropic nature of some of the data (e.g. voles in linear features). As a consequence it was decided to simplify the approach and use the distribution of animal spatial locations (point patterns) directly as a measure of occupancy of the landscape.

Artificial landscapes

The landscapes used in the simulation models consisted of a set of four artificial landscapes based on an orthophoto of a 1 × 1 km area in Denmark. All four landscapes were 8 × 8 km, the first being a scaled up version of the 1 × 1 km area, the second formed of four identical 4 × 4 km areas scaled in the same way, the third made from 16 identical 2 × 2 km scaled areas, and the last of 64 identical copies of the original 1 × 1 km area (Figure 1). This procedure ensured that the location of habitat patches varied among the landscapes with increasing fragmentation from the first to the last landscape while keeping the cover of each habitat type constant. Management carried out in one field in the least fragmented landscape is carried out simultaneously in 64 fields in the most fragmented landscape.

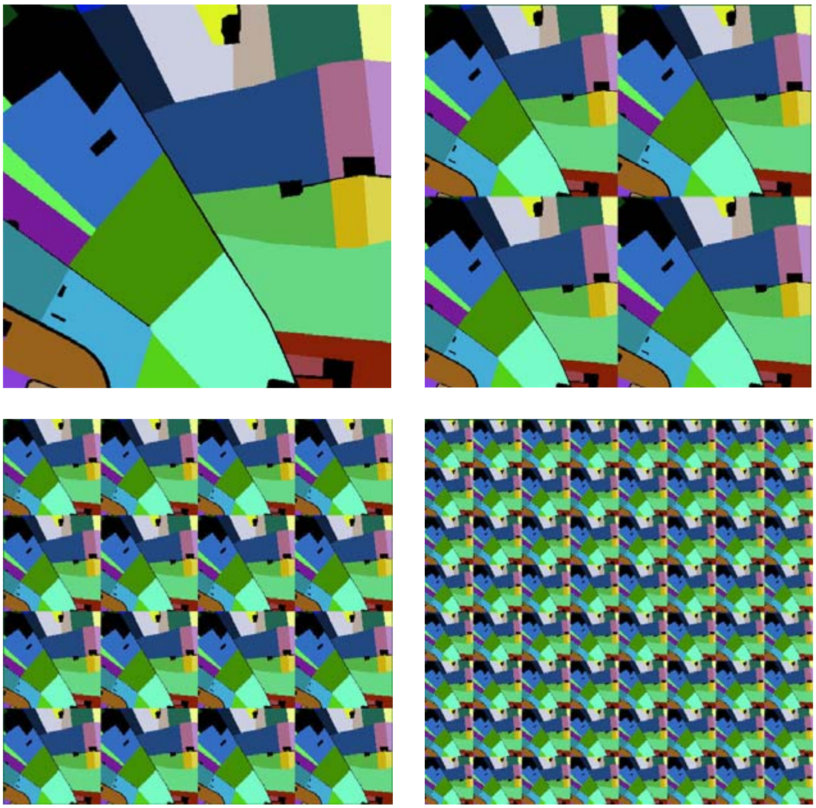

Figure 1: The four artificial landscapes used to test species responses using the impact index with heterogeneity increasing from top-left to bottom right. Note the landscapes are constructed of identical units scaled to increase heterogeneity by factor 4, 16, & 64.

The landscape used was predominantly agricultural with 10% by area of other habitats (**Fejl! Et bogmærke kan ikke henvise til sig selv.**).

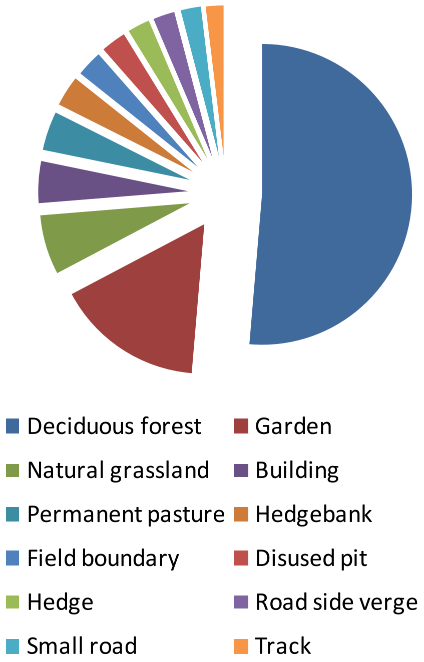

Figure 2: The proportion of the landscape occupied by different landscape types excluding agricultural fields which have an areal coverage of 90.01% These proportions are constant among landscapes used (Fig 1).

Land use scenarios

We developed four different scenarios and tested the response of all six animal species to these scenarios. In the scenario FOREST, 19.9% of the area was changed from arable land to deciduous forest. In the scenario HEDGE, 0.28% of the area was changed from field boundary to hedge rows. In the scenario PASTURE, 19.9% of the area was changed from arable land to permanent pasture. In the scenario CROP, the crop diversity was reduced to two crop types with one third being spring barley under-sown with grass followed by two years of clover/grass sward grazed in the autumn. The standard crops used other scenarios are listed in Table 1. This set of crops was chosen to be varied and relatively benign so as not to restrict species use of the landscape on this account in all but the CROP scenario.

Table 1: Standard crop and their areas as used for testing the impact index in all but the CROP scenario.

Crop	Coverage
Spring barley	38.9%
Winter wheat	13.9%
Potatoes	8.3%
Set-aside	8.3%
Winter barley	8.3%
Seed grass	5.6%
Winter rape	5.6%

Winter rye	5.6%
Field peas	2.8%
Triticale	2.8%

Model output

For each model run of 60 years, the location of each adult female in the landscape was recorded on 1st July each year from year 10 to year 60. The first ten years were discarded to allow the population size time to equilibrate. The number of individuals recorded was summed and the mean number of individuals across 50 years was used as a measure of abundance. To quantify occurrence we overlaid the 8 × 8 km area by a grid of 50 metres for the beetle and the spider, 100 metres for the vole, 200 metres for the skylark, and 400 metres for the hare and the partridge. Occurrence was quantified by the proportion of grid cells occupied by at least one individual for each annual recording of the locations of individuals of a species averaged across the 50 year sampling period. We used different sized grids for the species to account for the differences in the spatial scale at which the species operate. Ideally grids should be large enough to encompass more than one individual (since otherwise grid occupation and abundance would be equivalent). However, they should not be too large since then spatial distribution as a result of habitat heterogeneity would be lost. The scales used also approximated to the scale at which half the cells in the landscape would be occupied by females of a particular species. In these tests means of 10 replicates of 60 year runs were used to assess abundance and occurrence for each species in each scenario and in each artificial landscape (Figure 3).

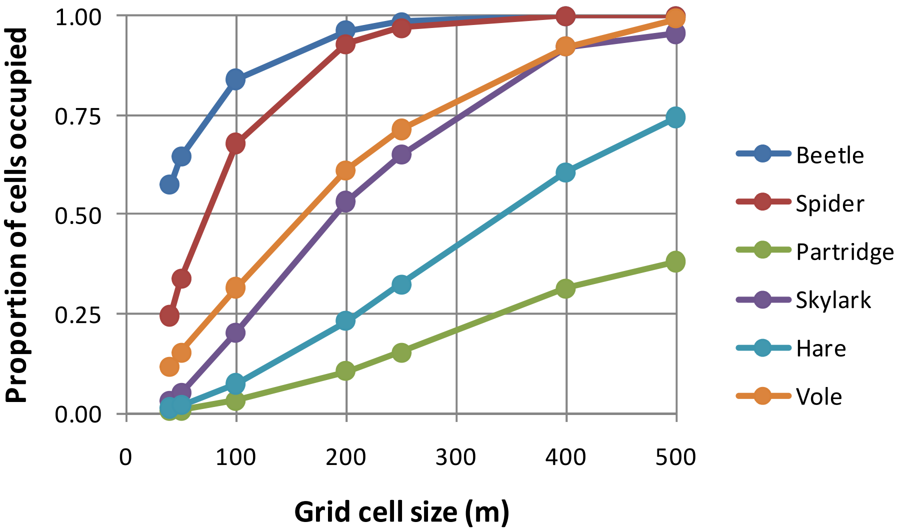

Figure 3: The relationship between the occupancy and grid size of occupancy grid for all side species in the baseline scenario in the most heterogenous artificial landscape.

Results

Landscape heterogeneity

The six model species responded very differently to variation in the degree of landscape heterogeneity. If we consider moving from the most heterogeneous to the most homogenous landscapes, the two arthropod species and the hare responded negatively to landscape defragmentation both in terms of abundance and occurrence, whereas skylark responded positively to the same landscape changes. Vole population size was unaffected, but vole occurrence was affected negatively and the partridge exhibited a complex response, where occurrence and abundance first increased and then decreased below original levels both in terms of occurrence and abundance. The most heterogeneous landscape contained a greater occurrence of five out of six species and a greater abundance of four out of six species (Figure 4).

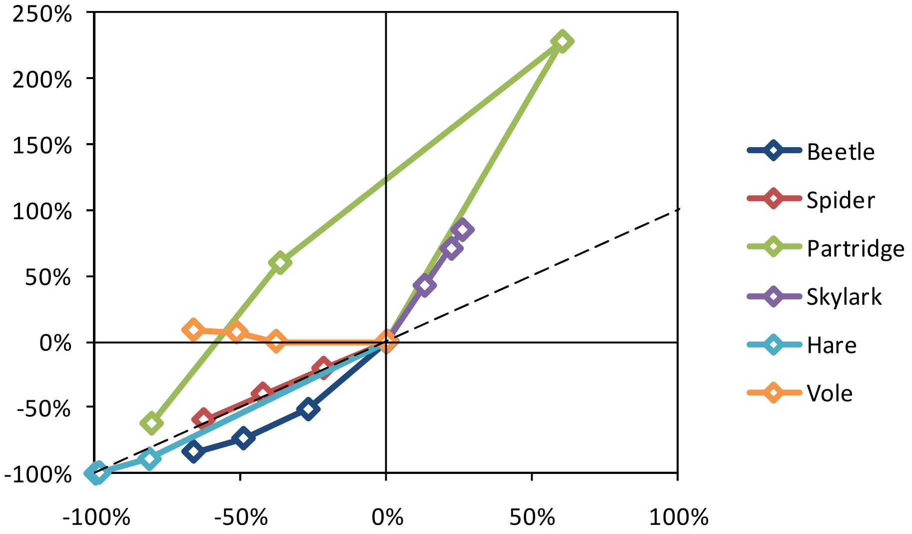

Figure 4: The change in impact index moving from the most heterogeneous to the most homogeneous landscapes for the six model species. The dotted line shows the 1:1 ratio between distribution and abundance, and would indicate no interaction between landscape structural change and abundance.

