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Assessing the regional impacts of increased energy maize cultivation on farmland birds

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Abstract The increasing cultivation of energy crops in Germany substantially affects the habitat function of agricultural landscapes. Precise ex ante evaluations regarding the impacts of this cultivation on farmland bird populations are rare. The objective of this paper was to implement a methodology to assess the regional impacts of increasing energy maize cultivation on the habitat quality of agricultural lands for farmland birds. We selected five farmland bird indicator species with varying habitat demands. Using a crop suitability modelling approach, we analysed the availability of potential habitat areas according to different land use scenarios for a real landscape in Northeast Germany. The model was based on crop architecture, cultivation period, and landscape preconditions. Our results showed that the habitat suitability of different crops varied between bird species, and scenario calculations revealed an increase and a decrease in the size of the potential breeding and feeding habitats, respectively. The effects observed in scenario 1 (increased energy maize by 15 %) were not reproduced in all cases in scenario 2 (increased energy maize by 30 %). Spatial aggregation of energy maize resulted in a negative effect for some species. Changes in the composition of the farmland bird communities, the negative effects on farmland bird species limited in distribution and spread and the relevance of the type of agricultural land use being replaced by energy crops are also discussed. In conclusion, we suggest a trade-off between biodiversity and energy targets by identifying biodiversity-friendly energy cropping systems.

Keywords Agriculture · Energy cropping · Farmland biodiversity · Land use change · Indicator species

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Introduction

The cultivation of biomass crops for energy supply is one of the driving forces for recent land use changes in Germany. The amendment of the EEG (Renewable Energy Act) in 2004 with the simultaneous implementation of a bonus payment for the production of electricity from renewable raw materials increased the interest in energy crops. One of the main concerns in public discussion is the one-sided focus on maize cropping for energy plants. Maize is the predominant energy crop for biogas production in Germany, used in over 90 % of the biogas plants (DMK 2012). As the highest yielding biogas crop (Amon et al. 2006; Bauer et al. 2010), maize cultivation has increased substantially in recent years with further growth predicted (Schümann et al. 2010; Kivelitz and Lütke Entrup 2010). For economic reasons, long transport distances of the biomass should be avoided, because the biomass is harvested at high water content, when the dry matter content is below 30 % (Anderson and Fergusson 2006). The desire for short transport distances has led to a substantial increase in local aggregation of maize cultivation near biogas plants. The conflicts between the governmental strategy for biodiversity maintenance (biodiversity strategy) and the promotion of renewable energies (energy concept) are already frequently raised in public discussions (Jackson 2011; Huston and Marland 2003; Petersen 2008), and the anticipation of these conflicts is of primary interest to policy makers.

Birds are useful indicators of the quality of landscapes and habitats because they are highly mobile species and often wide ranging so they can represent the state of an entire landscape (Furness and Greenwood 1993; Achtziger et al. 2004). The widespread public interest in birds gives them a symbolic strength that helps to foster political interest, resulting in the incorporation of ecological goals into political agendas (Bird Life International 2012). Bird indicators are used to assess the achievement of national targets such as the reduction of the current rate of biodiversity loss by 2010 (Gregory et al. 2008; PECBMS 2009). Hence, farmland bird indicators are suitable to illustrate farmland biodiversity.

Throughout Europe, farmland bird populations are showing a substantial decline; half of the European farmland birds disappeared in the last quarter of a century (PECBMS 2009; Donald et al. 2006; Wretenberg et al. 2007). A similar situation is occurring in Germany, where the farmland bird population sizes are still far below the national target value set for 2015 at only 66 % of the set achievement levels (BMU-Federal Ministry for the Environment, Nature Conservation and Nuclear 2010). Agricultural intensification is seen as the main cause for the general population decline all over Europe (Donald et al. 2001; Guerrero et al. 2012). Guerrero et al. (2012) identified several factors affecting farmland bird densities at landscape and field levels, including the field size, number of different crops, land use diversity, and high yields, which are all associated with farming intensification. However, the exact cause–effect relationships are hard to determine, and modelling is a good option to illustrate the complex processes.

