A modelling approach to evaluating the effectiveness of Ecological Focus Areas: the case of the European brown hare

Keywords: agent-based modelling, agri-environment measures, ALMaSS, biodiversity, common agricultural policy, ecological focus areas, European brown hare, farmland, greening, land-use change, *Lepus europaeus*

ABSTRACT

With the current implementation of the Common Agricultural Policy (CAP) for 2014-2020, the European Commission wants to move towards “greener” farming practices in the European Union. Therefore, the EU funds both obligatory measures, such as Ecological Focus Areas (EFAs) through the Green Direct Payment program, and voluntary agri-environment measures. However, empirically evaluating the effectiveness of these measures is challenging. We therefore demonstrate here that mechanistic simulation models are a valuable tool for performing these evaluations. As an example, we use the Animal, Landscape and Man Simulation System (ALMaSS), an established simulation system that has been used to simulate a wide range of farmland species relevant to biodiversity. We analysed the benefits of seven greening scenarios for the European brown hare (*Lepus europaeus*), which has been in widespread decline throughout Europe since the 1960s. We examined the effects of the following EFA types on hare population dynamics: the cultivation of legumes such as (1) peas and (2) beans, (3) permanent and (4) rotational set-asides, (5) permanent extensive grasslands, and (6) herbaceous and (7) woody field margins. The cover of each type was increased separately up to 5% of the area in three Danish landscapes, which are characterised by low hare densities. The effects on female and yearling abundance were observed over a period of 30 years. All greening scenarios had significant positive effects on hare populations. The relative change in female abundance ranged from a factor of 0.4 in the peas scenario to 3.6 in the permanent set-aside scenario. However, only one EFA type, permanent set-asides, led to densities of more than 10 females per km^2 in all three landscapes, which we assumed to be the threshold for population viability. Herbaceous field margins were the second best EFA type, leading to population viability in two landscapes. Our results indicate that overall, 5% coverage with Ecological Focus Area is insufficient to improve the living conditions of the brown hare to a necessary degree. Permanent set-asides seem to be the most valuable type of EFA, but this needs to be confirmed for a wider range of species and landscapes. Using mechanistic simulation models for a suite of representative species, types of agricultural landscapes, and eco-regions could help in achieving the aim of the European Commission to promote biodiversity in the European community via greener farming practices.

INTRODUCTION

The intensification of agriculture in recent decades is accelerating the loss of habitats and putting many species commonly found in agricultural areas at risk. With the current reform of the Common Agricultural Policy (CAP) for 2014-2020, the European Commission wants to achieve, inter alia, a change towards a more environmentally friendly, sustainable and “greener” agricultural policy in the European Union. Therefore, a new policy instrument, the Green Direct Payment program (European Commission, 2013), was introduced from 2015 onwards, which links direct payments to farmers to requirements for obligatory environment-friendly farming practices, the so-called “greening” of farming (European Commission Regulation (EU) No 1307/2013). “Greening” practices include (1) crop diversification, (2) the maintaining of permanent grassland and (3) Ecological Focus Areas (EFAs). EFAs are areas of ecological interest or measures considered to have environmental benefits. From 2015 on, agricultural holdings with more than 15 hectares must establish 5% of their land as an EFA (European Commission Regulation (EU) No 1307/2013). In addition to these obligatory measures, the CAP promotes various voluntary agri-environment measures (Council Regulation (EC) No 1698/2005, European Commission, 2005).

However, critical voices have been raised recently, accusing the new CAP prescriptions of being so diluted that they are unlikely to benefit biodiversity (Pe'er *et al.*, 2014). Thus, it is critical to evaluate actual CAP measures from a biodiversity conservation perspective. Empirical evaluations are challenging, if not infeasible, as they would require large scale and long term monitoring of abundance and distribution for a wide range of species, landscapes, and eco-regions and for the implementation of different EFA types. We therefore demonstrate here that well-tested mechanistic simulation systems are suitable for assessing the effectiveness of EFAs.

In particular, agent-based models (ABM) are ideally suited to this task as they simulate how the structure and dynamics of complex systems emerge from first principles such as adaptive behaviour and energy budgets (Grimm *et al.*, 2005, Grimm & Berger, 2016). They combine physiological and behavioural processes at the individual level with demographic processes at the population level (Railsback & Grimm, 2012). Comprehensive agent-based simulation models can take landscape features, including farming practices into account, and can represent the social-ecological processes necessary to understand management and policy implications relevant to agricultural systems (Malawska *et al.*, 2014, Malawska & Topping, 2016). Importantly, they can represent existing expert knowledge and are rich enough in their structure and mechanisms to be evaluated and validated simultaneously at different levels of organisation and different scales (Grimm *et al.*, 2005, Augusiak *et al.*, 2014).

As a promising and well-established example of a simulation system, we used the spatially explicit agent-based Animal, Landscape and Man Simulation System (ALMaSS) (Topping *et al.*, 2003). ALMaSS represents real landscapes and farming practices in great detail and at a high spatial and temporal resolution, and has been used to predict population dynamics and the consequences of different landscape structures and pesticide applications for a wide range of species. ALMaSS has been in use and under development since 1998 and includes a hare model (Topping *et al.*, 2010). The hare model is well tested (Topping *et al.*, 2010) and fully documented using an extended version of the ODD protocol for describing agent-based models (Grimm *et al.*, 2006, Grimm *et al.*, 2010), which combines software for documenting program code with the rationale of ODD (ALMaSS Model Documentation 2014). The resulting ODDox documentation is a hypertext which is openly available on the internet (http://www2.dmu.dk/ALMaSS/ODDox/ALMaSS_ODDox/V1_02/index.html). A range of population control parameters was evaluated using “pattern-oriented modelling” (Wiegand *et al.*, 2004, Grimm *et al.*, 2005). Model testing followed “the modelling cycle” (Railsback & Grimm, 2012), which is an iterative process whereby models are tested against carefully selected performance criteria (Topping *et al.*, 2010, Augusiak *et al.*, 2014). Moreover, the generation of the Danish landscapes and implementation into ALMaSS is described in detail in Topping *et al.* (2016). Therefore, as the model has already been documented and tested comprehensively, we here will use it as a given “virtual laboratory” and restrict tests and and model analyses to the features we added in the definition of the agricultural landscapes.

To demonstrate the potential of ALMaSS and similar modelling systems in general for evaluating CAP measures, we used the case of the European brown hare (*Lepus europaeus* PALLAS, 1778). The brown hare has been in widespread decline throughout Europe since the 1960s (Flux & Angermann, 1990, Homolka & Zima, 1999, Edwards *et al.*, 2000, Smith *et al.*, 2005, Smith & Johnston, 2008). Although present across a wide geographic range, the brown hare is listed under Appendix III of the Bern Convention in Europe (Smith & Johnston, 2008), and several countries have placed the species on their Red List as “near threatened” or “threatened” (Reichlin *et al.*, 2006). Located in the European cultural landscape, the hare is a typical example of many other open farmland species in Europe (e.g., European hamster, Eurasian skylark and Grey partridge) that are affected by agricultural intensification and its side effects (Donald *et al.*, 2001, Stoate *et al.*, 2001). Having an average home range of more than 20 hectares depending on the landscape type (Schai-Braun & Hackländer, 2014), the brown hare is an excellent species to examine agricultural changes in a larger section of landscape and across fields.

Numerous studies show that monocausal explanations of hare population dynamics are not possible (Marboutin *et al.*, 2003, Schmidt *et al.*, 2004, Smith *et al.*, 2005). Thus, assessments and evaluations of hare population trends are difficult to perform due to the interactions that occur between multiple stressors and the spatial and temporal variability in field data (Smith *et al.*, 2005, Topping *et al.*, 2010). Furthermore there is still a lack of long-term and large-scale population data, despite extensive observation efforts in recent decades (Strauss *et al.*, 2008). To understand the ecological significance of agricultural effects on hare populations, habitat use must be examined precisely in space and time (Rühe & Hohmann, 2004, Smith *et al.*, 2004, Strauss *et al.*, 2008). In the present study, we use ALMaSS for this task.

In this study, we assessed the benefits of several EFA types for the brown hare. Specifically, we addressed the following research questions: (1) How do hare populations respond to an increased proportion of several EFA types in the landscape? (2) Are these enlarged EFA sites sufficient for hares to achieve viable population densities? (3) Are there qualitative differences between the effects of different EFA types regarding hare population dynamics? As the population density of hares fluctuates enormously at a local scale and depends on many external factors, previously published reports provide only very few reliable numbers. Homolka & Zima (1999) estimated that typical densities of stable hare populations in Europe range from 20 to 70 individuals per km^2. Based on this estimation we set our long-term viability criterion for this study at 10 females per km^2.

To answer our research questions, EFAs that are assumed to be relevant to the brown hare were selected according to the EU Regulation No 1307/2013 (Article 45, 46) and Delegated Regulation (EU) No 639/2014 (Article 45). We implemented seven greening scenarios in which the cover of the following EFA types was increased to 5% of the whole agricultural area: cultivation of nitrogen-fixing crops such as (1) peas and (2) beans, (3) permanent and (4) rotational set-asides, (5) permanent extensive grasslands, and (6) herbaceous and (7) woody field margins. We expected all greening scenarios to lead to higher hare abundances but also expected noticeable differences between their effects. For example, one might assume that areas such as set-asides or grasslands would be more beneficial as they provide larger contiguous habitats for hares than do narrow field margins. Likewise, permanent measures, such as long-term set-asides, might be more effective than temporary measures, such as rotational set-asides, as they provide year round food sources and cover. However, quantitatively verifying and accurately predicting these effects without a detailed, mechanistic models seems impossible.