Scenarios

Species responses to four landscape scenarios differed greatly both among species and scenarios (Figure 5). Adding FOREST was bad for all species both in terms of occurrence and abundance, whereas the three other scenarios (HEDGE, PASTURE and CROP) were good for some species and bad for others. In all cases, changes in abundance and occurrence were in the same direction, but rarely of equal magnitude. In cases where changes in abundance and occurrence were not of equal magnitude, changes in abundance were almost always greater than changes in occurrence. The most dramatic positive and negative responses were seen in the CROP scenario, where all species except the partridge responded positively to a shift towards lower crop diversity (Figure 5). This indicates that it is not easy to generalize impacts across species nor among scenarios, each species and scenario combination needs to be evaluated separately.

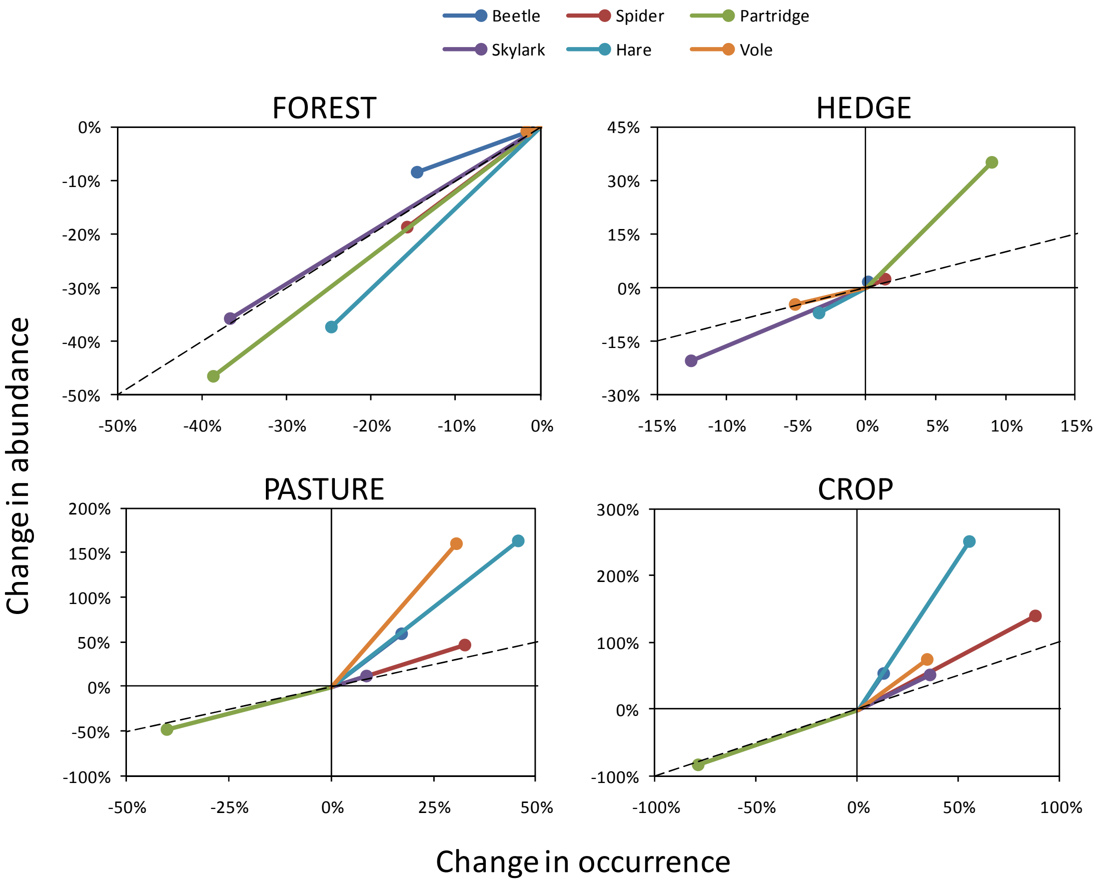

Figure 5: Impact index responses of the six species to the four scenarios on the most heterogeneous landscape.

In some cases, the effect of landscape scenarios interacted with the degree of fragmentation of the landscape. For instance, the skylark was most abundant and had the widest range in the least fragmented landscape, but this was dependent on the crop diversity. In the CROP scenario skylarks were most abundant and had the widest range in the most fragmented landscape (Figure 6).

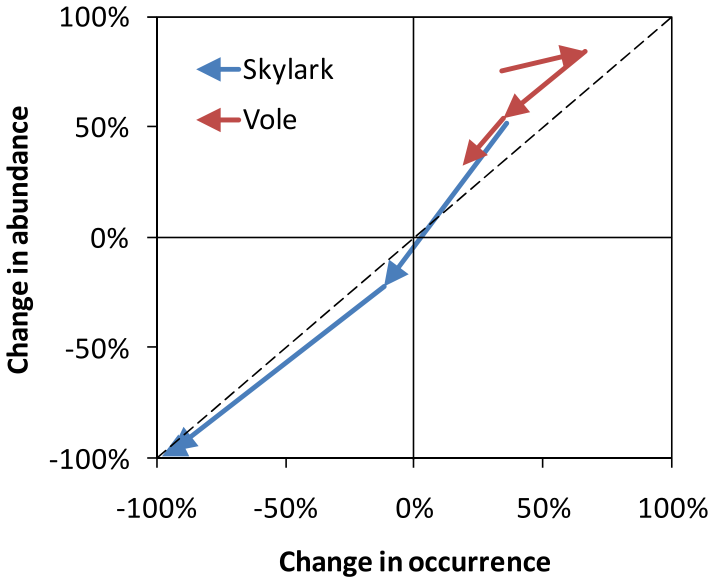

Figure 6: Two examples of the interactions between landscape structure and scenario. The arrows show the change in impact index when moving from most heterogeneous to most homogenous landscapes under the CROP scenario. In the case of the skylark we see a dramatic reversal of the effect of crop simplification with simplified rotation performing very badly in the homogenous landscapes.

Interpretation

Species respond to changes in habitat or landscape composition at different scales (Revilla & Wiegand 2008). The characteristic spatial scale of a species has been described as the spatial scale at which a species responds most strongly to the amount of habitat (Holland et al. 2004). Importantly, the spatial scale of the landscape needs to be distinguished from the spatial scale at which individuals of a species are recorded. In many cases, land-use or landscape structural changes will affect both the number of individuals as well as their occurrence in the landscape. Most field studies are incapable of recording the location of individuals and efforts to evaluate the consequences of land-use changes are restricted to estimates of changes in abundance. At the same time, most attempts to predict species responses to scenarios of future land-use dependent on presence-absence data. Hence, field studies address changes in abundance while species distribution models describe changes in the occurrence or ranges of species.

Our results demonstrate that, at the landscape scale, changes in occurrence and abundance are rarely in a one-to-one relationship (although see below w.r.t. grid size), and the reason for this is found in the ecology of the species. The prime example was the response of the skylark to crop rotation simplification and landscape structure. There are two dynamics that are important here. The first is the structure of the landscape, which in the case of the skylark limits nesting possibilities by increasing the likelihood of proximity to trees, buildings or tall crops.