Initial results regarding the impact of increasing energy crop cultivation on biodiversity were analysed by Dziewiaty and Bernardy (2007). The survey is based on real survey data and considers the effects of different crops on the breeding and feeding situation of farmland birds. Using the agent-based model system ALMaSS, Gevers et al. (2011) calculated a marked decline of the population size of the skylark (*Alauda arvensis*) with respect to increased energy maize cultivation. Engel et al. (2012) used a spatially explicit ecological model to assess the effects of the reduction of crop type richness, the proportion of energy crops, and the average field size on skylark abundance. Both models (Gevers et al. 2011; Engel et al. 2012) cover the regional landscape scale but do not take the crop scale into account. Moreover, the results were only provided for the skylark, and other farmland bird species with different habitat requirements received no consideration.

The objective of this paper is to assess the regional impacts of increasing energy maize cultivation on the habitat quality of agricultural lands for farmland birds. More specifically, the presented methodology aims to (1) calculate the habitat suitability of crops based on crop stand structure, (2) assess the potential regional breeding and feeding situation of farmland birds with different habitat requirements in relation to increased maize cultivation and (3) analyse the effects of an aggregated cultivation of maize on the habitat quality as compared to random cultivation.

This paper provides a concept for the development of a habitat suitability model that includes multiple scales on the crop and landscape levels. The model assesses the effects of different crop species and thereby enables a comparison of different crop types. The results can be transferred to different crop rotations, allowing an evaluation of crop alternatives. The habitat suitability model helps to support policy and landscape planning regarding the ex ante assessment of energy cropping systems.

Materials and methods

Study area

Our analysis focused on a real landscape in Northeast Germany located in Brandenburg in the Uckermark district (see Fig. 1). With a size of 290 km^2, the study area included the entire catchment area of the small stream Quillow. The climatic conditions of Germany were characterised by a west–east gradient from the Atlantic to continental climate. In the Quillow catchment area, the average annual temperature was 9 °C and rainfall was approximately 520 mm (measured from 2000 to 2008 at the Dedelow Research Station of the Centre of Agricultural Landscape Research). The geomorphology and structure of the study area contained deposits of the last Ice Age (Weichselian Glacial) and post-glacial processes. Compared with the average Brandenburg state soil conditions, the study area presented relatively fertile soil types which

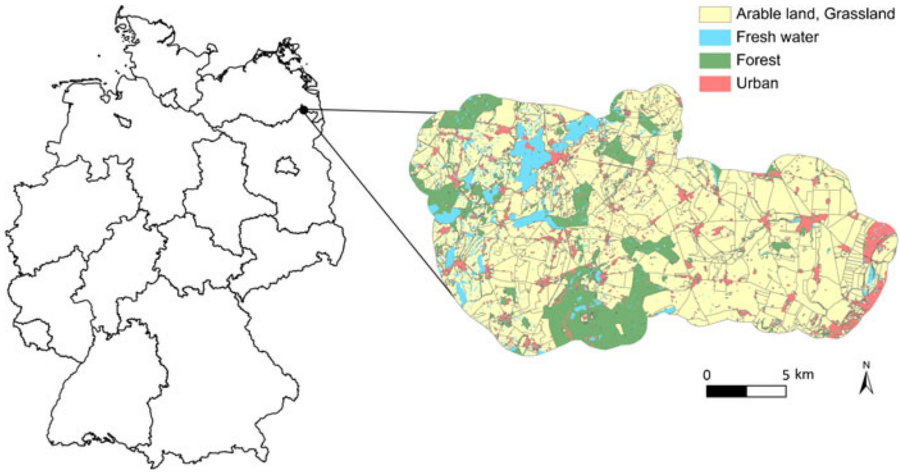

Fig. 1 Location of the Quillow catchment area

included sand, loamy sand, sandy loam, loam and clay. As a whole, the Quillow catchment area exhibited heterogeneity of soil types, and the entire study area was predominantly used as agricultural land. The proportion of cultivated crops in 2003 over the total area is shown in Table 1. Four biogas plants are located in the Quillow catchment. Spatial data on soil types, soil value numbers, land use, biotope structures as well as agricultural holding data are available in digital form. Biotope maps are based on aerial imagery conducted in 1995, at the scale of 1:10,000 and backed up by terrestrial mapping of linear structures conducted between 2002 and 2005. Soil data were compiled from the German soil inventory ("Reichsbodenschätzung") at the scale of 1:10,000 and the medium-scale agricultural site mapping ("Mittelmaßstäbige Landwirtschaftliche Standortkartierung-MMK") at the scale of 1:100,000 (Schmidt and Diemann 1981). We used the "Reichsbodenschätzung" to get information about the soil texture and the MMK to get information about the soil types.