METHODS

Landscape simulation system

ALMaSS was developed as a predictive analytics tool to answer policy questions regarding the effect of land-use change on different key animal species (Topping *et al.*, 2003). Therefore, the model combines agent-based animal models with a detailed and dynamic landscape simulation, which is explicit in space and time and based on a detailed land use map. Integrated weather information, farm management practices and vegetation growth simulations directly influence the structure and dynamics of the simulated landscape. Every vegetation unit is based on its own growth model, and the specific management of agricultural land is simulated in detail, thus facilitating a wide range of different scenarios (Topping *et al.*, 2003). The landscape model creates the environmental conditions for the hare model in ALMaSS. References to a full model description and comprehensive tests of the hare model in ALMaSS are provided in the introduction.

The landscape simulation model is grid-based and represents detailed landscape structures at a resolution of 1 m² (Topping *et al.*, 2003). Every grid cell has a reference number to a polygon, which is classified into one of 64 polygon types featuring specific attributes and behaviours. The polygon types are differentiated into non-vegetated areas, such as roads or streams, and vegetated areas, such as arable fields or field boundaries. The vegetation growth curves and farm management simulations for each polygon depend directly on weather data, which include daily records for mean temperature, mean wind speed, total daily precipitation and geographically determined daylight times. Vegetation growth for each crop model contains three curves to predict total leaf-area index (LAI), live (green) LAI and vegetation height (Topping & Olesen, 2005, Topping *et al.*, 2016). Vegetation cover is calculated using Beer's law, and biomass is calculated from the cover, LAI values, insolation, and crop management practices.

A general overview of the processes by which ALMaSS incorporates farm management information is provided by Topping *et al.* (2016), Appendix 2. All farms are managed by the *FarmManager*, which defines farm units, farm types and individual crop husbandry plans for all arable fields. Field polygons in the real world are simulated as farm units in the model. Each farm type (e.g., conventional arable farm) includes a specific crop rotation scheme, which determines the replacement of crops in a field on an area basis. The crop rotation scheme consists of 100 crop entries with multiple entries of each crop type in accordance with typical agricultural farming practices (Table 1). At the start of the simulation, a random crop in the rotation is taken as the starting point for each arable field and the next crop in the list is assumed to be grown in the same field in the following year. After four years, all fields of one farm type would have raised each of the 100 crops in the rotation list once. If a specific crop, e.g., spring barley, occurs 37 times out of 100 in the rotation (Table 1) it will on average occur on 37% of all fields covered by that rotation at any point in time. Unique crop husbandry plans for each crop are created from a set of farm events, such as harvesting, that directly influence the model animals in each field each day. Examples of the implementation can be found in the ALMaSS ODdox (ALMaSS Model Documentation 2014).

Table 1. The crop rotation scheme of a conventional arable farm. Eight crop types with different numbers of entries are included in the rotation list. Spring barley, for example, occurs 37 times out of 100, representing 37% of the farm's crop type.

Crop type in ALMaSS	Number of entries
SpringBarley	37
WinterWheat	35
WinterRape	11
WinterBarley	7
WinterRye	4
Oats	3
CloverGrassGrazed1	2
SeedGrass1	1
Sum	100

The landscape simulation in ALMaSS is based on weather and farm management data from Denmark. We assume that the climatic conditions and the agricultural management practices in Denmark are similar to those in Northwestern Europe, and therefore the results of the model should be relevant for other countries of the same agro-climatic zone too. We selected three landscape maps from different regions in Denmark (Mors, Naestved and Odder, each 10 km x 10 km) as a basis for the greening scenarios (Figure 1, Appendix: Figure A1-A2). The detailed generation of these landscapes is described in Topping *et al.* (2016). The landscapes represent agricultural areas with a range of landscape configurations that display different amounts of landscape structures and land cover types (Table 2, Appendix: Table A1-A3).

The landscapes in Mors and Naestved are characterised by large areas of fields and a low proportion of grasslands and forests, even though Mors consists of smaller fields and landscape structures. Odder exhibits greater forest and grassland areas and less field area. Regarding farm types, Mors is dominated by conventional pig farms, Naestved by conventional arable farms and Odder has a mix of both (Table 3). Pig farms are classified as farms with more than 20 animal units, of which pigs comprise 75% or more, or where the proportion of land used for grazing pigs is above 15%. Arable farms are characterised by large areas with few or no animals and little or no grazing (Topping et al., 2016).

Figure 1. Visual overview of Mors, 10 x 10 km, mapping the basic elements of the landscape visible at this scale.

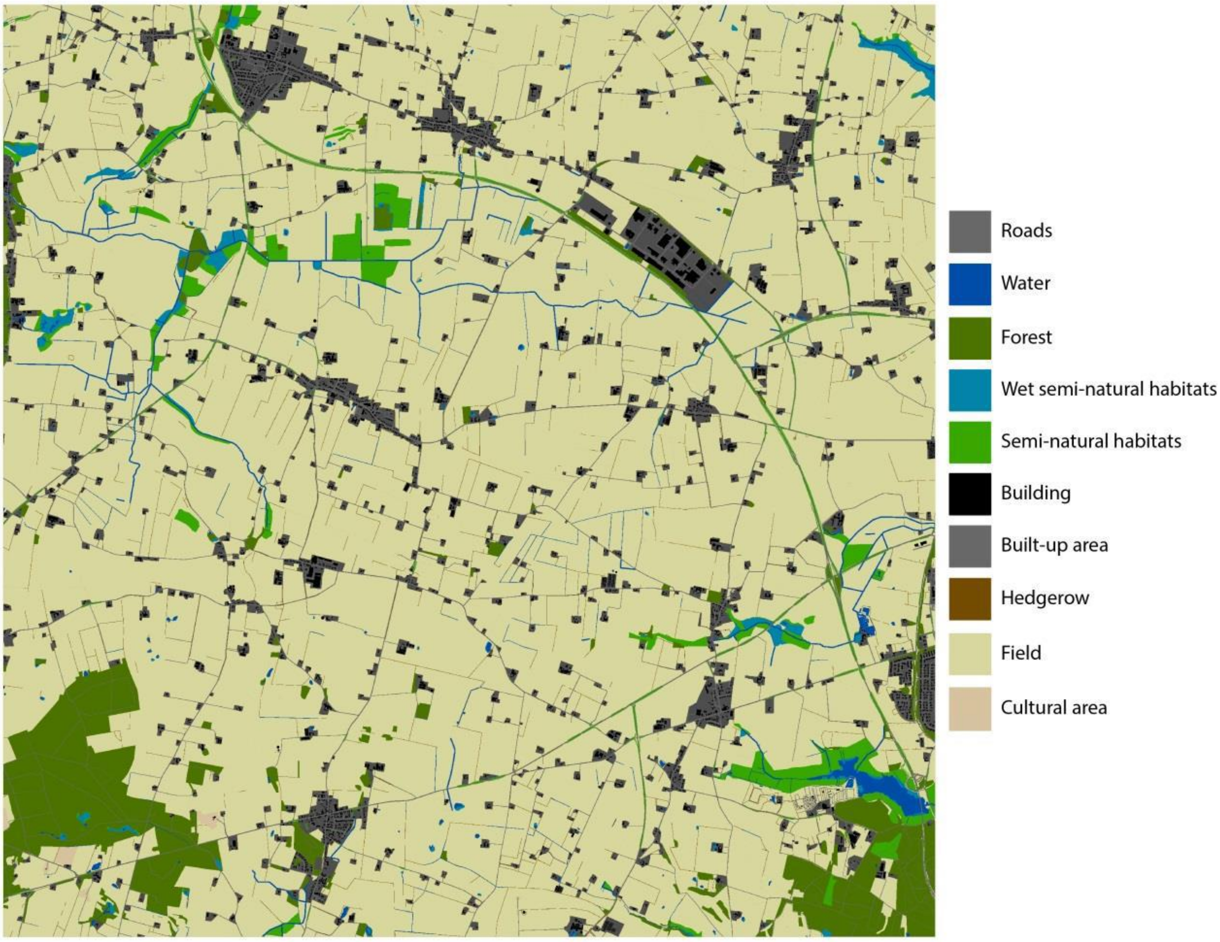

Table 2. Percent cover of basic landscape elements in the three model landscapes.

Landscape element	Mors	Naestved	Odder
Field	75.2	77.6	67.6
Forest	5.0	5.4	12.2
Wasteland	2.0	2.2	2.4
Road	1.1	0.9	1.0
Building	1.4	0.9	0.7

Table 3. The most common farm types in the three model landscapes by area.

Mors		Naestved		Odder	
Type	% area	Type	% area	Type	% area
Conv. pig	56%	Conv. arable	61%	Conv. pig	42%
Conv. cattle	18%	Conv. mixed stock	16%	Conv. cattle	14%
Conv. arable	18%	Conv. pig	8%	Conv. arable	36%
Conv. hobby	5%	Conv. cattle	7%	Conv. hobby	4%

Conv. = Conventional

Hare model

ALMaSS integrates a detailed agent-based model of the European brown hare, which is a behaviour-based model built upon a state/transition principle (Topping *et al.*, 2003). This means a hare is in a specific state where it exhibits specific behaviour; a transition to another state, and thus behaviour, takes place when predetermined conditions are fulfilled, e.g., according to certain probabilities and internal or external events (Figure 2). The model was based on available literature data and multiple patterns observed in Denmark (Topping *et al.*, 2010). All individuals belong to one of five specific life-stages: males, females, juveniles (36-265 days), mobile young (12-35 days) and infants (1-11 days), each showing an associated range of potential behavioural patterns.

A simulated population manager tracks every animal object and runs the particular behaviour, e.g., foraging, in 1-minute time-steps. As a result, the hares respond quickly to changes in environmental conditions and landscape configurations. They are able to extract food resources over a wide area when not occupied with nurturing offspring. The key behaviours are movement (dispersal/foraging), growth, lactation and starvation, all of which are described in the ALMaSS Hare ODdox (ALMaSS Model Documentation 2014). Energy is the primary driving variable, and if a hare exceeds a fixed number of consecutive days at a negative energy balance, it dies. Forage quality is based on a combination of vegetation type, vegetation age and vegetation structure. Farming activities actively influence the model animals via changes in habitat structure and direct disturbances. Hunting takes place in autumn, and other external influences are related to life-stage specific probabilities (e.g., predation) or management activities.