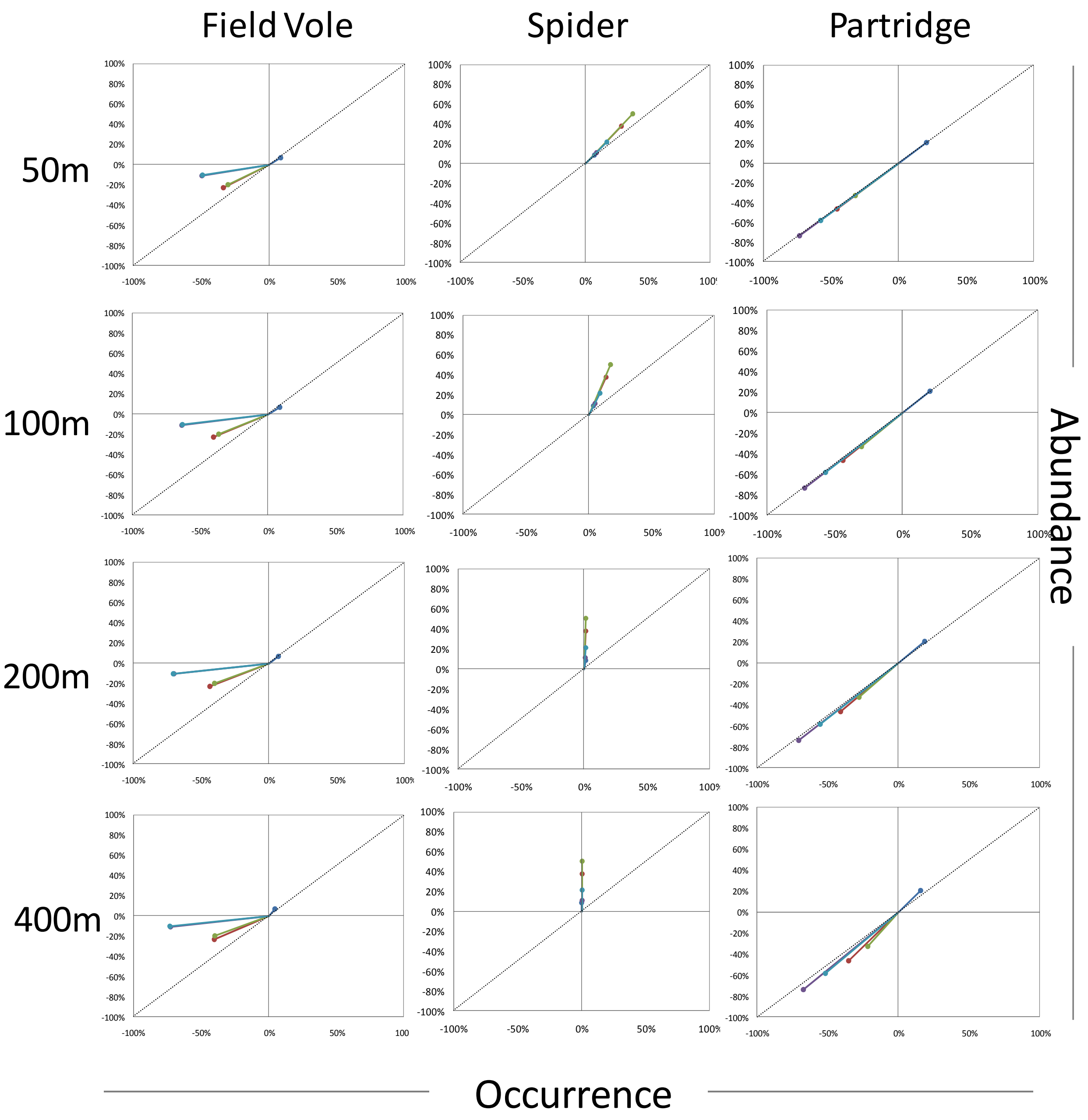

Figure 7: The impact index as applied to five different scenarios for the vole, spider and partridge but calculated using different grid sizes. These demonstrate a lack of sensitivity for the vole, but for the spider and partridge choosing the correct grid size is critical.

In a heterogeneous landscape a simplified rotation, not including tall crops, increases the number of possible nesting locations. On the other hand, in a homogeneous landscape with a simple rotation the access to food may be reduced simply because of field size, therefore a diverse rotation increases the chance of suitable forage being near the bird, and therefore increases breeding success. The balance of these two factors changes depending upon the scenario, leading to the complex response observed.

The responses of the species in terms of the impact index were in general both easily observable and as expected. Since they occurred as expected in response to the controlled variables we feel that their usage for evaluating scenarios without controlled factors, i.e. application to the projects case studies, is justified. In using the impact index we should keep in mind that there is a great deal of information that is lost, and that the effect is generalised at the whole landscape scale and may hide within landscape dynamics. It is, however, easy to communicate the impacts observed, which was the main point of developing this approach.

Figure 7 shows the results of the application of the impact index to the vole model for five different scenarios (baselines from Section II). In general the patterns obtained are very similar no noticeable differences. The choice of 100m for the grid size of the vole could have been doubled without altering the general picture of impacts. This situation is different for the partridge and spider. These two species show to opposite but extreme situations. In the case of the spider a large grid size means that all grids in the landscape are occupied, hence for 400m there is no possible deviation on the x-axis. For the partridge we see the opposite situation where at smaller grid sizes each grid only contains one individual (points lie on the diagonal, ie abundance = occurrence). In order to obtain sensitivity in the occurrence axis a grid size of 400m is needed for this species. It is important to note that the grid size chosen here is specific to the baseline distributions found, and may not apply to other baseline scenarios. For instance in the case of the partridge at densities found in the 1940s, which were at least an order of magnitude higher, a smaller grid size may also have been suitable. The underlying distribution of animals would therefore need to be checked for extremes in any future application of the index, and a suitable grid size chosen accordingly.

Section II: Application of ALMaSS to two pesticide case studies

Materials and Methods

This section details the use of the impact index developed in Section I to determine the impact of the two policy scenarios i.e. unsprayed margin scenario and quota scenario, for all six species considered in all three landscape structures. The inputs to ALMaSS scenarios were primarily provided by Dalgaard et al (2010) and Wulff et al (2010), each being a separate work package in the overall project. Tables providing this data are to be found in Appendix I.

The starting point for each scenario analysis was the development of a baseline situation for the two real-world study areas (Bjerringbro and Odense). This was obtained from Dalgaard et al (2010) which detailed the area coverage of 10-12 farm types in the two study areas (Table A1 & TableA2). However, the crop classification used to describe the real world was more detailed than could be represented in ALMaSS, hence a number of crop types were amalgamated to create ALMaSS crop distributions. Table A3 & Table A4 provide the resulting areas covered per farm type for the Bjerringbro and Odense study areas.

Since mapping information for the Odense area was not available to this project, evaluation of the effect of local topography was incorporated by simulating both Bjerringbro and Odense rotations on three different landscapes. These being Bjerringbro (Bj), Herning (He) and Sjælland (Sj) (Figure 8). Each landscape consisted of a detailed GIS mapping of a 10 x 10 km area with different topography. Overall coverage of landscape elements was broadly similar between the three landscapes, but differed in details (Table 2). In all three landscapes the individual farm units were identified based on data available from 1998-2000. The baseline landscapes were then created by allocation of farms to the landscape based on a pro-rata assumption of farm-type coverage. The net result was a patchwork of farms and farm types with an area accurately matching the distribution of farms in 2006/7, i.e. Table A1 & Table A2. As part of this exercise it was necessary to adjust the area of permanent grass which was reduced compared to the mapping exercise in 2000 from which the maps originated. Grass fields were removed and re-allocated to the map as arable fields on a random basis until the proportion of permanent pasture matched the real-world conditions.

Table 2: Proportion of landscape covered by main habitat types for the three landscapes used in this project.

Landscape Element Type	Bjerringbro	Herning	Sjælland
Bushes/scrub	1.5	0.8	0.3
Fields (rotation+permanent pasture)	60.3	71.7	66.1
Heathland	0.0	3.4	0.0
Linear features (excl. hedgebanks)	1.8	3.9	2.5
Hedgebank	0.1	0.9	0.3
Unmanaged grassland	4.1	2.6	2.5
Urban/Park/Garden	9.0	4.6	6.4
Water	1.7	0.6	0.7
Wetland	1.1	2.1	1.2
Woodland	19.0	8.6	19.6
Woodland plantation	1.5	1.7	0.6

Changes to the baseline scenarios used to create the SCO1 (unsprayed margin) and SCO2 (quota) scenarios were provided by the Bedriftsmodel. Crop changes to the nearest 1 % per farm type are listed for Bjerringbro in Table A5 and for Odense in Table A6. These changes were applied to the rotations generated for the baselines by replacing entries as appropriate. The Bedriftsmodel also provided changes in pesticide usage in terms of changes in application index. These were averaged per crop. The largest changes after translation to ALMaSS crop types are shown in Table 3. These changes were included in the ALMaSS crop management for these crops for each scenario by creation of a scenario specific version of the crop management. Changes were assumed to reflect herbicides, insecticides and fungicides equally.

In all cases scenarios were run for all six species considered with sufficient replication to provide reliable predictions[2].

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[2] Variability between individual runs is normally different for each species, hence it was not possible to predict the number of replicate runs necessary before hand. Hence to determine the number of replicates needed, a convergence criterion was used. This criterion was based on the stability of the resulting mean population size and was interpreted as the point where adding further references did not alter the mean by greater than ±2%. The application of this criterion was, however, stricter than this in that long-term mean stability was also considered (Figure 7). The result was that 50

ALMaSS was configured to produce daily measure of breeding female population size and annual point patterns on the 1st July to calculate abundance. Note that for the beetles and spiders ALMaSS is designed to use super-individuals (i.e. one individual represents more than one individual in reality). The super individual scaling factors that were used were 10 & 200 for beetles and spiders respectively. These figures were chosen to reduce unnecessary calculations for species with very high local densities. Even so peak beetle numbers reached 25 million and spiders upwards of 2 million simultaneous agents during the resulting runs with beetle replicates taking almost five CPU days each.

ALMaSS results were obtained over a simulation run of 50 years, but only the last 20 years of each run were used for analysis to allow the model to equilibrate. For most species/scenario combinations this was a conservative measure, but for the partridge and hare this length of time was required before a stable population could be achieved, for example see Figure 9C.

Table 3: The major changes in pesticide application per crop type as a percentage of the baseline situation (zero or <0.1% changes or < 1% crop by area ignored).

Scenario	Spring Barley	Oats	Winter Barley	Spring Rape	Winter Rape	Field Peas	Silage Grass	Clover Grass Grazed
Unsprayed Margin	0.1	0.2	-31.3	0.0	0.0	0.0	-2.4	-6.5
Quota	-9.3	-34.9	-85.3	-60.5	-60.5	-100.0	-10.9	-12.2

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replicates were used for each scenario for each species except the vole which required 70, and the beetle which was very stable and required only 30 replicates.