Species selection

We selected five farmland bird species that were typical and widespread in agricultural landscapes known to occur frequently in Brandenburg state (Ryslavy and Mädlow 2008) and were suitable indicators for the state of agricultural landscapes according to Achtziger et al. (2004). Focusing on crop species effects, we selected bird species with their main habitat on agricultural land, with each bird species covering a range of different habitat

Table 1 Cultivation area and proportion of crops in 2003

Crop	Cultivation area	
	Area [ha]	Total area [%]
Winter wheat	5,728	31.3
Oilseed rape	3,757	20.5
Silage maize	1,512	8.3
Winter barley	1,358	7.4
Grassland	1,314	7.2
Triticale	1,246	6.8
Set aside	755	4.1
Sugar beets	616	3.4
Pasture and hay meadow	393	2.1
Oat	360	2.0
Winter rye	230	1.3
Summer barley	217	1.2
Forage grass	201	1.1
Grass-clover	174	1.0
Alfalfa	140	0.8
Waste land	93	0.5
Alfalfa/grass-clover undersowing	92	0.5
Field pea	41	0.2
Grain maize	37	0.2
Hemp	21	0.1
Sunflowers	14	0.1
Potatoes	4	0.0
Fodder beets	3	0.0
Sum	18,307	100

demands: skylark (*Alauda arvensis*), corn bunting (*Miliaria calandra*), lapwing (*Vanellus vanellus*), whinchat (*Saxicola rubetra*) and red-backed shrike (*Lanius collurio*). Skylark, corn bunting, lapwing and whinchat use arable fields as breeding and feeding habitats. The red-backed shrike prefers breeding in habitat structures adjacent to crop fields such as hedges and bushes, while the fields serve only as a feeding habitat.

Combining species requirements and crop structure

There is extensive information on habitat requirements and population dynamics for the selected farmland bird species. Thus, species behaviour and habitat preference were parameterised using a comprehensive literature review (Fuchs and Matthews 2008) focused on Northeast Germany. The bird-related data used in this study are listed in Table 2. The crop structure (height and coverage) input data were obtained from survey data from a biogas-related research project (Vetter et al. 2010). We used data from the experimental station in the Güterfelde location because of the similarity in natural frame conditions (climate and soil) to the study area in this research. Representative crops, being the main crop in the crop rotation, were selected from years with an average climate with typical sowing date. Missing data on vegetation structure from crops were completed using expert knowledge.

Data model

The data model consists of three modules: species habitat module, crop module and spatial module (see Fig. 2). According to Anderson and Fergusson (2006), the structure of the model is based on three important aspects used to assess the impact of biomass crop cultivation on biodiversity: (1) the crop species, vegetation structure and crop management; (2) the biodiversity value of the biomass crop compared with the alternative land use type and (3) the landscape-scale effects, such as the spatial distribution of the biomass crops.

Potential habitat suitability of the crops

Habitat use of farmland birds on arable land was described as determined by the vegetation structure and dynamics of the cultivated crops, as well as disturbances caused by agricultural management according to Anderson and Fergusson (2006). The structure of the crop stands varies between crop species, depending on the time of sowing, harvest and the length of the cultivation period. The farmland bird species have different habitat requirements for vegetation coverage and height, and differing timing and lengths of their breeding periods (see Table 2).