For the simulations, the starting number of the hares was set at 10 individuals per km². After 50 years all landscapes showed baseline densities of less than 10 females per km², which is characteristic for species-poor regions, as e.g., intensively used agricultural landscapes.

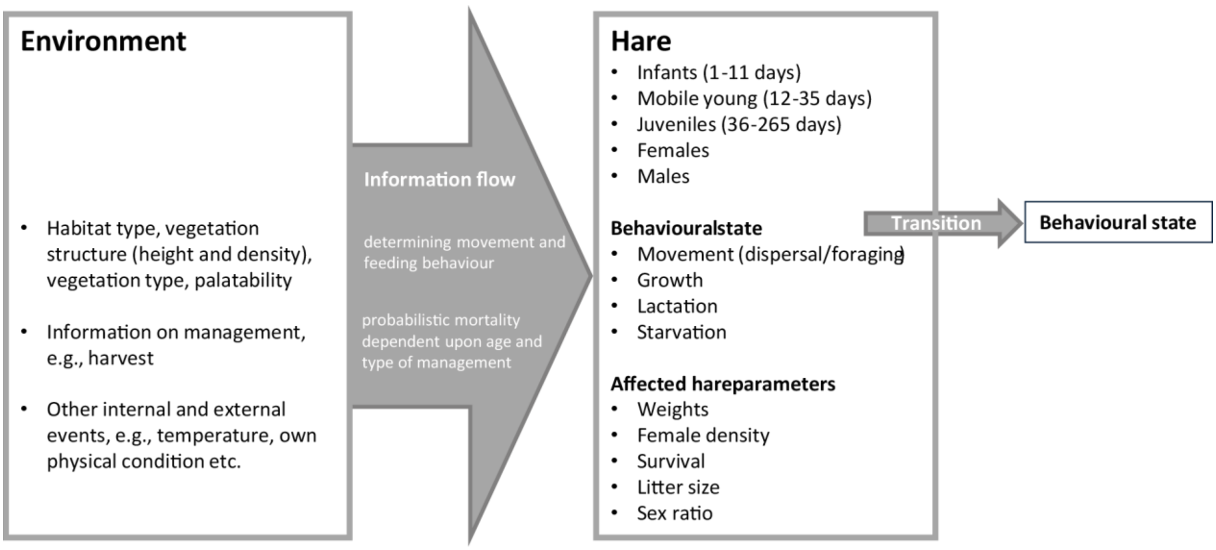

Figure 2. Effect of environmental conditions on hare simulation settings. Hares are categorised into five life stages that showing specific behavioural states.

Greening scenarios

We developed seven greening scenarios to analyse the influence of different EFA types, which may be enhanced by the current EU CAP reform, on the European brown hare. We selected measures that can be assumed to have direct effects on habitat and survival of the hares: the cultivation of legumes, such as peas and beans, permanent and rotational set-asides, permanent extensive grasslands, and herbaceous and woody field margins. Permanent grasslands cannot directly be classified as an EFA, but maintaining permanent grasslands is one of the three greening options. For each scenario, the area of the one EFA type being considered was increased at the start of the simulation to approximately 5% of the whole agricultural area of the landscape (Table 4). We decided to implement EFAs on landscape level, because farms that are legally obliged to fulfill the EFA requirement cover more than 94% of the agricultural area in each model landscape. The EFAs were randomly distributed in the model landscape (Figure 3).

Table 4. Percentages of EFA types in the three model landscapes. The baseline is the original unchanged landscape, where almost all of the measures are already included to some degree. The scenario percentages show small deviations from 5% because the implementation could not be precisely achieved in the model in some cases. Where model code terms are, for historical reasons, different from scenario terms used here, these are specified.

Scenario Type	Scenario		Mors	Naestved	Odder
Rotation	Peas	Baseline	0.05	0.05	0.10
		Scenario	4.85	4.80	4.75
	Beans (*BroadBeans*)	Baseline	0.00	0.00	0.00
		Scenario	4.85	4.80	4.75
	Rotational set-asides (*Setaside*)	Baseline	0.00	0.00	0.00
		Scenario	4.85	4.80	4.75
Field	Permanent set-asides (*PermanentSetaside*)	Baseline	0.27	0.38	0.57
		Scenario	5.01	5.00	5.00
	Permanent grasslands (*PermPastureTussocky*)	Baseline	0.13	0.00	0.03
		Scenario	5.00	4.99	5.00
Edge structure	Herbaceous field margins (*FieldBoundary*)	Baseline	0.54	0.49	0.43
		Scenario	5.00	5.00	5.02
	Woody field margins (*Hedges*)	Baseline	0.69	0.60	0.32
		Scenario	5.01	5.00	5.06

Three of the scenarios directly influence the crop composition of the farm management model: the planting of peas and beans and establishing rotational set-asides. Therefore, we conducted new crop rotations for each farm type, replacing winter wheat with peas or beans or converting it to a rotational set-aside (Appendix: Table A4-A6). The replacement decisions were made with regard to agricultural restrictions on crop rotations. For example, beans stay in the field over winter, and therefore, they must precede a crop in the rotation that does not have any autumn activities, e.g., spring barley.

All other scenarios affect the landscape configuration. Permanent set-aside sites and extensive grasslands are fixed landscape polygons outside the field area. We increased their amount up to 5% by reducing field area (Appendix: Table A7). In a second set of simulations we increased the percentage of these two EFA types in one landscape (Mors) to 7%, 10% and 15%, to obtain an idea of the sensitivity of the hare population development beyond the 5% scenario.

Field margins are fixed edge structures that are also outside the field area. For these scenarios, we used landscape maps where all edge structures were widened to approximately 5 metres. These extensions use an additional polygon type in ALMaSS, named “chameleon”, which can be changed from one habitat type to another at run-time. Thus the same map can be used for comparing different field margin management practices, applying elements of theoretical landscape models (Pe'er *et al.*, 2013). We calculated the correct percentages of these structures for the field margin scenarios and assigned the remaining amount to one farm (Appendix: Table A8).

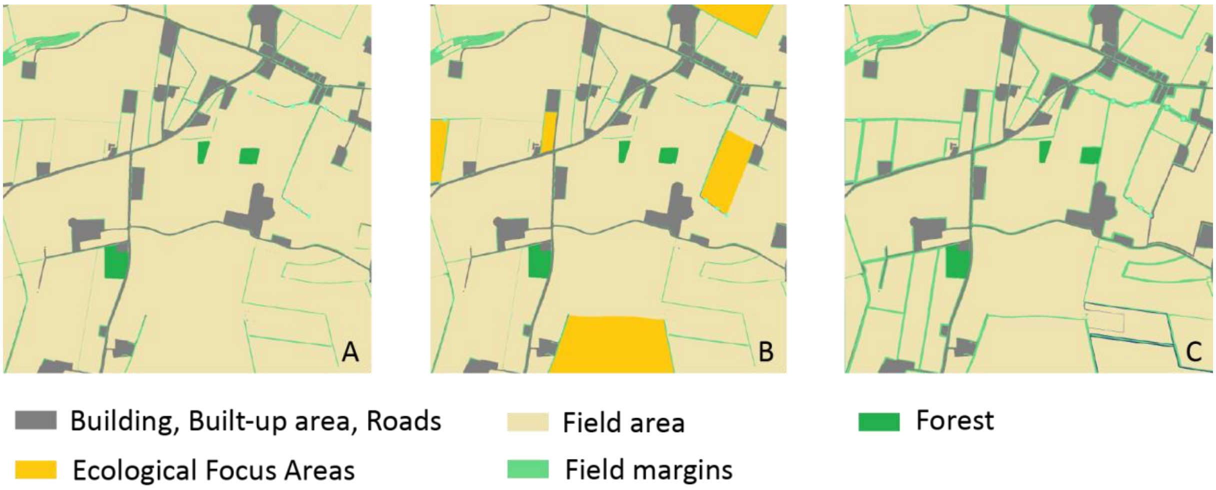

Figure 3. Exemplary presentation of the scenario changes in Mors. The landscape section (1 x 1 km) shows the baseline conditions (A), the distribution of field related EFA types (B) and the widened field margins (C).

Data analysis

Ten replicates of each scenario were run in each of the three model landscapes. Initial conditions for each replicate differed in the initial distribution of hares across the landscape and the initial allocation of crops in the fields. The total number of simulations was 240. To obtain results that did not depend on the randomly chosen initial distribution of individuals and crops, 50 years were simulated before data were recorded. Then, output data were recorded for each year from a simulation of the subsequent 30 years.

To display population responses in detail, we recorded and analysed three different outputs: female abundance, yearling abundance and AOR (Abundance-Occupancy Relationship)-index. Regarding female abundance, the number of females at day 270 of each year in the landscape was counted. We focused on females because males do not limit the population size. Yearling abundance was calculated by counting the average number of infants, young and juveniles alive at day 270 of each year. Boxplots display the effects of the scenarios on female abundance for each landscape, including the yearly output data for ten replicates.

The AOR-index is an indicator that facilitates the interpretation of agent-based model outputs by simultaneously quantifying the relative changes in abundance and occupancy in response to a scenario (Hoye *et al.*, 2012). Occupancy is quantified based on the proportion of grid cells with at least one individual, and abundance based on the mean number of individuals in the occupied cells (Hoye *et al.*, 2012).

Wilcoxon rank sum tests were used to test the significance of the differences between the values at baseline and for the scenarios for each landscape. We used a number of replicates (10) that corresponds to the replicate numbers used in many empirical studies. Therefore, we did not artificially increase the significance levels by increasing the number of simulations. Moreover, mean female abundance showed only little change with an increasing number of replicates (Appendix: Figure A3). All statistical evaluations were performed with R 3.2.2 (R Development Core Team, 2015).