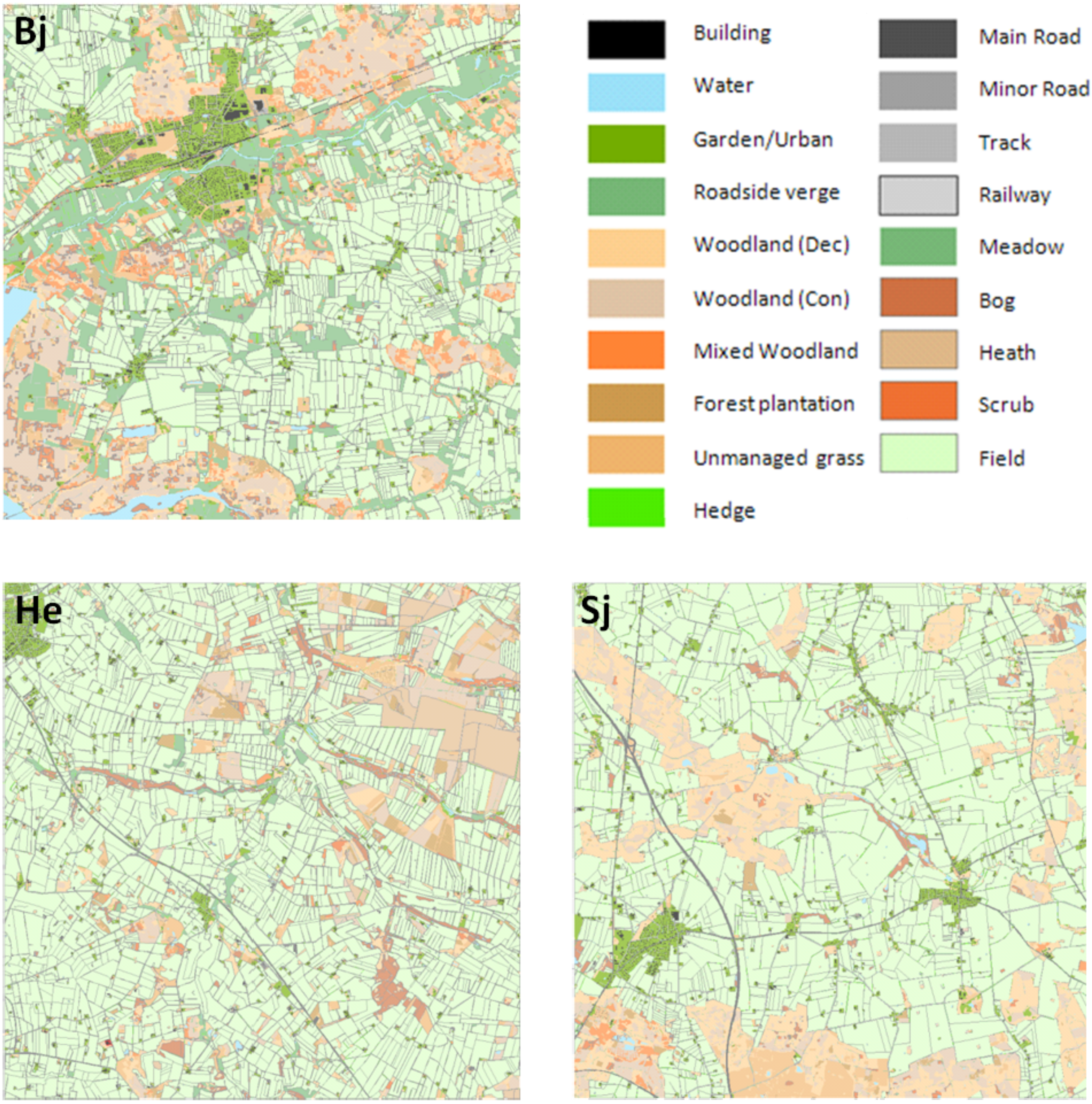

Figure 8: The three landscapes used in SC01 (unsprayed margin) & SC02 (quota scenario). These landscapes are representative of different landscape structures in Denmark provide an indication of the extent to which results are affected by local topographic conditions. Note especially the relatively homogenous areas of farmland in He & Sj and the generally larger field and forest sizes in Sj.

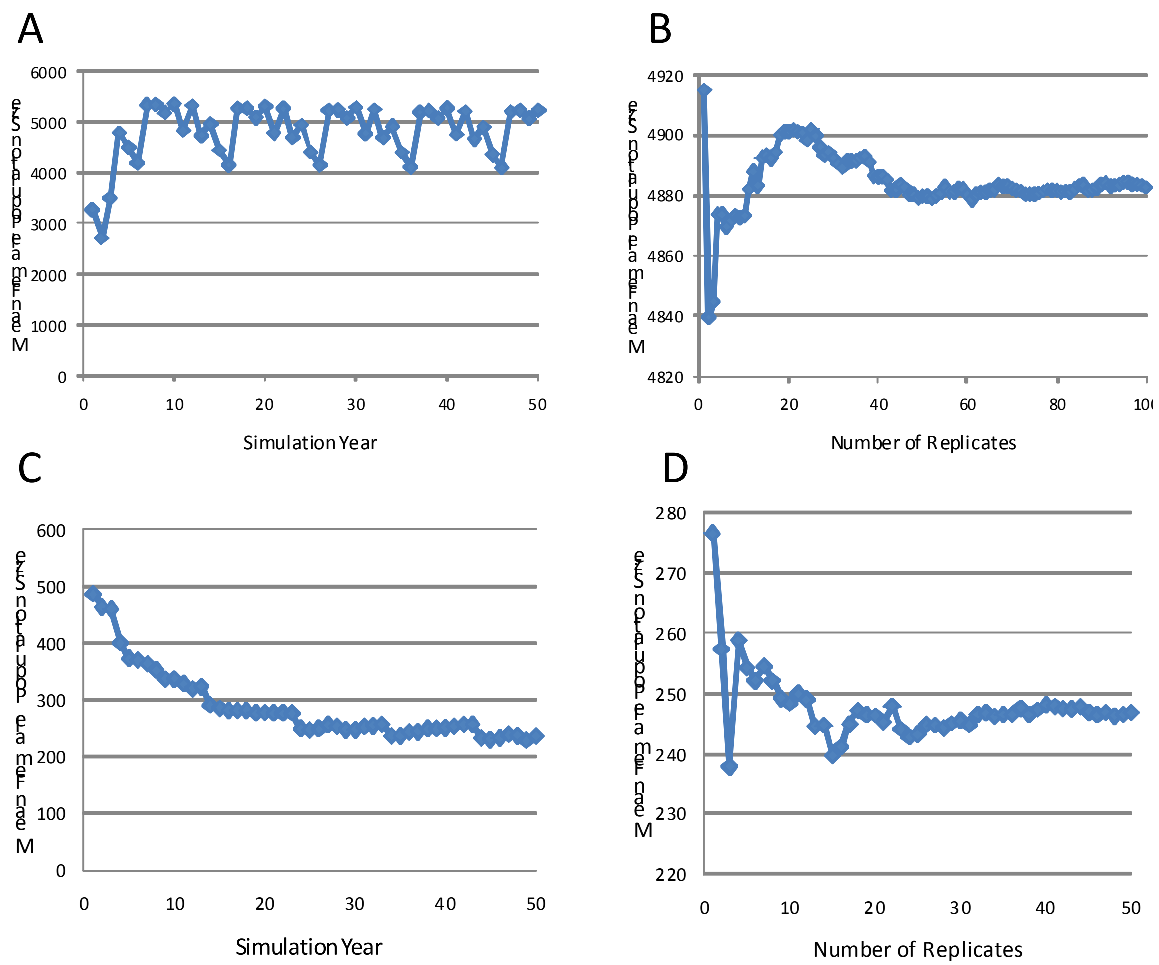

Figure 7: Two examples of time series and convergence testing. A) Time series for 70 replicates of the field vole in Bjerringbro+Odense rotation. B) Change in overall mean population size (years 30-50) with each additional replicate for field vole with Bjerringbro and Odense rotation. 70 replicates was selected are the target number of replicates required for each scenario C) Time series for 50 replicates of the partridge in Bjerringbro+Odense rotation. D) Change in overall mean population size (years 30-50) with each additional replicate for partridge with Bjerringbro and Odense rotation.

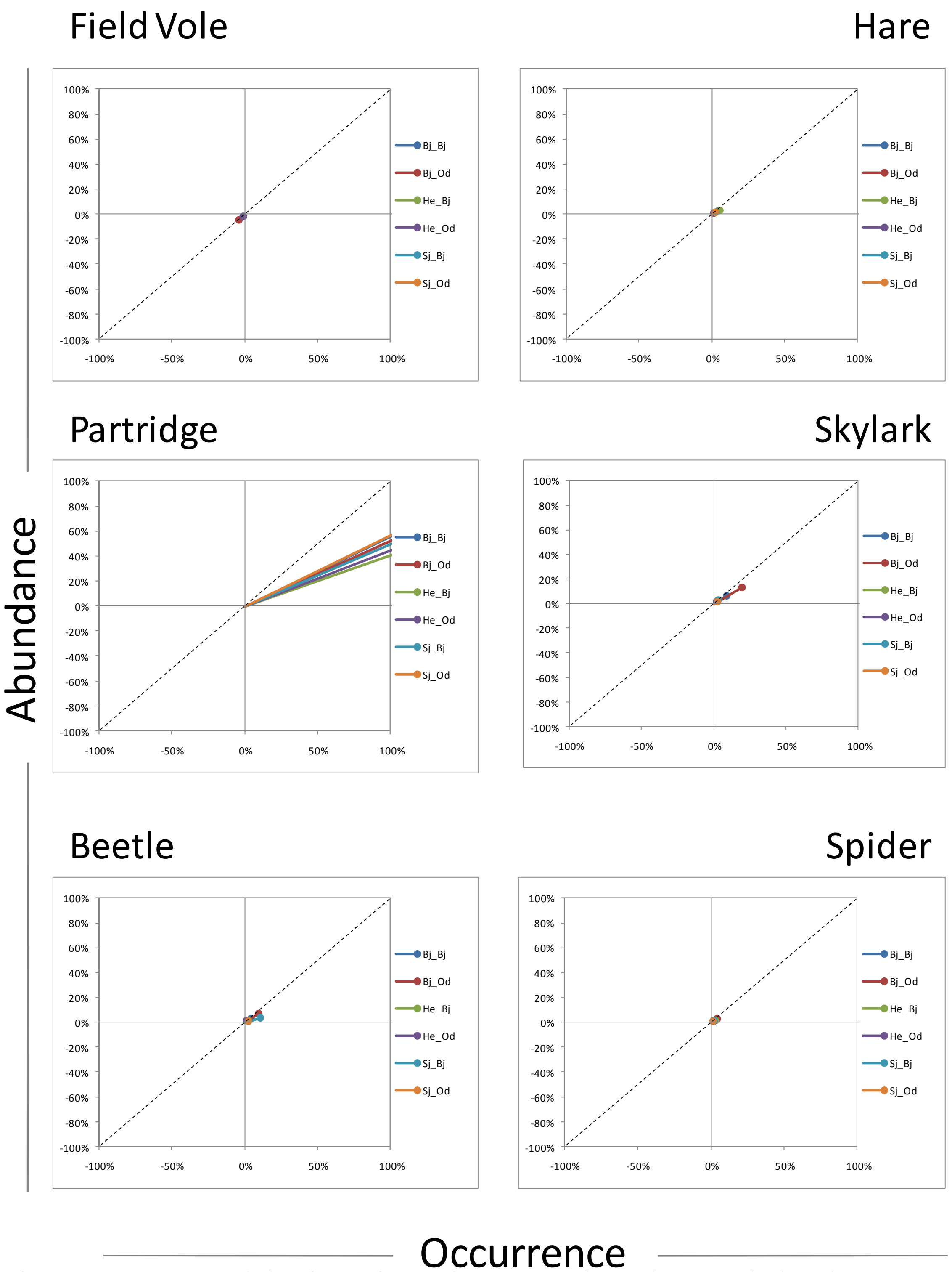

Figure 10: Responses of the six species to the unsprayed margin scenario (SC01). All graphs are scaled to +/- 100% on both axes. Only the partridge and to a much lesser extent the skylark demonstrated a noticeable response to the scenario. Hare, beetle and spider all showed small positive responses, whiles the vole showed a very small negative response to this scenario.