The accessibility of arable habitats and their suitability as shelter were expressed using vegetation structure data for the different types of crops. We matched the bird requirements for crop coverage and height during breeding and feeding with the vegetation structure provided by the crops. Figure 3 illustrates the overlap between vegetation structure and bird requirements using crop coverage of winter wheat and the requirements of skylark and lapwing as an example. Additional inputs to the calculation included the cultivation period of the crops, the breeding period, the period of bird activity on the fields and the brood duration (time between egg deposition and the fledging of the chicks). To create a consistent timeline of the

Table 2 Breeding period and habitat preferences for vegetation structure of the selected farmland birds (based on a literature review of Fuchs and Matthews (2008))

Bird species	Breeding period	Preferences for the crop coverage [%]		Preferences for the crop height [cm]	
		Breeding habitat	Feeding habitat	Breeding habitat	Feeding habitat
Skylark (*Alauda arvensis*)	Apr II–Aug I	35–80	55–80	20–50	20–50
Corn bunting (*Miliaria calandra*)	May III–Jul III	70–100	50–90	50–120	30–70
Lapwing (*Vanellus vanellus*)	Mar III–Aug I	0–50	ns	0–100	ns
Whinchat (*Saxicola rubetra*)	May II–Jul II	30–60	30–60	5–30	0–30
Red-backed shrike (*Lanius collurio*)	May II–Aug I	–	0–50	–	0–70

ns not specified, *I* first third of the month, *II* second third of the month, *III* last third of the month

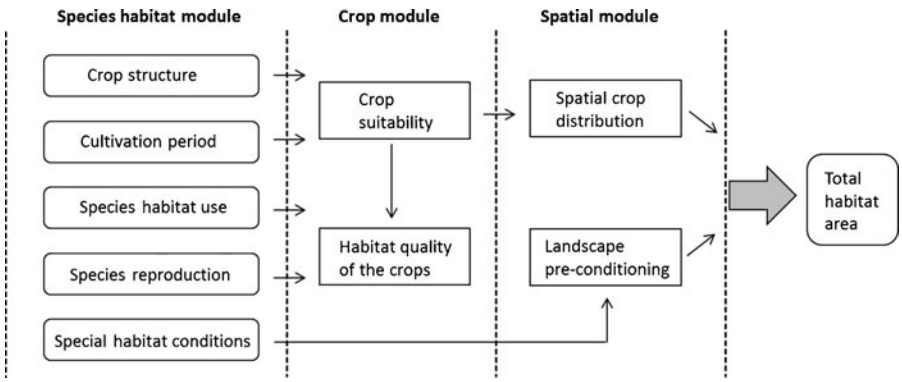

Fig. 2 Structure of the data model

data, the year was divided into 10-day periods. The calculation of potential breeding or feeding habitat suitability was implemented based on if-then rules (outlined in Fig. 4). Breeding or feeding habitat suitability was calculated only for the overlapping of both breeding period or period of activity on the fields (see Table 2) and crop cultivation period. The 10-day periods were checked if vegetation density and height of the crops overlapped with the requirements of the birds on these parameters. Breeding habitat suitability was defined when there were at least two consecutive 10-day periods on which the abovementioned conditions applied. In addition, agricultural measures like harvesting or grass cutting should not be done within this period or within the following 10-day period; the following 10-day period also had to lie within the breeding period of the species. For the skylark, which can have a second or third brood, we calculated the potential breeding option for each brood separately. To identify the crop as being a suitable feeding habitat for the birds, just one 10-day period with the corresponding conditions was sufficient. But the entire period was checked to determine the number of suitable feeding 10-day periods.

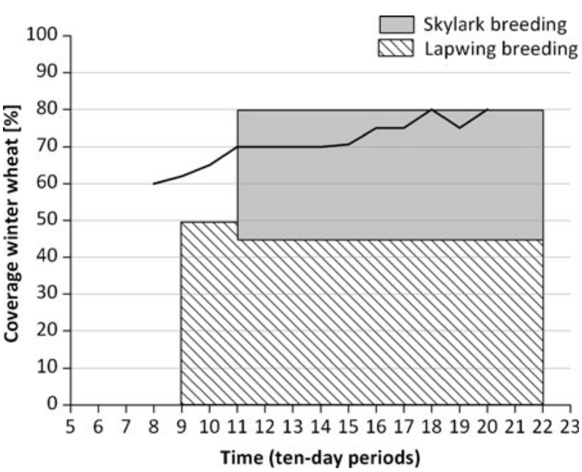

Fig. 3 Overlap of the crop coverage of winter wheat and the requirements of skylark and lapwing on the vegetation coverage for breeding

Number of suitable feeding periods of the crops

To assess the crop feeding suitability, we recorded the time period that the crop provided suitable feeding conditions for each bird species. The number of suitable periods was calculated and totalled for all investigated farmland birds.