RESULTS

Baseline hare densities varied between 1.1 and 4.1 female hares per km² (Table 5). Odder showed the highest female abundance, whereas the females in Mors nearly went extinct (Figure 4). The number of yearlings ranged between 2.6 and 10.5 individuals per km² (Table 5, Figure 4). Direct comparisons with field counts under comparable conditions are not possible, but the numbers match current observations of Danish hare populations (Management Plan for the Hare 2013). The literature does not provide estimates of overall hare population sizes for Denmark as densities vary between different regions depending on land use, topography and the presence of predators.

Table 5. Baseline hare densities predicted for each landscape.

Landscape	Mors	Naestved	Odder
Total females/km²	1.06	2.09	4.11
Total yearlings/km²	2.58	5.35	10.45

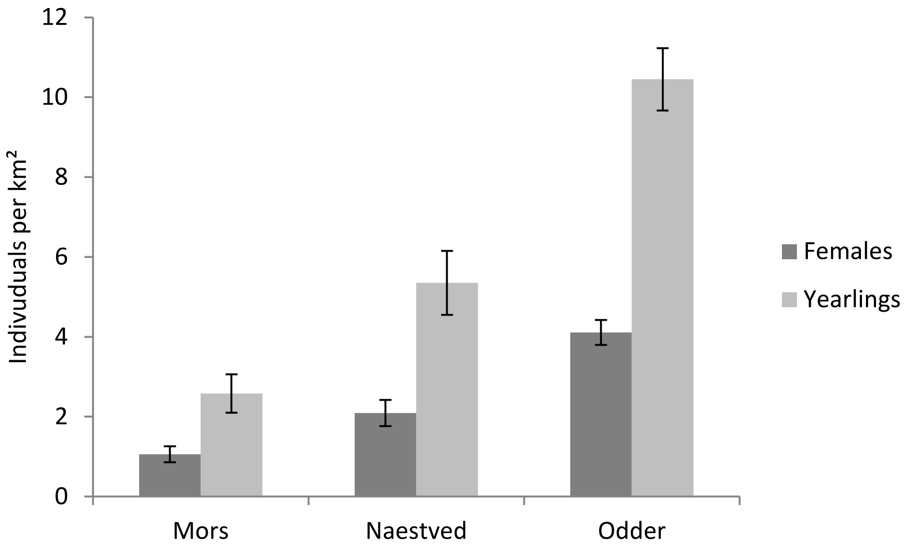

Figure 4. Female abundance and number of yearlings in the three model landscapes under the baseline scenario, observed on day 270 in each of 30 simulated years. The bars indicate the 95% confidence interval calculated for the ten replicates.

All greening scenarios had significant positive effects ($P < 0.01$) on the hare populations (Table 6, Figure 5, Appendix: A9-A10). The effect on female and yearling abundances was not significantly different for each scenario type. Regarding legumes, beans had a significantly greater effect on hare population densities than did peas ($P < 0.001$). Likewise, permanent set-aside sites resulted in greater effects than rotational set-asides ($P < 0.001$). Overall, permanent set-aside sites and herbaceous field margins produced the largest population responses of all scenarios, i.e., female abundance increased by factors of 3.6 and 3.5, respectively. In contrast, extensive grasslands had a minor effect ($P < 0.001$). Woody field margins had a far smaller effect than that of herbaceous field margins (factor of 1.7 and 3.5, respectively; $P < 0.001$).

Table 6. Factors by which female and yearling abundances increased relative to the baseline scenarios. Factors are averaged across the three landscapes considered.

Scenario		Females per km²	Abs. change	Rel. change	Yearlings per km²	Abs. change	Rel. change
Baseline		2.4			6.1		
Legumes	Peas	3.3	0.9	0.4	8.3	2.2	0.4
	Beans	7.6	5.2	2.2	19.2	13.1	2.1
Set-asides	Rotational	7.9	5.5	2.3	20.7	14.6	2.4
	Permanent	11.0	8.6	3.6	30.2	24.1	4.0
Grasslands	Extensive	9.4	7.0	2.9	25.4	19.3	3.2
Field margins	Herbaceous	10.8	8.4	3.5	25.2	19.1	3.1
	Woody	6.4	4.0	1.7	14.7	8.6	1.4

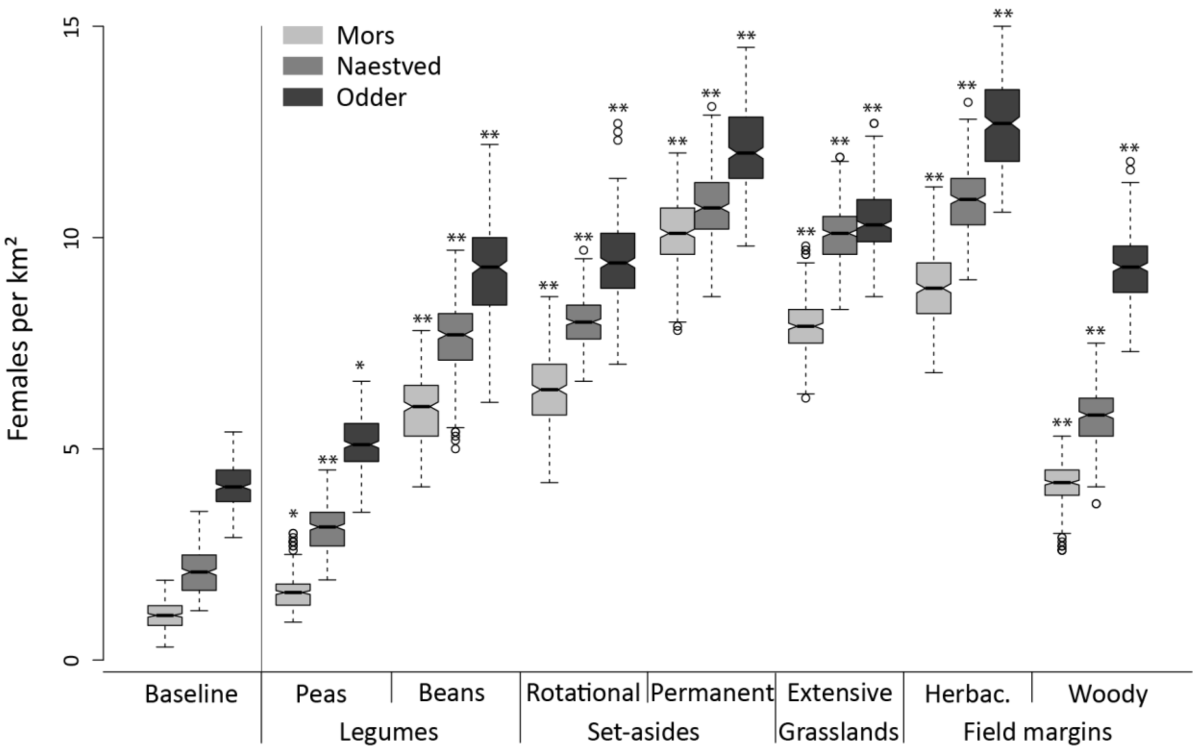

Figure 5. Effect of the evaluated scenarios on female abundance in each landscape. Stars specify the level of significance, i.e., $^{**}P \leq 0.001$, $^{*}P \leq 0.01$, for each scenario relative to the baseline.

The average increase in female abundance relative to the baseline was greatest in Naestved (ø 6 females) and lowest in Mors (ø 5 females) (Appendix: Table A9-A10). Only one EFA type, permanent set-asides, achieved an increase in female density that exceeded 10 females per km² in all three landscapes (ø 11 females, Figure 6). Extensive grasslands and herbaceous field margins reached or exceeded this threshold in Naestved (10 and 11 females, respectively) and Odder (10 and 13 females, respectively). Using 5% herbaceous field margins in Odder achieved the highest female density of all scenarios.

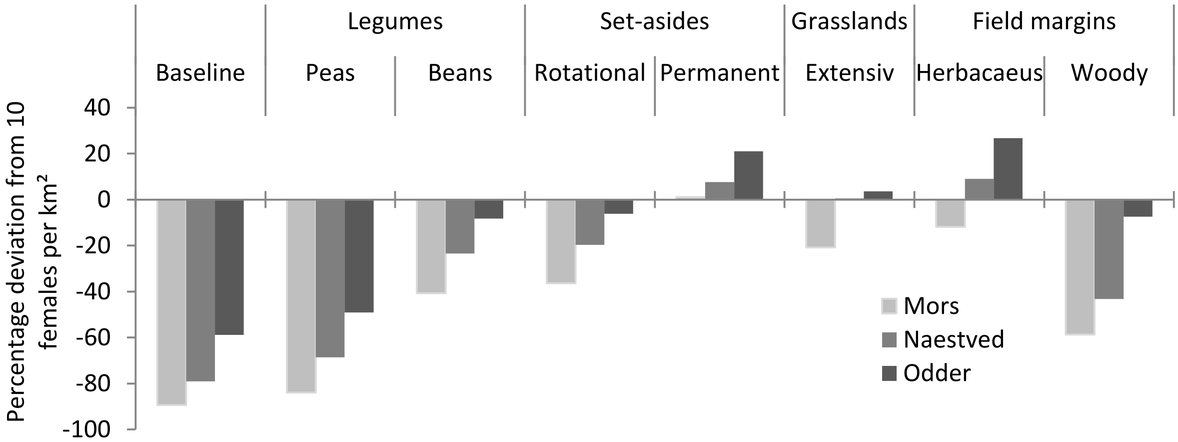

Figure 6. Percentage deviation from the long-term viability criterion of 10 females per km².

The AOR plots show that all scenarios affected the hare population in similar ways but to varying degrees (Figure 7). They are all located in the first quadrant, which means population size, habitat quality and the proportion of favourable habitat was improved. Increases in abundance but not in occupancy indicate that the quality of the habitat is clearly different between the scenarios. Again, the biggest effect was observed with permanent set-asides and the lowest with peas. A comparison of the landscapes shows that the effects of EFA types, especially permanent set-asides, are increased in Mors and reduced in Odder.