Results

Baseline Conditions

Comparison of the baseline landscape/rotation combinations provides a background variability against which the impacts of the scenarios can be evaluated. Baseline female densities and impact index occurrence are shown Table 4 & Table 5. In Figure 10 all combinations of landscape/rotation are presented relative to the Bjerringbro landscape together with the Bjerringbro rotation. Hence, the impact index for Bj_Od shows the impact of switching the rotation to the Odense rotation whilst keeping the landscape constant. It is clear that particular combinations of landscape and rotation illicit large responses, but there is little consistency between species. However, in all species impacts of greater than 50% are possible indicating that they are all sensitive to at least one of the factors considered here. For example rotation (_Od or _Bj) appears to impact the field vole and skylark least, but had large impacts on the other species (compare red and green lines for each species in Fig 10).

Table 4: Predicted baseline densities per km^2 for the six species in each landscape/rotation combination.

	Bj_Bj	Bj_Od	He_Bj	He_Od	Sj_Bj	Sj_Od
Skylark	5.2	5.0	8.9	10.6	8.8	9.9
Partridge	2.0	2.4	1.1	1.4	0.5	0.8
Field Vole	54.3	58.2	41.9	43.5	48.6	48.8
Hare	3.5	4.4	4.0	5.1	0.5	0.7
Beetle	3.97E+06	4.08E+06	6.38E+06	6.96E+06	4.49E+06	5.34E+06
Spider	3.11E+06	3.39E+06	4.29E+06	4.68E+06	3.46E+06	3.78E+06

Table 5: Baseline occurrence for the six species modelled for all landscape/rotation combinations.

	Bj_Bj	Bj_Od	He_Bj	He_Od	Sj_Bj	Sj_Od
Skylark	14.0%	13.9%	17.3%	19.8%	17.5%	19.3%
Partridge	18.7%	21.6%	12.1%	14.6%	6.1%	9.0%
Field Vole	10.6%	11.5%	6.3%	6.8%	3.9%	3.9%
Hare	36.5%	42.0%	38.6%	45.2%	6.3%	9.1%
Beetle	62.2%	60.7%	80.4%	82.3%	67.4%	71.6%
Spider	31.5%	33.7%	40.5%	43.3%	34.3%	36.8%

An important point to note is the poor performance of the Herning and Sjælland landscapes for the hare and partridge. The Bjerringbro baseline is typical of the average Danish population density for these species with 2 or 3.5 females per km2 for partridge and hare respectively (Table 4). Both these values are at a very low level and are indicative of a non-sustainable hunting situation, therefore the poorer performance in the other two landscapes indicates a baseline population in a very poor condition (still in decline after 50 years of simulation in some cases). Population responses in these landscapes to further changes should be considered critically because large percentage changes can be obtained for a very small change in actual abundance.

Skylark – The response of the skylark to landscape structure is complicated by two opposing mechanisms. The first is the necessity to obtain a breeding location at least 70m from trees or other tall features where predators may sit. This means it responds positively to wide open spaces such as fields. However, crop rotation also plays a role and some crops are wholly or partially unsuited to breeding (e.g. rape crops), hence open spaces are only good if they are planted with the correct crops. A third factor which plays a role is the heterogeneity of the landscape. When local conditions are less than optimal, a heterogeneous crop landscape provides better foraging possibilities compared to a homogenous one. Hence, and open landscape of small fields with open and accessible shorter crops is the ideal for skylarks and the response to the mosaic landscape of Bjerringbro with its many small forested areas is clear. The skylark is also sensitive to the rotation due to its sensitivity to crop structure, hence here we see the largest responses to rotation changes.

Vole – the primary driver here is the area of optimal habitat, ie the area of designated unmanaged grass. There is little response to the rotation for this species because it is not generally present in the cropped fields and avoids grazed areas. Hence, impacts due to rotation changes are primarily a function of altered landscape permeability.

Hare – the hare responds to the area of open habitats but also requires a mosaic to obtain a year long supply of forage. This is in short supply in all landscapes due to modern intensive cropping methods, but in the Sjælland landscape this mosaic is virtually absent. Hence in all landscapes population densities are low.

Partridge – like the hare the partridge is excluded from most of the modern cropped areas by intensive management. However, it also requires co-occurrence of nesting habitat and brooding habitat, limitation of either of which will render an area unsuitable. Partridge responses are therefore often difficult to predict, especially as like the hare they exist in very low densities. In the baselines the mosaic of the Bjerringbro landscape appears to be more suitable for partridges than the other two, but also like the hare population densities are low and sensitive to small changes for better or worse.

Beetle – the beetle is primarily affected by the co-occurrence of field and field margin habitats, and permanent pasture. Hence, both the Præsø and Herning landscape provide better conditions than Bjerringbro. In addition the beetle was sensitive to certain changes in rotation, with the Odense rotation benefiting abundance more than occurrence.

Spider – the spider is the simplest of the species in that it is the most r-selected, and most associated with disturbed systems. Increases due to increased field area or more benign rotation occur equally in terms of abundance and occurrence.

Responses to Scenarios

SC01 – the unsprayed margin scenario

This scenario is based on a 6m unsprayed margin around the arable fields. There is no reduction of fertilizer inputs to this margin, and all fields are assumed to have unsprayed margins regardless of the current boundary conditions.

Responses to this scenario are shown in Figure 11. In general there was little response to the scenario compared with the magnitude of response to landscape structure, and expected responses based upon the scenarios from Section I. The detailed responses of each species are described below.

Field Vole – the level of responses to from the field vole were minimal, with all but one response being under 1% in both abundance and occurrence. This is as close to zero as to be negligible. In the one case were the response was -4% in both occurrence and abundance (Bj_Od) this suggests an interaction between rotation and the scenario changes decreasing connectivity in the Bjerringbro landscape slightly and therefore we are seeing a small reduction in the number of habitat patches occupied in this mosaic landscape.

Hare – with a maximal response of +4% in occurrence this scenario had no significant impact on the hare. Those changes that were observed would probably be caused by small changes in the rotations, but small increases in weed biomass in the unsprayed margins will also play a part assuming the crop structure provides access.

Partridge – the partridge shows an extremely positive response to the addition of the field margins. Responses over +100% for occurrence occur in all landscapes, and in terms of population increases there was a response range from +80% to + 300% with largest changes occurring in landscape/rotation combinations with lowest baseline densities. The relatively large response in occurrence indicates that habitat quality has been improved in space by this measure. The mechanism by which this occurs is related to the need for both nesting habitat and brood habitat. In this case of the unsprayed margins the increase in weed and insect abundance provides food for chicks in the first few days of life in areas that otherwise would have been unsuitable for brooding. If these areas coincide with suitable nesting habitats then the effect is to increase the area of overall suitable habitat. Tests indicated however, that this effect is critically balanced with the assumptions regarding accessibility of the crop to foraging partridges. Small changes reducing this access remove this response.

Skylark – The skylark responds positively in all cases, but only with increases in both dimensions of 2-4% in all but the Bjerringbro landscape, where increases are 6-19%. The positive increase is to be expected due to the increase in food resources at the edge of the fields, however, this increase will not affect the suitability of the crops for nesting and will therefore only increase the survivorship of young in years where weather conditions are partially limiting. This effect will be reduced in landscapes with large fields (small area of margin i.e. Sjælland), or where many of the fields are rendered unsuitable as nesting locations by the presence of hedges. A diverse crop landscape of small fields will also reduce the impact of this measure since alternative foraging will be available in any case. The latter two mechanisms are the likely cause of the relatively low response in the Herning landscape.