Landscape pre-conditions

Often, farm land bird species prefer specific habitat conditions like particular soil conditions or minimum distances from forests, and depend on specific habitat structures neighbouring the agricultural fields. For example, the lapwing prefers breeding and feeding on moist or wet soils (Kooiker and Buckow 1997; Milsom et al. 2002; Eglington et al. 2008). The whinchat occurrence is dependent on hedges, shrubs or similar structures because they use them to perch and mark their territory (Bastian and Bastian 1996). The red-backed shrike breeds in habitat structures adjacent to crop fields and therefore requires hedges and bushes close to the feeding habitats (Latus et al. 2004). (For all important landscape features driving the spatial occurrence of the

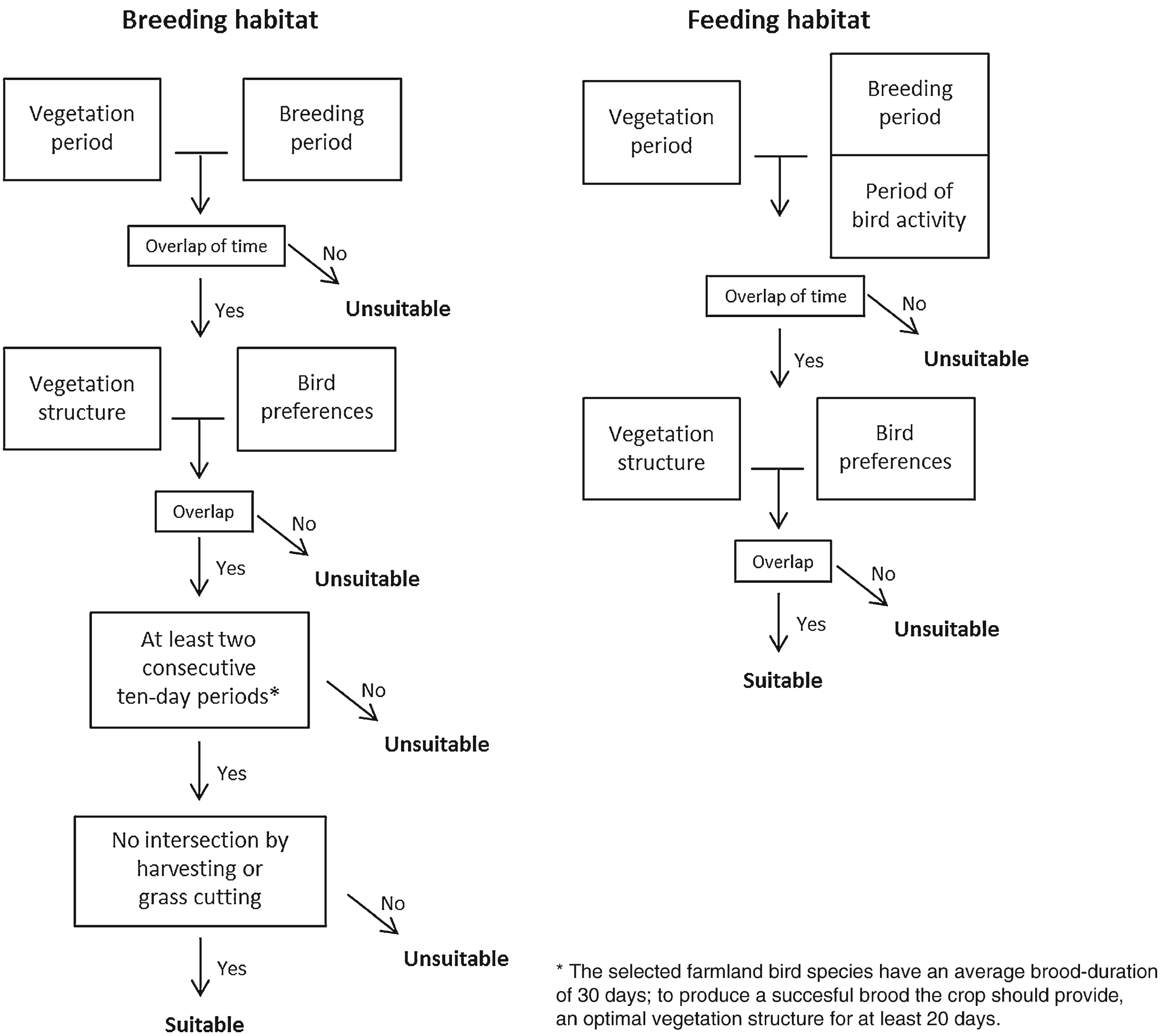

Fig. 4 If-then rules used to calculate the potential breeding and feeding habitat suitability of the crops

bird species in our analysis, see Table 3). The examples show that bird occurrence is not evenly distributed but pre-structured by landscape parameters. Consequently, we excluded particular areas which did not present the specific habitat conditions. Areas with the required habitat conditions or located in the surrounding of special landscape elements, depending on the activity range of the species, were included. For instance, solely agricultural areas in a radius of 250 m (activity range of the red-backed shrike) from structures like hedges and bushes were defined as being a potential feeding habitat for the red-backed shrike. By integrating the landscape pre-conditions into the modelling, a differentiated determination of the potential habitat areas could be implemented.

Taking into account these interrelations, we integrated a sub-module for landscape pre-conditions in our model. Using a geographical information system (GIS), we analysed the spatial information on soil and habitat types in the study area. The habitat requirements of the particular bird species were transferred to soil maps and biotope maps to qualify the spatial distribution of potential habitats within the landscape.

Land use scenarios