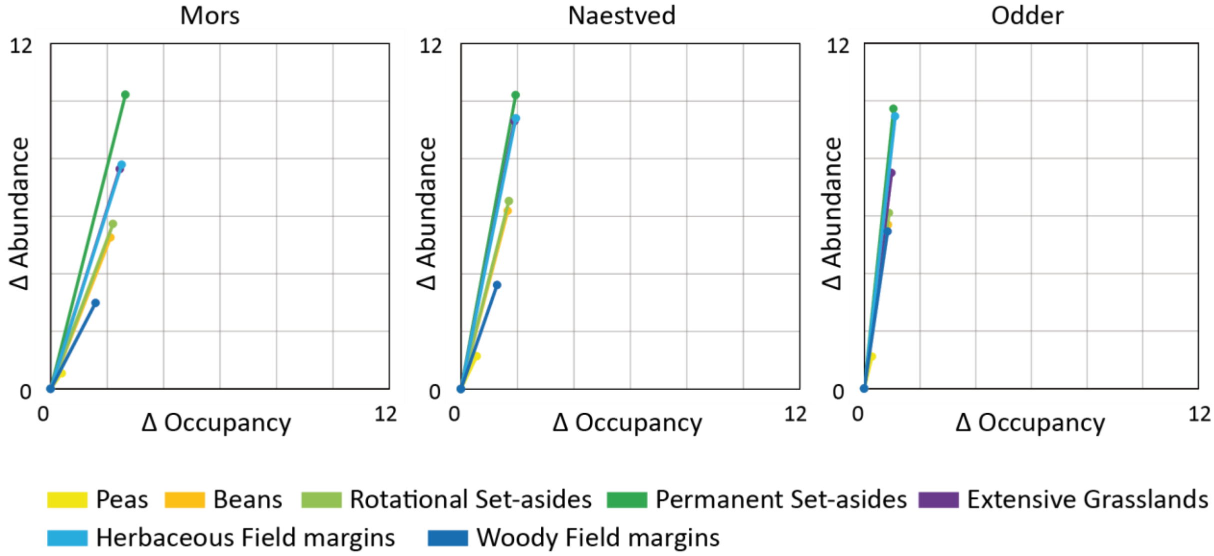

Figure 7. The AOR (abundance-occupancy relationship)-index plotted for the evaluated scenarios in all three landscapes relative to the baseline.

The exemplary percentage increase of the EFA types permanent set-asides and extensive grasslands in Mors leads to an approximation of the female abundance (Figure 8, Appendix:

A11). While the effect of these two measures raises with increasing percentage, it seems to asymptotically approach a female density of 15 hares per km².

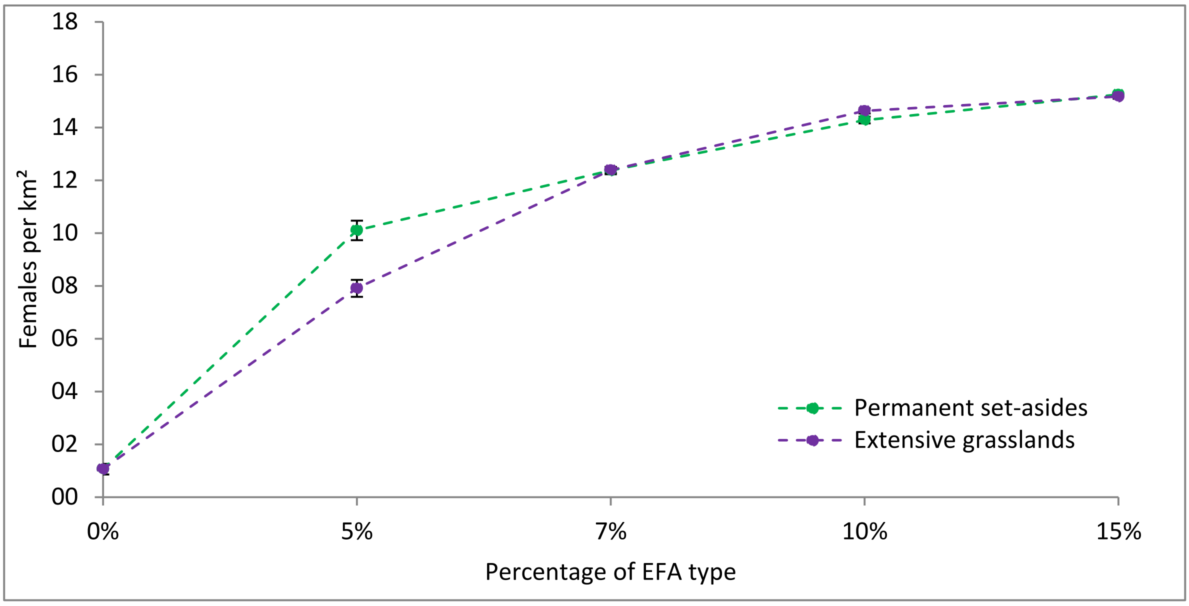

Figure 8. Effect of a percentage increase of two EFA types on female abundance in Mors. The bars indicate the 95% confidence interval calculated for the ten replicates.

Discussion

Current global environmental issues require the development of new approaches in environmental research. This study shows that it is possible to evaluate policy measures with simulation models. For the first time, the effects of mitigation measures on hares were analysed solely using a computer model. ALMaSS is rich enough in structure to map environmental effects in detail and to reproduce interactions between landscapes, management practices, weather data and the traits of individuals. Thus, it opens up endless possibilities for addressing environmental questions.

The greatest strength of ALMaSS is its ability to depict landscape structures at a resolution of 1 m² and the details of farm management practices in 1-day steps, while considering behavioural changes at an even finer resolution. Previous studies have shown how sensitive hares are in reacting to farming and landscape changes (Topping, 2011, Topping *et al.*, 2016). Landscape structure has a proven impact on habitat quality and thus on the living conditions of species (Dauber *et al.*, 2003); however, landscape composition is a greater determinant than landscape configuration (Bennett *et al.*, 2006). The Danish model landscapes used in this study vary in their proportion and distribution of landscape elements and edge structures, field sizes, spatial diversity and degree of fragmentation.

However, the Danish landscapes were used here as a demonstration only. Other landscapes are easy to incorporate into ALMaSS, and a diverse pool of European landscapes are necessary to allow for a wider assessment of these issues in the EU. A set of tested models for a range of key animal species are already present, which cover invertebrates, birds and mammals (e.g. Bilde & Topping, 2004, Topping *et al.*, 2010, Topping *et al.*, 2012).

Previously published research shows that quantitative estimates of the effects of mitigation measures on population development are rare and usually relate to plants, birds or insects (Kleijn *et al.*, 2001, Vickery *et al.*, 2004, Kleijn *et al.*, 2006, Concepcion *et al.*, 2008). While there are currently no reliable evaluations of the CAP reform's greening measures, studies on the overall effects of agri-environment schemes (AESs) can be found as this instrument was established in most European countries in the early 1990s. These studies describe some examples of limited positive effects of AESs on biodiversity (Kleijn *et al.*, 2006, Whittingham, 2007, Concepcion *et al.*, 2008). Regarding the brown hare, there are only a few studies analysing the effects of specific agri-environmental measures on population trends in several European countries (Genghini & Capizzi, 2005, Zellweger-Fischer *et al.*, 2011, Petrovan *et al.*, 2013, Meichtry-Stier *et al.*, 2014). Our results show that all of the analysed EFA types had moderate, positive effects on the development of hare populations. However, only one EFA type, permanent set-asides, led to a viable hare density of 11 females per km², averaged for the three landscapes. Herbaceous field margins and extensive grasslands barely reached this point in two landscapes. Based on this, our results indicate that the 5% limit for Ecological Focus Areas is insufficient to improve the living conditions of the European hare to a necessary degree.

How consistent are the observed effects of EFAs on hare populations with what we know about hare behaviour? Checking for such consistency is important, even for the most realistic and well-tested models. We should never blindly trust model outputs and should make sure we understand why and how these outputs emerged (Augusiak *et al.*, 2014).

It is undisputed that the land use changes of the last decades have changed the food supply of hares enormously. The main causes are restricted crop rotations, the drastic decline in the cultivation of perennial crops such as lucerne and clover, the lack of catch crops, the strong dominance of a small number of crops (e.g., maize), and the intensification of crop husbandry and the use of agrochemicals (herbicides) (Smith *et al.*, 2005, Pépin & Angibault, 2007, Zellweger-Fischer *et al.*, 2011). Our results show that a small increase in crop diversification via the cultivation of legumes, such as peas and beans, which are forage plants for hares, positively influences hare population development. Beans have a much higher effect because the crop is sown late, provides resources over the winter, is easy for hares to access and is usually ploughed in the spring. Therefore, it is a good food source for wildlife in the summer and especially in the winter.

Set-asides are often considered to be biodiversity hotspots and important retreat areas for many species (e.g. Van Buskirk & Willi, 2004). Although they were an established CAP agri-political instrument, the European Commission abolished the set-aside requirement in 2008, removing most of the set-asides from EU landscapes. As a consequence, the living conditions of many species common to agricultural areas worsened, especially if no compensating areas were provided and if the land was used for the cultivation of monocultures such as energy crops (Gevers *et al.*, 2011). Our results show that a 5% increase in permanent set-asides strongly favours hare population development. Hares prefer set-aside sites over field area with arable crops throughout most of the year (Smith *et al.*, 2004) because this habitat meets several important requirements. First, it is a foraging habitat with a high proportion of herbaceous plants and grasses. Second, the height of the vegetation provides protection for young hares against predators. In ALMaSS, permanent set-asides are assumed to be patchy; therefore, forage is accessible. Thus, the improvement in forage and protection for successful breeding resulted in permanent set-asides having the strongest positive influence of all the analysed EFA types. In contrast, although similarly positive in its effects, the resources provided by rotational set-asides are only present during part of the year, and there is the potential for increased mortality of the young during ploughing; hence, the benefits of this type of EFA were lower.