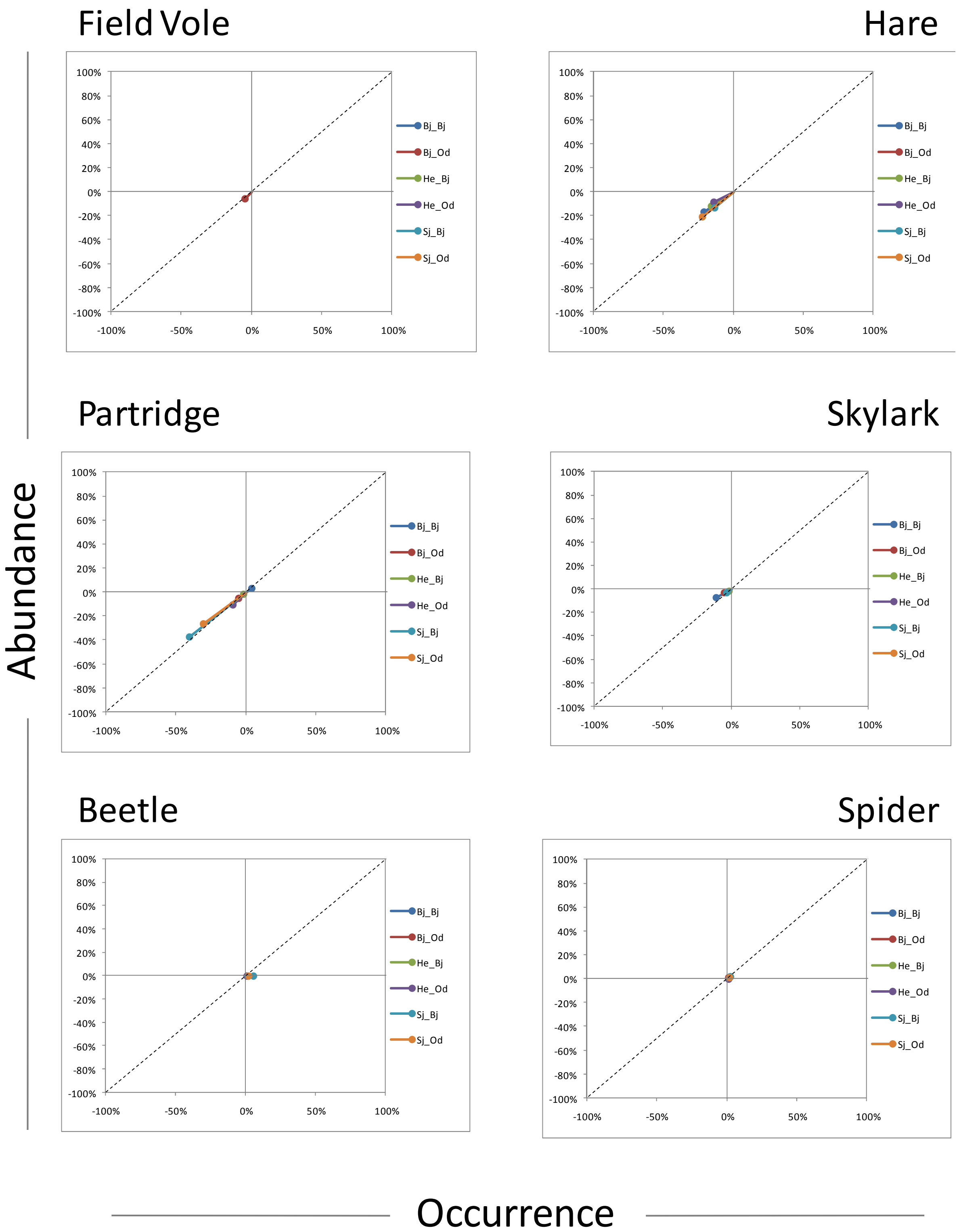

Figure 11: Responses of the six species to the quota scenario SC02. Graphs are scaled to +/- 100% on both axes and indicate noticeable responses only in hare and partridge, and

primarily here where densities are particularly low. Skylark and vole both reacted very slightly negatively to this scenario, whilst beetle and spider produced almost zero response.

Beetle – beetle responses were in all cases positive ranging from 2 to 10% increase in occurrence and 1 to 8% increase in abundance. The impact here is due to the beetles being largely dependent on field margin habitats for overwintering, hence improved conditions around the margins improves conditions for the beetles, especially during dispersal to and from the margins. The slightly higher increase in occurrence compared to abundance also indicates a marginal improvement of habitat quality in the landscape as a result of some areas previously being of poor quality becoming suitable due to better boundary conditions. The effects we see here are, however, limited by the fact that the beetles range widely into the fields and therefore only benefit from the reduced spraying in a small but important part of their range. Note due to the very large numbers of beetles and the very low between run variability, the changes in beetle numbers observed although small are considered significant.

Spider – Spider responses were very small but in all cases positive between 1 and 2%. This effect is due to the reduction in pesticide sprays and therefore the reduction in mortality in the unsprayed margins. Since the spiders disperse widely and do not (in the model) seek out the margins the effect observed is lower than found in the beetles.

SC02 – the quota scenario

This scenario is based on the reduction in pesticide use and the resulting change in rotation from the Bedriftsmodel. Responses to this scenario are shown in Figure 12. Like SC01 there was little response to the scenario compared with the magnitude of response to landscape structure, and expected responses based upon the scenarios from Section I. The detailed responses of each species are described below.

Field Vole – responses were indistinguishable from zero in all but one landscape/rotation combination where the response was -4% in both dimensions. This response mirrors the response from the SC01 scenario and is probably due to the same cause, although in the SCO2 scenario the changes in rotation are larger.

Hare – Shows a significantly reduced population in all landscapes. This effect is entirely due to changes in rotation and grassland areas. Reductions in spring crops relative to winter crops must be the main driver. It is important to note once again that the initial poor population density for the hare in all these landscapes increases its vulnerability to further negative factors, hence it takes little more to change a population from a stable zero growth situation to negative growth when it is already well below the landscapes carrying capacity.

Partridge – like the hare this species is sensitive to further negative impacts. In this case the reduction in spring barley is likely to be the main driver since it is a relatively more accessible crop than winter crops, at least during the early breeding season. There would also be a slight increase in food availability as a result of the decreased pesticide, but this effect was either outweighed by the loss of spring crops, or occurred in crops already unsuitable for breeding. As expected the impact is greatest in the Sjælland landscape where populations were already at low densities and close to permanent decline.

Skylark – The skylark responded in the same way as the partridge although responses were much less extreme. Impacts ranged from 0 to -7% with broadly the same antagonistic drivers as the partridge. One additional complication with the skylark is their use of tramlines, which are typically opened in summer as a result of pesticide application. Hence, although reduced pesticides will have some benefit, the reduction in crop access as a result of fewer open tramlines will push in the opposite direction. As with SC01 the responses were largest in the Bjerringbro landscape, probably due to the stabilising structural factors related to field size and lack of woodland/tree proximity in the other two landscapes.

Beetle – the responses of the beetle were 0-2% and indicate that although there is a positive impact of reducing pesticides its effect is minimal when targeted in this way. Changes in rotation may also have caused corresponding decreases but this is not possible to determine without isolating this factor from the pesticide reduction.

Spider – the spider shows the same minor response as the beetle, with 1-2% increase in abundance and occurrence in all landscape/rotation combinations. The drivers in this case are identical to the beetle and it is not possible to attribute changes to rotation or pesticide reduction based on the current simulation.

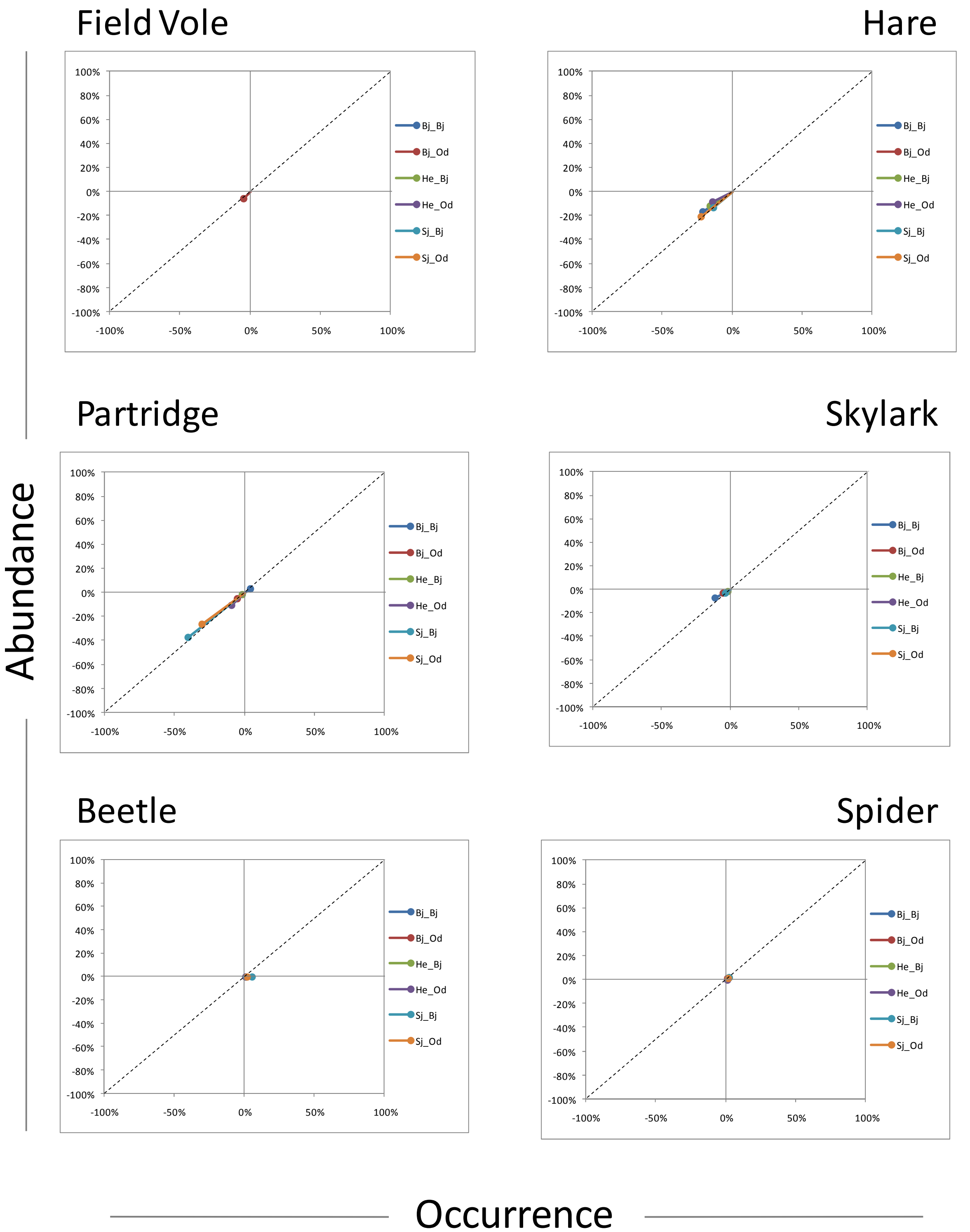

Figure 8: Responses of the six species to the quota scenario SC02. Graphs are scaled to +/- 100% on both axes and indicate noticeable responses only in hare and partridge, and primarily here where densities are particularly low. Skylark and vole both reacted very slightly negatively to this scenario, whilst beetle and spider produced almost zero response.