Four future crop production scenarios were defined to assess the potential effects of increased energy maize cropping on the landscape scale. As a baseline

Table 3 Results of a literature review on habitat preferences for the selected bird species. The parameters used in the calculation are listed with their associated references

Bird species	Habitat use fields	Habitat preferences	References
Skylark	Breeding and feeding	Open areas	Pätzold (1994), Bezzel (1993), and others
		Minimum distance from forests (for breeding): 100 m	Pätzold (1994) and Bezzel (1993)
		Sparse and low vegetation→sandy and dry soil types as optimum habitat	Toepfer and Stubbe (2001), Chamberlain et al. (1999), and others
Corn bunting	Breeding and feeding	Avoids large landscape elements like forests	Meyer et al. (2007)
		Minimum distance from forests (for breeding): 60 m	Fuchs and Matthews (2008)
		Moist and heavy (clay and loam) soil types	Bezzel (1993) and others
Lapwing	Breeding and feeding	Moist or wet soil types (gleys, clay soils or luvisols) for breeding and feeding	Kooiker and Buckow (1997) and others
Whinchat	Breeding and feeding	Activity range of 400 m	Fuchs and Matthews (2008)
		Hedges, shrubs or similar structures (for catching insects or marking territory)	Fuchs and Matthews (2008), Bastian and Bastian (1996), and others
Red-backed shrike	Feeding	Breeding location: marginal structures like hedges and shrubs	Latus et al. (2004), Bauer and Berthold (1996), and Flade et al. (2003)
		Activity range of 250 m	Fuchs and Matthews (2008)

scenario, the real land use situation from 2003 was selected, which should contain no energy cropping due to the crucial amendment of the EEG (Renewable Energy Act) in 2004. Anderson and Fergusson (2006) found that the spatial distribution of the biomass crops affected the biodiversity value of a landscape. For future scenarios, we distinguished between the increase of energy maize cultivation (scenarios 1 and 2) and a varying spatial configuration of the energy maize (scenarios A and B):

- Scenario 1: additional 15 % of energy maize area
  - (A) randomly distributed
  - (B) aggregated around the biogas plants
- Scenario 2: additional 30 % of energy maize area
  - (A) randomly distributed
  - (B) aggregated around the biogas plants