Permanent, extensive grasslands had a slightly lower effect on hare population development than was observed for permanent set-asides. Previous research shows that hare densities are often low in grassland sites and decrease with stocking density (Barnes *et al.*, 1983, Smith *et al.*, 2005, Zellweger-Fischer *et al.*, 2011). Grazing pressure is included in ALMaSS and can generate a 25% reduction in forage availability as it shifts from low to high levels. Thus, hares will leave permanent grasslands if their energy balance is low. Combined with the lower vegetation height caused by grazing, the suitability in the model of grasslands for foraging is limited at high grazing densities. However, some grazing is beneficial in that it prevents grass from becoming too tall and dense both in ALMaSS model and in the real world (Karmiris & Nastis, 2007).

Herbaceous field margins showed a similar strong influence on female abundance to that of the permanent set-asides. Hares select field margins during active and inactive periods of the day and more frequently remain closer to field boundaries than within large fields (Petrovan *et al.*, 2013). These landscape structures offer both species-rich vegetation, including essential forage plants, such as wild herbs and grasses (higher food value in the model), and protected resting sites for young hares. In contrast, woody field margins, such as hedges or tree lines had a significantly lower impact on hare abundances, which was caused by the higher amount of inedible woody plants (lower food value in the model) and their unsuitability as breeding areas.

In line with the results of other studies, our results show that the EFA types that are most favourable for hare population development are those that enable year-round forage and protection at the farm level (Tapper & Barnes, 1986, Smith *et al.*, 2004, Macdonald *et al.*, 2007, Pépin & Angibault, 2007). Nevertheless, 5% Ecological Focus Area coverage is probably not enough to improve the living conditions of the brown hare to ensure long-term population viability. To support this conclusion, the general validity of the results must be verified with further studies.

The AOR plots display comparable population responses for each scenario. However, permanent grasslands in Mors had a remarkably higher impact compared to those of the other EFA types. This suggests that the benefit of this measure is higher in intensively farmed landscapes. In contrast, the effects of permanent grasslands and herbaceous field margins in Odder were nearly equal. Nevertheless, one should be aware of the context dependency in relation to landscape and farming, which limits the generalisation of these results (Topping, 2011, Topping *et al.*, 2016).

The ecological quality and quantity of greening measures, as well as an appropriate management plan, is critical for their environmental outcomes. In the case of hares, those EFA types that promote landscape heterogeneity at the farm-level scale and provide year-round shelter and food sources are the most suitable, especially in intensively managed landscapes. As these features are also important for other open farmland species, the particular importance of permanent set-asides should be reconsidered and valued through the reintroduction of a set-aside requirement.

One limitation of our study is that we increased each EFA type to approximately 5% to make the single measures comparable. In practice, these 5% areas consist of various measures, which do not need to be explicitly hare-friendly. Thus, the scenarios used in our simulations would not normally be implemented in reality; however, they provide important insights into the impacts of EFA measures.

Another limitation is that the model is based on Danish landscapes and Danish farm management practices. The agriculture of each country depends on national policy provisions and regional characteristics. In this case, Danish agriculture is characterised by a high proportion of small farms (< 50 ha), often with small fields, a high proportion of animal husbandry (especially pigs) and intensive fertilization. To increase the validity of the results, we have examined landscapes (Mors, Naestved and Odder), which differ in farm types and field sizes. Regarding farm types, Mors is dominated by pig farms (56%), Naestved by arable farms with crop production (61%) and Odder has a mix of both (42% pig farms, 36% arable farms). Thus, we have tested both landscapes that are featured with a high amount of livestock production and landscapes that are featured with a high amount of crop production. We are aware that the transferability of the specific results of our study may be limited due to Danish faming conditions, but we predict that the trends demonstrated will be similar in other EU countries with similar agricultural systems. Further studies will be needed to reveal regional variations across the EU regarding the implementation and impact of greening measures.

If it turns out that 5% of EFA is not enough to attain a sustainable benefit for a large spectrum of open farmland species, the question arises of which obligatory percentage is enough. Our results show that an increase of permanent set-asides and extensive grasslands from 5% to 7% enhances the female abundance by 22% and 57%. At 15% it is 51% and 92%, respectively. From about 10% on, the measures do not seem to favor hare population development very much more, indicating that other factors controlling population density, such as predation or intra-specific competition, limit the carrying capacity of the landscapes. Other studies suggest an increase of areas covered by high-quality AES options and semi-natural habitats to at least 14% (Meichtry-Stier *et al.*, 2014), or even just 10% (Oppermann *et al.*, 2012) may be required to sustainably protect agricultural biodiversity.

The EU regulations say that EFAs only have to be implemented on farms with more than 15 hectares and that certain landscape features can be credited. Hence, greening measures only have to be applied to approximately 50% of EU farmlands and many farms are excluded from this implementation (Pe'er *et al.*, 2014). Our results indicate that these restrictions might severely limit the effectiveness of greening measures. Simulation systems such as ALMaSS could be used to quantitatively assess these restrictions.

CONCLUSIONS

We demonstrated that EFAs and other elements of the CAP reform can be quantitatively assessed with well-tested, mechanistic simulation models. Our results indicate that overall, 5% coverage with Ecological Focus Area is insufficient to improve the living conditions of the brown hare to a necessary degree. In order to allow general statements about the effectiveness of EFAs, investigations for other open farmland species are needed. If it turns out that EFAs fail to attain a sustainable benefit for a large spectrum of open farmland species, the European Commission should consider increasing the obligatory percentage of

EFAs in the course of the EU evaluation of the CAP reform in 2017. To substantiate this assumption with facts, we recommend a scientifically thorough evaluation of the greening regulations regarding their environmental benefit. Kleijn & Sutherland (2003) suggest that periodic ecological evaluations be mandatory for any agri-environmental scheme in the future. As in pesticide risk assessments, where a range of test species is used to assess potential adverse effects at different scales and for different taxa, an assessment scheme based on tools such as ALMaSS could cover a range of species, eco-regions, and farmland practices, as well as projected changes in climate and land use. This would not only allow for the assessment of specific measures but also for the optimization of measures in a given region.

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Appendix

Figure A1. Visual overview of Naestved, 10 x 10 km, mapping the basic elements of the landscape visible at this scale.

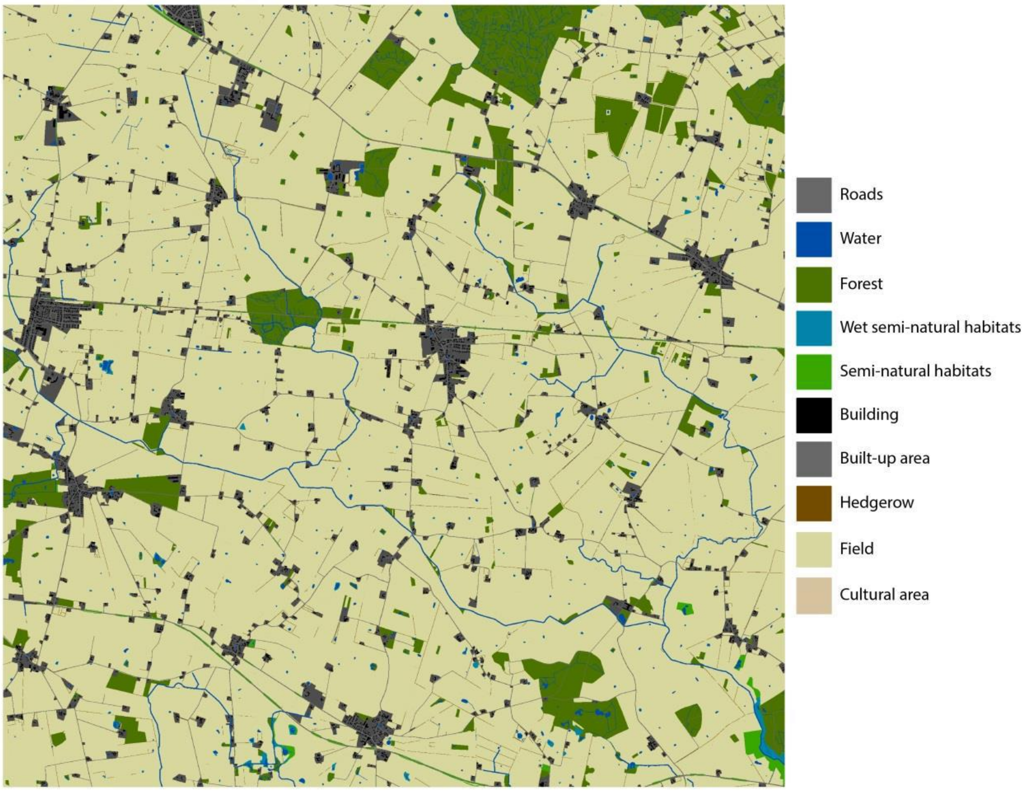

Figure A2. Visual overview of Odder, 10 x 10 km, mapping the basic elements of the landscape visible at this scale.