Discussion

One of the main advantages of using an agent-based modelling system such as ALMaSS is the ability to design experiments that would be difficult to carry out in the real world. In this case the effect of the two scenarios is independently evaluated across six species, for two crop rotations, and on three landscapes. The responses measured are the population responses for the whole landscape, whereas the treatment applied (scenario) is only applied to the landscape structures for which it is sensible, in this case fields. In other words apart from the variables considered above, all other factors are kept constant. The result is therefore a measurement of the population response to the changes in the variables relative to the baseline starting conditions.

The impact measure used shows responses in terms of changes in abundance and occurrence. This simple measure is easy to interpret when there are large responses, but lacks some resolution when responses are small and nuanced. Unfortunately for clarity, both unsprayed margin and the quota scenario the responses of the species were in general minor compared to the responses obtained from impact index test scenarios and comparison of landscapes. This is naturally a function of very small changes in scenarios themselves since changes predicted by the Bedriftsmodel were minimal with the largest overall change being a 2.2% change in the area of spring barley as calculated as a percentage of the total arable area. There was also the reduction in pesticide usage, but this was implemented in a realistic manner which means that reductions were not equally distributed over all crops but were targeted, meaning that reduction in exposure was not guaranteed for all individuals. The net result is that if pesticides are not the limiting factor to usage of the crop as habitat, then the reduction in pesticides in those crops will have little no effect. A case in point is the large reductions in pesticide use in winter and spring rape. Rape crops are generally unsuitable habitats, hence this pesticide reduction will not confer benefits on the species modelled here.

A further complication is that reduction in pesticide usage and increase in insect and weed biomass may be rendered of limited use if the crop itself does not permit ingress of the species. This is typically the case with modern intensive agriculture and will primarily affect skylark, partridge and hare. Added to this is the issue of open tramlines, often resulting from pesticide application, which is essential in cereal crops if skylark breeding is to be successful. This type of effect can effectively be summarized as the factor that is currently most important in limiting the potential for a crop to be utilized as habitat is not often pesticide usage.

The key advantage to using the agent-based simulation is that this range of factors can be integrated into a single scenario. In this case, the integration of these effects in these scenarios resulted in very small responses, and only in the case of partridge and hare did we obtain a strong impact.

In both these cases where impacts were noticeable (hare response to quota and partridge to unsprayed margin scenario) it is likely to be a specific combination of factors with the already low population density that illicit the observed responses. Both of these species are at very low densities nationally although with wide regional differences, and in both cases it is relatively easy to depress populations further and even to exterminate them as a result of relatively small changes in habitat quality. For the hare the loss of a little spring crop and replacement by even greater areas of winter crop may be enough to further its decline. In the case of the partridge the sudden increase in forage potential alongside nesting habitat is enough to explain this response the positive response. The important question is whether these responses are likely to occur in the real word. In the case of the impact of changing spring barley to winter crops the effect is perhaps not so surprising, since it is 10% of the spring barley area was lost and replaced with less attractive winter crops, even though this accounted for only 2.2% of the farmland. The hare is particularly sensitive to this factor since it is believed that it is a summer bottleneck in resources that causes the hare's difficulties in modern intensive agriculture (Olesen & Asferg, 2006). Hence, the result of changing from spring to winter crops in a landscape where conditions are already poor will probably be a further limitation of resources as a result of temporal unavailability, and result in potentially large population declines.

The partridge positive response to unsprayed margins is probably also realistic in direction, although the magnitude of the response is dependent upon the assumption of access to the crop on the margins. Currently the model allows this access, but it is debatable as to whether this is realistic. In intensively managed fields it may simply be impossible for the partridges to enter the crop at all, which would render the improvements in forage as a result of use of unsprayed margins useless. What is clear, however, is that if either the access is possible, or if the unsprayed margin were to have a significantly lower crop biomass such as would result from have the margin unfertilized, then the response of the partridge would be positive. The size of the positive response will depend on the availability of nesting habitat (ideally hedgebanks along well managed hedgerows) in addition to the new forage habitat, and will naturally also depend on the crops grown and how intensively the landscape is managed. This latter factor is not yet implemented in ALMaSS, hence all farms are assumed to be managed efficiently. It is important to reiterate that like the hare, the partridge response is as much a function of its current low density and the general unsuitability of the modern agricultural landscape for this species. Under these conditions a small positive increase in habitat quality can produce dramatic effects as seen in relative terms, but returning populations to pre-decline densities would require a very much larger impact.

The impacts of the scenarios on the other species were all in a direction and magnitude that is unsurprising and are relatively safe if rather unexciting predictions.

Summary

The effect of the unsprayed margin and quota scenarios are generally very minor. This might have been predicted for the field vole which is rarely found in the fields, but is perhaps unexpected for the other species. The cause of the low impacts can be summed up as a combination of the following factors:

- Pesticides are not the primary limiting factor determining the abundance and occurrence of the species considered.
- The knock-on effects of pesticide changes in terms of changes in crop rotations were minimal.
- Pairs of factors are antagonistic, e.g. reductions in spraying may increase insect biomass, but reduction in open tramlines reduces access, hence responses to single factors are rarely as clear as expected when integrating over landscape and population levels.
- Realistic distribution of pesticide reductions did not lead to significant reductions in exposure or microhabitat in crops where pesticides could have been a limiting factor.
- The structure (height and biomass) of the crop was not assumed to alter significantly as a result of reductions in pesticide use. Restrictions on fertilizer use in unsprayed margins would have resulted in larger impacts on the vertebrate species.

However, all of these species will respond strongly to simple drivers, so it is not an impossible task to imagine managements that would be widely beneficial. The exercise as carried out here is therefore a case demonstrating that the policy level manipulation of pesticide usage is a blunt instrument for purposes of improving conditions for wildlife within the agricultural areas. Naturally this was not the only aim of these measures and other benefits need to be taken into account, but this also begs the question of what would happen to these other benefits if wildlife-targeted instruments were used instead.

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Appendix I: Tables describing farm classifications, rotations and scenario deviations from baseline as inputs to ALMaSS

The following tables are based on inputs received from the Bedrifts-model for scenario changes (Wulff et al, 2010) and Dalgaard et al (2010) for the baseline conditions.

Table A1: Distribution of land between permanent pasture of low and normal yield and arable land for the 10 farm types present in Bjerringbro.

Farm Type	Permanent Pasture - Low Yield	Permanent Pasture – Normal Yield	Arable	Total Area	Proportion
Other sandy soils	2.20	15.00	91.89	109.09	0.008
Cattle other soils	0.00	52.15	322.22	374.37	0.029
Cattle loamy soil	0.00	0.00	181.03	181.03	0.014
Cattle sandy soil	57.39	77.07	1445.15	1579.61	0.123
Crop other soils	72.80	55.59	1239.39	1367.78	0.106
Crop loamy soils	4.64	15.41	266.41	286.46	0.022
Crop sandy soils	106.66	151.07	4664.88	4922.61	0.382
Pigs other soils	8.01	20.20	709.02	737.23	0.057
Pigs loamy soils	5.12	2.10	127.98	135.20	0.010
Pigs sandy soils	7.23	39.07	3144.50	3190.80	0.248
Total	264.05	427.66	12192.47	12884.18	1.000
Proportion	0.02	0.03	0.95	1.00	

Table A2: Distribution of land between permanent pasture of low and normal yield and arable land for the 10 farm types present in Odense

	Permanent Pasture - Low Grazed	Permanent Pasture - Normal Yield	Arable	Total Area	Proportion
Andet Andenjord	12.2	19.4	1650.6	1682.2	0.027
Andet Lerjord	4.1	5.2	15.3	24.6	0.000
Andet Sandjord	1.9	14.6	331.3	347.8	0.006
Kvaeg Andenjord	12.3	164.8	2168.9	2346.0	0.037
Kvaeg Lerjord	29.9	112.5	2967.6	3109.9	0.050
Kvaeg Sandjord	61.8	366.3	2240.6	2668.7	0.043
Plante Andenjord	540.3	654.9	12653.8	13849.1	0.221
Plante Lerjord	147.4	439.1	10813.2	11399.7	0.182
Plante Sandjord	511.0	522.2	10184.9	11218.1	0.179
Svin Andenjord	48.3	67.9	4788.9	4905.1	0.078
Svin Lerjord	41.0	69.2	7297.5	7407.7	0.118
Svin Sandjord	52.6	29.0	3651.3	3732.9	0.060
Total	1462.8	2465.1	58763.7	62691.6	1.000
Proportion	0.023	0.039	0.937	1.000	

Table A3: Proportion of the total area covered by each ALMaSS crop for the 10 farm types present in the Bjerringbro area. These proportions are calculated out of the total arable area, i.e. excluding permanent crops and come from the baseline data obtained from Dalgaard et al 2010.