The area of 15 and 30 % energy maize corresponds with the calculated range of suitable cultivation area for energy plants in Germany determined for 2030 by considering criteria of sustainable development (Fritsche et al. 2004). Table 4 shows how many hectares of the total cash crop cultivation area in 2003 had to give way to energy maize cultivation. The replacement rules were based on economic aspects and contractual restrictions for the cropping. In the study area, winter barley was mostly cultivated before oilseed rape. Due to this dependence, we decided to reduce the two crops to the same extent. Moreover, we defined all fodder crops (silage maize, forage grass, grass–clover, alfalfa, field pea, fodder beet, pasture, hay meadow and grassland) as unchanged because of the demands for animal husbandry at local farms. Waste land was also defined as unchanged because it offered no real alternative for energy maize cultivation due to low soil fertility. Furthermore, we determined fixed proportions of the cash crops sugar beets, potatoes and oats due to regular long-term contracts.

Because of transportation costs, energy maize is often concentrated around biogas plants (Anderson and Fergusson 2006). The aggregation of energy maize was determined within a radius of 3 km surrounding four potential or already existing biogas plants in the study area. A radius of 3 km corresponds to the average extent of agricultural holdings in the study area.

The spatial distribution of the crops was performed using an algorithm programmed with a GIS based on defined rules. The crops were randomly distributed in the fields using an error margin of 1 % for energy maize, oilseed rape, winter cereals and silage maize and 5 % for perennial and annual crops. Due to a requirement for specific soil conditions, the spatial distribution of sugar beets, potatoes, oats, waste land, grassland, pasture and hay meadow remained unchanged with respect to 2003 within every scenario. Energy maize was not assigned to

Table 4 Cultivation area of the cash crops: baseline, scenario 1, and scenario 2

Crop	Cultivation area (ha)		
	Baseline (2003)	Scenario 1 (15 %)	Scenario 2 (30 %)
Winter wheat	5,728	5,728	4,588
Oilseed rape	3,757	3,757	3,357
Winter barley	1,358	1,358	958
Triticale	1,246	125	0
Set-aside	755	0	0
Sugar beets	616	616	616
Oat	360	360	360
Winter rye	230	230	130
Summer barley	217	0	0
Waste land	93	93	93
Grain maize	37	0	0
Hemp	21	0	0
Sunflowers	14	0	0
Potatoes	4	4	4
Sum	14,437	12,271	10,106
Energy maize	0	2,166	4,331

fields with poor soil quality (a soil value number under 23). The spatial allocation of the crops was repeated three times for each scenario in order to calculate an average.

Calculating the total habitat area for each bird species

Based on the assessment of breeding and feeding suitability of the individual crops for the bird species, the effects of changing cropping structure were calculated. The potential habitat suitability of the particular crops was allocated to the spatial positions in the respective scenarios. We defined the crop suitability area for every bird species in relation to the breeding and feeding habitat. By intersecting the crop suitability layer with the landscape pre-conditions layer within a GIS, we defined the final potential habitat area of the bird species for every scenario as the overlapping area of both layers. The intersecting method was used with the baseline scenario and the three repetitions of the crop production scenarios. Next, we determined the size of the potential habitat area of every scenario and calculated an average of the three repetitions per scenario. Finally, these scenario averages were compared to the area size of the baseline scenario.

Results

Potential habitat suitability of the crops

Potential breeding habitat

The habitat suitability of the different crops varied between the bird species (Table 5). Winter cereals provided a suitable vegetation structure for skylark and corn bunting, while lapwing and whinchat avoided winter cereals for breeding. We identified maize as a potential breeding habitat only for lapwing and oilseed rape only for corn bunting. Beets, including sugar beet and fodder beet, were suitable breeding habitats for skylark, lapwing and whinchat but were unsuitable for corn bunting. Perennial forage crops such as alfalfa, grass–clover and forage grass provided suitable habitats for skylark breeding but not for other farmland bird species. Summer wheat, oat and summer barley served as a suitable breeding habitat for the lapwing, but these crops did not offer a suitable habitat for the other farmland bird species. We calculated a small number of crops with suitable vegetation structure for the whinchat brood; these crops include, in addition to beets, pasture, hay meadow, grassland and potatoes. Beets, potatoes and grassland were a potential habitat for the skylark second brood. All other crops were suitable for only one potential brood of skylarks a year.