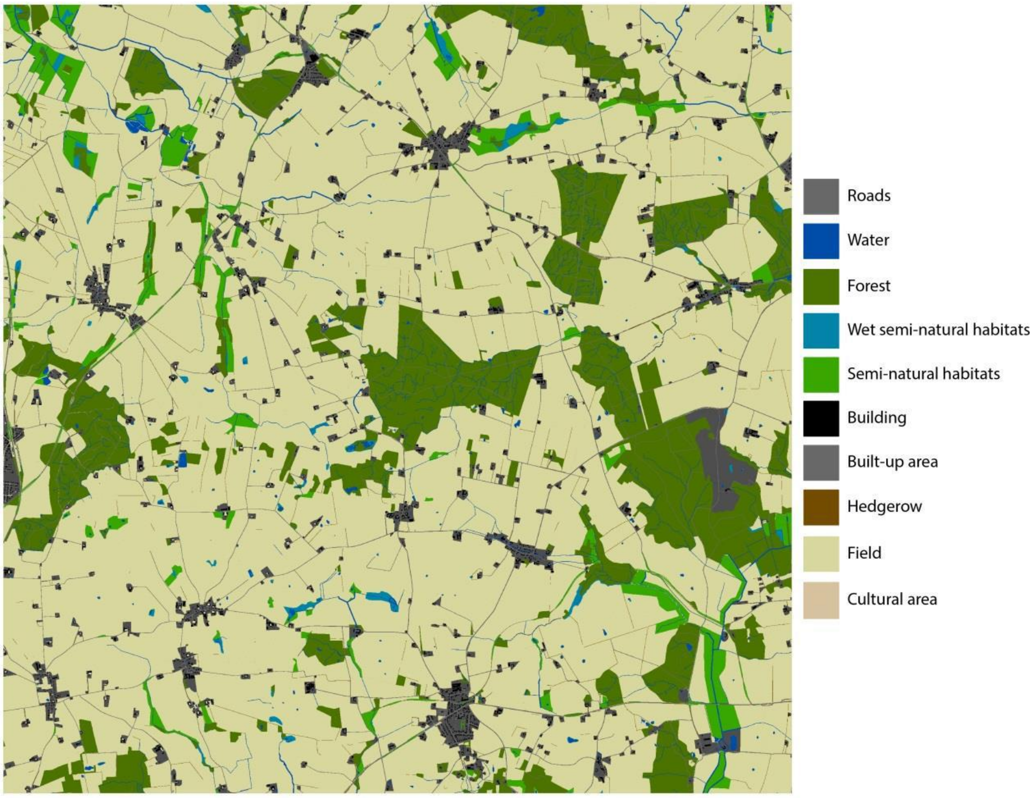

Table A1. The amount of all landscape elements in Mors

Polygon type in ALMaSS	Landscape element	Area [m²]	%	%*
5	Building	1416036	1.42	1.42
8	Rural residential	762835	0.76	0.76
11	Garden	4206600	4.21	4.21
12	AmenityGrass	338061	0.34	0.34
13	RoadsideVerge	561749	0.56	0.56
20	Field	75154612	75.15	69.89
27	PermPastureTussocky	132395	0.13	0.11
33	PermanentSetaside	271002	0.27	0.24
35	PermPasture	1807788	1.81	1.61
40	DeciduousForest	19776	0.02	0.02
41	Copse	313888	0.31	0.31
50	ConiferousForest	74594	0.07	0.07
55	YoungForest	6192	0.01	0.01
56	Orchard	14781	0.01	0.01
60	MixedForest	4998688	5.00	5.00
70	Scrub	1380	0.00	0.00
90	Freshwater	431233	0.43	0.43
94	Heath	31943	0.03	0.03
95	Marsh	800206	0.80	0.80
96	River	374849	0.37	0.37
98	RiversidePlants	318040	0.32	0.32
110	NaturalGrassDry	24591	0.02	0.02
115	ActivePit	142018	0.14	0.14
121	LargeRoad	564084	0.56	0.56
122	SmallRoad	1104618	1.10	1.10
123	Track	1062506	1.06	1.06
130	Hedges	689938	0.69	1.01
140	HedgeBank	962945	0.96	0.64
150	Chamaeleon		0.00	5.52
160	FieldBoundary	536650	0.54	0.54
201	RoadsideSlope	292045	0.29	0.29
203	Carpark	17872	0.02	0.02
204	Churchyard	37495	0.04	0.04
205	NaturalGrassWet	294879	0.29	0.29
206	Saltmarsh	2159	0.00	0.00
207	Stream	39709	0.04	0.04
208	HeritageSite	6967	0.01	0.01
209	Wasteland	2007325	2.01	2.01
210	NaturalGrassDry	57416	0.06	0.06
211	WindTurbine	243	0.00	0.00
212	Pylon	6791	0.01	0.01
216	WoodyEnergyCrop	113100	0.11	0.10
Σ		99999999	100.00	100.00

Table A2. The amount of all landscape elements in Naestved

Polygon type in ALMaSS	Landscape element	Area [m²]	%	%*
5	Building	868071	0.87	0.87
8	Rural residential	336990	0.34	0.34
11	Garden	3597150	3.60	3.60
12	AmenityGrass	266573	0.27	0.27
13	RoadsideVerge	383294	0.38	0.38
16	BuiltUpWithParkland	1840	0.00	0.00
20	Field	77567804	77.57	72.83
33	PermanentSetaside	378691	0.38	0.31
35	PermPasture	810581	0.81	0.73
40	DeciduousForest	26133	0.03	0.03
41	Copse	252947	0.25	0.25
50	ConiferousForest	63645	0.06	0.06
55	YoungForest	487715	0.49	0.44
56	Orchard	1225444	1.23	1.14
60	MixedForest	5389529	5.39	5.39
70	Scrub	8572	0.01	0.01
90	Freshwater	510837	0.51	0.51
94	Heath	499	0.00	0.00
95	Marsh	316911	0.32	0.32
96	River	440500	0.44	0.44
98	RiversidePlants	416838	0.42	0.42
101	SandDune	54	0.00	0.00
110	NaturalGrassDry	16285	0.02	0.02
118	Railway	113101	0.11	0.11
121	LargeRoad	325521	0.33	0.33
122	SmallRoad	875933	0.88	0.88
123	Track	679586	0.68	0.68
130	Hedges	601033	0.60	0.88
140	HedgeBank	910501	0.91	0.63
150	Chamaeleon		0.00	5.02
160	FieldBoundary	486048	0.49	0.49
201	RoadsideSlope	70829	0.07	0.07
203	Carpark	1881	0.00	0.00
204	Churchyard	14916	0.01	0.01
205	NaturalGrassWet	74800	0.07	0.07
207	Stream	62107	0.06	0.06
208	HeritageSite	2989	0.00	0.00
209	Wasteland	2205689	2.21	2.21
210	NaturalGrassDry	5804	0.01	0.01
211	WindTurbine	279	0.00	0.00
212	Pylon	2287	0.00	0.00
214	PlantNursery	30272	0.03	0.03
216	WoodyEnergyCrop	169525	0.17	0.15
Σ		100000004	100.00	100.00

Table A3. The amount of all landscape elements in Odder

Polygon type in ALMaSS	Landscape element	Area [m²]	%	%*
5	Building	725515	0.73	0.73
6	UrbanNoVeg	209059	0.21	0.21
11	Garden	2958120	2.96	2.96
12	AmenityGrass	656848	0.66	0.66
13	RoadsideVerge	309657	0.31	0.31
20	Field	67611303	67.61	63.54
27	PermPastureTussocky	29180	0.03	0.03
33	PermanentSetaside	565184	0.57	0.53
35	PermPasture	4002591	4.00	3.61
40	DeciduousForest	4574	0.00	0.00
41	Copse	224329	0.22	0.22
55	YoungForest	975076	0.98	0.89
56	Orchard	22710	0.02	0.02
60	MixedForest	12231602	12.23	12.23
90	Freshwater	323990	0.32	0.32
94	Heath	16893	0.02	0.02
95	Marsh	1282697	1.28	1.28
96	River	180819	0.18	0.18
98	RiversidePlants	670666	0.67	0.67
101	SandDune	8505	0.01	0.01
110	NaturalGrassDry	200716	0.20	0.20
118	Railway	61145	0.06	0.06
121	LargeRoad	302465	0.30	0.30
122	SmallRoad	997203	1.00	1.00
123	Track	920064	0.92	0.92
130	Hedges	319456	0.32	0.47
140	HedgeBank	487054	0.49	0.34
150	Chamaeleon		0.00	4.59
160	FieldBoundary	433704	0.43	0.43
201	RoadsideSlope	129378	0.13	0.13
203	Carpark	583	0.00	0.00
204	Churchyard	14939	0.01	0.01
205	NaturalGrassWet	485102	0.49	0.49
206	Saltmarsh	1086	0.00	0.00
207	Stream	192434	0.19	0.19
208	HeritageSite	721	0.00	0.00
209	Wasteland	2433652	2.43	2.43
210	NaturalGrassDry	3979	0.00	0.00
211	WindTurbine	63	0.00	0.00
212	Pylon	2322	0.00	0.00
216	WoodyEnergyCrop	4617	0.00	0.00
Σ		100000001	100.00	100.00

* Landscapes with widened edge structures

Table A4. Farm types in the three model landscapes

Farm types in ALMaSS	Number of farms		
	Mors	Naestved	Odder
ConventionalPig	35	11	28
ConventionalCattle	37	23	38
ConventionalArable	35	75	34
ConventionalHobby	51	39	38
ConventionalMixedStock	4	17	5
ConventionalBeet		2	
ConventionalVeg		1	
OrganicMixedStock		1	
OtherFarmTypes	4	5	2

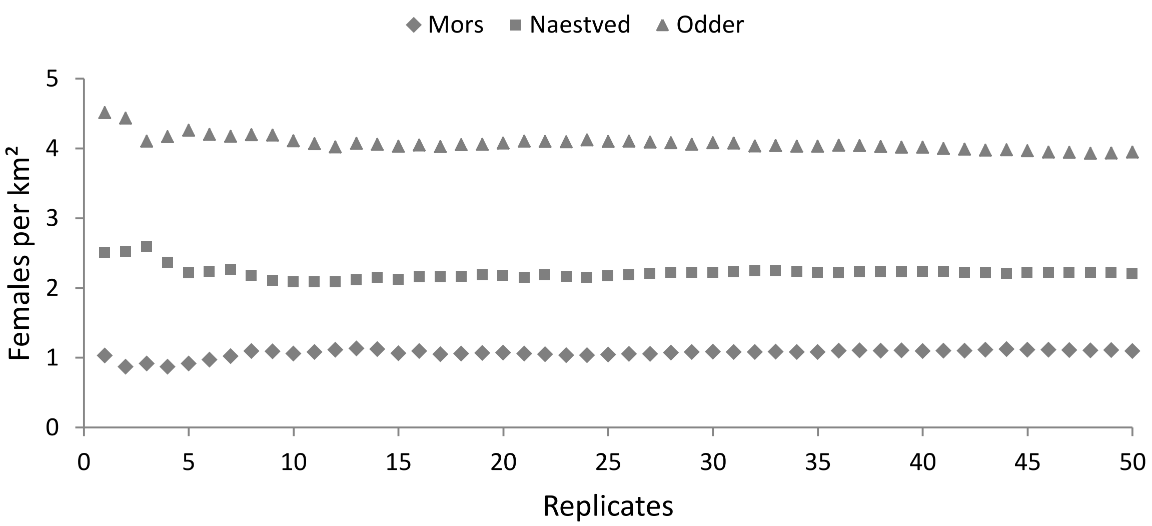

Figure A3. Effect of increasing number of replicates on the mean female abundance for the baseline scenarios in Mors, Naestved and Odder.