	Andet Sandjord	Kvæg Andenjord	Kvæg Lerjord	Kvæg Sandjord	Plante Andenjord	Plante Lerjord	Plante Sandjord	Svin Andenjord	Svin Lerjord	Svin Sandjord
Spring Barley	0.281	0.230	0.449	0.208	0.162	0.252	0.231	0.202	0.716	0.194
Oats	0.005	0.061	0.000	0.027	0.044	0.014	0.036	0.008	0.000	0.030
Winter Barley	0.187	0.000	0.012	0.030	0.124	0.104	0.123	0.099	0.032	0.128
Winter Wheat	0.244	0.128	0.114	0.122	0.309	0.369	0.182	0.385	0.143	0.346
Winter Rye	0.000	0.000	0.000	0.000	0.019	0.000	0.001	0.000	0.000	0.005
Triticale	0.000	0.000	0.000	0.060	0.030	0.036	0.068	0.012	0.000	0.055
Spring Rape	0.000	0.000	0.000	0.000	0.002	0.000	0.000	0.000	0.000	0.000
Winter Rape	0.000	0.000	0.000	0.054	0.062	0.102	0.054	0.118	0.031	0.113
Field Peas	0.000	0.046	0.000	0.007	0.010	0.000	0.016	0.030	0.000	0.013
Silage Grass	0.000	0.000	0.056	0.041	0.012	0.000	0.018	0.000	0.000	0.000
Seed Grass	0.000	0.028	0.000	0.000	0.047	0.000	0.015	0.000	0.000	0.004
Potatoes Industry	0.000	0.000	0.000	0.000	0.021	0.000	0.000	0.000	0.000	0.000
Potatoes Eating	0.000	0.000	0.000	0.000	0.000	0.000	0.003	0.000	0.000	0.000
Fodder Beet	0.016	0.000	0.000	0.015	0.000	0.000	0.001	0.000	0.000	0.000
Clover Grass Grazed	0.004	0.007	0.000	0.064	0.026	0.000	0.024	0.027	0.000	0.007
Spring Barley Silage	0.168	0.373	0.295	0.306	0.053	0.031	0.099	0.040	0.000	0.020
Silage Maize	0.000	0.009	0.000	0.006	0.003	0.000	0.002	0.001	0.000	0.001
Setaside	0.095	0.117	0.073	0.053	0.073	0.093	0.069	0.079	0.078	0.084
Carrots	0.000	0.000	0.000	0.006	0.005	0.000	0.059	0.000	0.000	0.000

Table A4: Proportion of the total area covered by each ALMaSS crop for the 12 farm types present in the Odense area. These proportions are calculated out of the total arable area, i.e. excluding permanent crops and come from the baseline data obtained from Dalgaard et al 2010.

	Andet Andenjord	Andet Lerjord	Andet Sandjord	Kvaeg Andenjord	Kvaeg Lerjord	Kvaeg Sandjord	Plante Andenjord	Plante Lerjord	Plante Sandjord	Svin Andenjord	Svin Lerjord	Svin Sandjord
Spring Barley	0.233	0.081	0.220	0.171	0.162	0.178	0.228	0.242	0.285	0.181	0.196	0.221
Oats	0.049	0.000	0.000	0.000	0.008	0.006	0.015	0.016	0.023	0.015	0.020	0.013
Winter Barley	0.049	0.000	0.073	0.064	0.016	0.034	0.048	0.034	0.052	0.086	0.087	0.096
Winter Wheat	0.188	0.000	0.195	0.230	0.211	0.088	0.329	0.366	0.201	0.436	0.439	0.347
Winter Rye	0.004	0.000	0.000	0.004	0.001	0.005	0.009	0.001	0.013	0.009	0.000	0.008
Triticale	0.019	0.000	0.114	0.003	0.000	0.005	0.005	0.002	0.012	0.006	0.007	0.005
Spring Rape	0.033	0.000	0.010	0.002	0.015	0.010	0.005	0.002	0.002	0.004	0.002	0.000
Winter Rape	0.036	0.000	0.019	0.009	0.025	0.006	0.045	0.035	0.041	0.064	0.067	0.075
Field Peas	0.005	0.000	0.000	0.006	0.002	0.002	0.012	0.005	0.014	0.006	0.001	0.001
Silage Grass	0.001	0.000	0.000	0.005	0.003	0.002	0.002	0.007	0.004	0.000	0.000	0.000
Seed Grass	0.011	0.000	0.041	0.008	0.027	0.006	0.082	0.117	0.060	0.047	0.068	0.059
Potatoes Industry	0.010	0.000	0.000	0.000	0.000	0.005	0.004	0.000	0.003	0.000	0.000	0.003
Potatoes Eating	0.002	0.003	0.000	0.000	0.000	0.011	0.010	0.002	0.005	0.011	0.000	0.022
Fodder Beet	0.025	0.000	0.042	0.031	0.032	0.036	0.054	0.055	0.039	0.038	0.034	0.053
Clover Grass Grazed	0.154	0.458	0.056	0.130	0.160	0.240	0.038	0.026	0.143	0.012	0.006	0.018
Spring Barley Silage	0.025	0.000	0.010	0.037	0.045	0.032	0.003	0.001	0.011	0.000	0.000	0.000
Silage Maize	0.095	0.000	0.136	0.231	0.240	0.274	0.022	0.010	0.021	0.013	0.003	0.002
Setaside	0.056	0.343	0.084	0.068	0.053	0.060	0.082	0.075	0.071	0.073	0.069	0.075
Carrots	0.002	0.115	0.000	0.000	0.000	0.000	0.007	0.005	0.002	0.001	0.000	0.002

Table A5: Change in proportion of crop per each farm type in the Bjerringbro area for SC01 and SC02. Crops with <1% change are not included and where rounding caused a net change in area this was corrected by adjusting the change of the next most affected crop. Crops with no change in area are not included in this table. These results are inputs obtained from the Bedriftsmodel (Wulff et al, 2010).

SC01	Andet Sandjord	Kvæg Andenjord	Kvæg Lerjord	Kvæg Sandjord	Plante Andenjord	Plante Lerjord	Plante Sandjord	Svin Andenjord	Svin Lerjord	Svin Sandjord
Permanent Pasture - Low Yield	0	0	0	0.02	0	0	0	0	0	0
Winter Barley	0	0	0	0	-0.01	0	0.01	0	0	0
Spring Barley	0	0	0	0	0.01	0	-0.01	0	0	0
Spring Barley Silage	0	0	0	-0.02	0	0	0	0	0	0
SC02										
Spring Barley	0	0	0	0	-0.09	0	-0.09	0	0	-0.01
Spring Barley Silage	0	0	0	-0.02	0	0	0	0	0	0
Winter Barley	0	0	0	0	-0.01	0	-0.03	0	0	0.01
Permanent Pasture - Low Yield	0	0	0	0.01	0	0	0	0	0	0
Permanent Pasture - Normal Yield	0	0	0	0.01	0	0	0	0	0	0
Winter Rye	0	0	0	0	0.1	0	0.12	0	0	0

Table A6: Change in proportion of crop per each farm type in the Odense area for SC01 and SC02. Crops with <1% change are not included and where rounding caused a net change in area this was corrected by adjusting the change of the next most affected crop. Crops with no change in area are not included in this table. These results are inputs obtained from the Bedriftsmodel (Wulff et al, 2010).

SC01	Andet Andenjord	Andet Lerjord	Andet Sandjord	Kvaeg Andenjord	Kvaeg Lerjord	Kvaeg Sandjord	Plante Andenjord	Plante Lerjord	Plante Sandjord	Svin An-denjord	Svin Lerjord	Svin Sandjord
Carrots	0	-0.07	0	0	0	0	-0.01	-0.01	0	0	0	0
Clover Grass Grazed	0	0	0	0.03	-0.05	-0.03	0	0	0	0	0	0
Clover Grass Grazed	0	0	0	0	0.03	0	0	0	0	0	0	0
Oats	0	0	0	0	0	0	0	0	0	0	0	0
Permanent Grass - Low Yield	0	0	0	-0.01	0	-0.01	0	0	0	0	0	0
Permanent Grass - Normal Yield	0	0	0	-0.05	0	0.03	0	0	0	0	0	0
Silage Grass	0	0.07	0	0.01	0	0	0.01	0.01	0	0	0	0
Silage Maize	0	0	0	0	0	0.01	0	0	0	0	0	0
Spring Barley	0	0	0	0	0.03	0	0	-0.01	0.01	0	0	0
Spring Barley Silage	0	0	0	0.01	0	0	0	0	0	0	0	0
Spring Rape	0	0	0	0	-0.01	0	0	0	0	0	0	0
Winter Barley	0	0	0	0	0	0	0	0	-0.01	0	0	0
Winter Rape	0	0	0	0	0	0	0	0	0	0	0.01	0
Winter Rye	0	0	0	0	0	0	0	0	0	0	0	0
Winter Wheat	0	0	0	0.01	0	0	0	0.010	0	0	-0.01	0
SC02												
Carrots	-0.02	0.07	0	0	0	0	0	0	0	0	0	-0.01
Clover Grass Grazed	0	0	0	0	0.01	0	0	0	0	0	0	0
Fruit	0.02	-0.07	0	0	0	0	0	0	0	0	0	0.01
Permanent Grass - Low Yield	0	0	0	0	0.01	0	0	0	0	0	0	0
Silage Maize	0	0	0	0	0	0	0	0	0	0.01	0	0
Spring Barley	0.01	0	0	0	0	0	-0.02	-0.06	-0.03	-0.01	0	0
Winter Barley	0	0	0	0	0	0	0.01	0.01	0	0	0	0

Winter Rape	0	0	0	0	0	0	0	0	0	0	0.01	0
Winter Rye	0	0	0	0	0	0	0.01	0	0.03	0	0	0
Winter Wheat	-0.01	0	0	0	-0.01	0	0	0.05	0	0	-0.01	0

Table A7: Crop changes by area for Unsprayed margin scenario (SC01) and the quota scenario (SC02) with the Odense rotation

Crop	Area Change SC01	Area Change SC02
Permanent Grass Normal Yield	-0.10%	
Silage Maize	0.08%	
Winter Rape	0.08%	
Winter Wheat	0.08%	0.78%
Spring Barely	-0.05%	-2.12%
Spring Rape	-0.04%	0.06%
Permanent Grass Low Yield	-0.04%	
Winter Rye	0.04%	0.75%
Winter Barley	-0.02%	0.34%
Oats	0.01%	0.07%
Spring Barley Silage	0.01%	
Peas	-0.01%	
Clover Grass	-0.01%	-0.25%
Vegetables		0.46%