Table A5. Changes in the crop rotations of the conventional farm types for each scenario

Crop type in ALMaSS	Farm types in ALMaSS																											
	ConventionalPig				*ConventionalCattle*				*ConventionalArable*				*ConventionalHobby*				*ConventionalMixedStock*				*ConventionalBeet*				*ConventionalVeg*			
Scenario	B	P	B	RS	B	P	B	RS	B	P	B	RS	B	P	B	RS	B	P	B	RS	B	P	B	RS	B	P	B	RS
SpringBarleyCloverGrass	4	4	4	4	18	18	18	18	0	0	0	0	12	12	12	12	9	9	9	9	2	2	2	2	2	2	2	2
SpringBarley	26	26	21	26	6	6	1	6	37	37	32	37	22	22	17	22	26	26	21	26	34	34	29	34	5	5	2	5
SpringBarleySpr	0	0	5	0	0	0	5	0	0	0	5	0	0	0	5	0	0	0	5	0	0	0	5	0	0	0	3	0
SpringWheat	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Oats	3	3	3	3	1	1	1	1	3	3	3	3	2	2	2	2	2	2	2	2	0	0	0	0	0	0	0	0
WinterBarley	9	9	9	9	2	2	2	2	7	7	7	7	4	4	4	4	5	5	5	5	1	1	1	1	0	0	0	0
WinterWheat	35	30	30	30	9	4	4	4	35	30	30	30	14	9	9	9	22	17	17	17	29	24	29	24	3	0	3	0
WinterRye	4	4	4	4	2	2	2	2	4	4	4	4	3	3	3	3	5	5	5	5	0	0	0	0	0	0	0	0
WinterRape	10	10	10	10	2	2	2	2	11	11	11	11	4	4	4	4	8	8	8	8	2	2	2	2	0	0	0	0
SpringRape	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	23	23	23	23
FieldPeas	0	5	0	0	0	5	0	0	0	5	0	0	0	5	0	0	0	5	0	0	0	5	0	0	0	3	0	0
BroadBeans	0	0	5	0	0	0	5	0	0	0	5	0	0	0	5	0	0	0	5	0	0	0	5	0	0	0	3	0
Setaside	0	0	0	5	0	0	0	5	0	0	0	5	0	0	0	5	0	0	0	5	0	0	0	5	0	0	0	3
SeedGrass1	3	3	3	3	1	1	1	1	1	1	1	1	0	0	0	0	9	9	9	9	2	2	2	2	0	0	0	0
Potatoes	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	3	3	3
CloverGrassGrazed1	4	4	4	4	37	37	37	37	2	2	2	2	38	38	38	38	11	11	11	11	2	2	2	2	4	4	4	4
SpringBarleySilage	0	0	0	0	6	6	6	6	0	0	0	0	2	2	2	2	0	0	0	0	0	0	0	0	0	0	0	0
MaizeSilage	1	1	1	1	16	16	16	16	0	0	0	0	0	0	0	0	3	3	3	3	0	0	0	0	0	0	0	0
Carrots	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	59	59	48	59
Triticale	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SugarBeet	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	28	28	23	28	0	0	0	0
Σ	100				100				100				101				100				100				99			

B = Baseline, P = Peas, B = Beans, RS = Rotational set-asides

Table A6. Changes in the crop rotations of the organic and other farm types for each scenario

Crop type in ALMaSS	Farmtypes in ALMaSS							
	OrganicMixedStock				*OtherFarmTypes*			
Scenario	B	P	B	RS	B	P	B	RS
OBarleyPeaCloverGrass	12	12	12	12	17	17	12	17
OSpringBarley	13	13	13	13	0	0	0	0
SpringBarleySpr	0	0	0	0	0	0	5	0
OSpringWheat	8	8	8	8	0	0	0	0
OOats	17	17	17	17	3	3	3	3
OWinterBarley	0	0	0	0	0	0	0	0
OWinterWheat	4	9	9	9	4	4	4	4
OWinterRye	11	11	11	11	0	0	0	0
OWinterRape	0	0	0	0	0	0	0	0
OSpringRape	0	0	0	0	0	0	0	0
OFieldPeas	6	1	1	1	0	5	0	0
BroadBeans	0	0	0	0	0	0	5	0
Setaside	0	0	0	0	0	0	0	5
OSeedGrass1	5	5	5	5	0	0	0	0
OPotatoes	0	0	0	0	5	5	5	5
OCloverGrassGrazed1	19	19	19	19	67	62	62	62
OSpringBarleySilage	3	3	3	3	3	3	3	3
OMaizeSilage	0	0	0	0	1	1	1	1
OCarrots	1	1	1	1	0	0	0	0
OTriticale	1	1	1	1	0	0	0	0
OSugarBeet	0	0	0	0	0	0	0	0
Σ	100				100			

B = Baseline, P = Peas, B = Beans, RS = Rotational set-asides

We tried as far as possible to implement the rotation scenarios equally. The replacement decisions were made with regard to agricultural restrictions on the crop rotations.

Table A7: Changes in the polygon types for permanent set-asides and permanent extensive grasslands [%]

	Mors			Naestved			Odder		
Scenario	B	PS	PEG	B	PS	PEG	B	PS	PEG
Field	75.15	70.41	72.09	77.57	72.94	73.39	67.61	63.17	66.64
Permanent set-asides (*PermanentSetaside*)	0.27	5.01	0.27	0.38	5.00	0.38	0.57	5.00	0.57
Intensive grasslands (*PermPasture*)	1.81	1.81	0.00	0.81	0.81	0.00	4.00	4.00	0.00
Extensive grasslands (*PermPastureTussocky*)	0.13	0.13	5.00	0.00	0.00	4.99	0.03	0.03	5.00

B = Baseline, PS = Permanent set-asides, PEG = Permanent extensive grasslands

In the case of permanent extensive grasslands, we first converted all intensive grasslands into extensive grasslands and then filled in the missing amount with field area.

Table A8: Changes in the polygon types for the field margin scenarios [%]

	Mors			Naestved			Odder		
Scenario	B	HFM	WFM	B	HFM	WFM	B	HFM	WFM
Field	75.15	76.21	76.68	77.57	78.08	78.47	67.61	67.61	67.61
Herbaceous field margins (*FieldBoundary*)	0.54	5.00	0.54	0.49	5.00	0.49	0.43	5.02	0.43
Woody field margins (*Hedges*)	1.01	1.01	5.01	0.88	0.88	5.00	0.47	0.47	5.06
Chameleon	5.52	0.00	0.00	5.02	0.00	0.00	4.59	0.00	0.00

B = Baseline, HFM = Herbaceous field margins, WFM = Woody field margins

Table A9: Absolute and relative changes in female abundances for all three landscapes

		Legumes		Set-asides		Grasslands	Field margins	
	Baseline	Peas	Beans	Rotational	Permanent	Extensive	Herbaceous	Woody
Mors	1.1	1.6	5.9	6.4	10.1	7.9	8.8	4.1
Abs. change		0.5	4.9	5.3	9.0	6.9	7.8	3.1
Rel. change		0.5	4.6	5.0	8.5	6.5	7.3	2.9
Naestved	2.1	3.1	7.7	8.0	10.8	10.1	10.9	5.7
Abs. change		1.1	5.6	5.9	8.7	8.0	8.8	3.6
Rel. change		0.5	2.7	2.8	4.2	3.8	4.2	1.7
Odder	4.1	5.1	9.2	9.4	12.1	10.4	12.7	9.3
Abs. change		1.0	5.1	5.3	8.0	6.3	8.6	5.1
Rel. change		0.2	1.2	1.3	1.9	1.5	2.1	1.3

Table A10: Absolute and relative changes in yearling abundances for all three landscapes

		Legumes		Set-asides		Grasslands	Field margins	
	Baseline	Peas	Beans	Rotational	Permanent	Extensive	Herbaceous	Woody
Mors	2.6	3.9	14.7	16.1	26.7	20.6	18.8	8.9
Abs. change		1.3	12.1	13.5	24.1	18.0	16.2	6.3
Rel. change		0.5	4.7	5.2	9.3	7.0	6.3	2.4
Naestved	5.3	7.9	19.4	21.0	29.6	27.2	25.4	12.9
Abs. change		2.5	14.0	15.6	24.2	21.8	20.0	7.5
Rel. change		0.5	1.8	2.9	4.5	4.1	3.7	1.4
Odder	10.5	13.0	23.6	25.2	34.4	28.5	31.4	22.2
Abs. change		2.6	13.1	14.8	23.9	18.0	20.9	11.8
Rel. change		0.2	1.3	1.4	2.3	1.7	2.0	1.1

Table A11: Female abundances at percentage increase of the EFA types permanent set-asides and extensive grasslands in Mors.

	Percentage of the EFA type			
Scenario	5%	7%	10%	15%
Permanent set-asides	10.1	12.4	14.3	15.3
Absolute change		2.3	4.2	5.2
Relative change		0.2	0.4	0.5
Extensive grasslands	7.9	12.4	14.6	15.2
Absolute change		4.5	6.7	7.3
Relative change		0.6	0.8	0.9