Potential feeding habitat

The suitability scores of the crops for feeding (Table 6) differ from the results for breeding. Within the breeding period, winter wheat was only suitable as a feeding habitat for the skylark. Outside this period, corn bunting and red-backed shrike also used winter wheat for feeding. According to the calculation outputs, maize was only a potential feeding habitat for the red-backed shrike. For the other farmland bird species, maize was unsuitable for foraging. Oilseed rape was an unsuitable feeding habitat within the breeding period for all of the investigated bird species. However, looking outside the breeding period, oilseed rape was suitable for skylark, corn bunting and red-backed shrike. Beets, including sugar beet and fodder beet, forage crops such as alfalfa, grass-clover and forage grass, as well as pasture, hay meadow and grassland were potential feeding habitats for all farmland bird species. Summer wheat was suitable for corn bunting, whinchat and red-backed shrike.

Table 5 Breeding habitat suitability of different crops and main causes for potential unsuitability (and, in the case of the skylark, unsuitability for a second brood). Two types of causes for unsuitability are distinguished: structure and development of the crop vegetation, and disturbances due to agricultural management. Unsuitable vegetation structure and the growth rate of the crops can refer to crop density and/or crop height. The crop can exceed the required density or height too quickly (⇑, ↑) or achieve the required density or height too slowly (⇓, ↓). The causes for potential unsuitability can occur in combination and in chronological order within one cultivation period of the crop

Crop	Potential breeding habitat suitability																		
	Skylark							Corn bunting				Lapwing				Whinchat			
	Suitability	Reason (1. brood)			Reason (2. brood)			Suitability	Reason			Suitability	Reason			Suitability	Reason		
		Veg.str			Veg.str				Veg.str				Veg.str				Veg.str		
		Density	Height	Dist.	Density	Height	Dist.		Density	Height	Dist.		Density	Height	Dist.		Density	Height	Dist.
Winter wheat	1					↑		1				0	⇑			0	⇑	↑	
Winter rye	0		↑					1				0	⇑			0	⇑	↑	
Winter barley	1					↑		1				0	⇑			0	⇑	↑	
Triticale	1					↑		1				0	⇑			0	⇑	↑	
Oilseed rape	0	⇑	↑					1				0	⇑			0	⇑	↑	
Maize (grain/energy/silage)	0		↑					0	⇓			1				0	⇓	↑	
Summer barley	0	⇓	↑					0	⇓			1				0		↑	
Oat	0	⇓	↑					0	⇓			1				0		↑	
Sunflowers	0							1				1				0		↑	
Sugar beets	2							0		↓		1				1			
Fodder beets	2							0		↓		1				1			
Field pea	0		↑↓					1				1				0	⇑	↑	
Potatoes	2							1				1				1			
Grassland	2							0			!	1				1			
Pasture	1					↑↓	!	0			!	1				1			
Hay meadow	1					↑↓		0			!	1				1			
Forage grass	1				⇑	↑↓	!	0		↓	!	0	⇑			0	⇑		
Grass–clover	1				⇑	↑↓	!	0			!	0	⇑			0	⇑	↑	
Alfalfa	1				⇑	↑↓	!	0			!	0	⇑			0	⇑	↑	
Alfalfa/grass–clover undersowing	1				⇑	↑↓	!	0			!	0	⇑			0	⇑	↑	
Set aside	1					↑		1				1				0		↑	
Waste land	1					↑		1				1				0		↑	
Hemp	1					↑		1				1				0		↑	

Veg.str. vegetation structure; *Dist.* disturbance; *0* breeding unsuitable; *1* breeding suitable; *2* second brood suitable (only for the skylark); ⇑ growth rate too high, vegetation structure too dense; ⇓ growth rate too low, vegetation structure too sparse; ↑ growth rate too high, vegetation structure too high; ↓ growth rate too low, vegetation structure too low; *!* disturbance by agricultural management (harvesting or grass cutting)

Table 6 Feeding habitat suitability of different crops, number of potential 10-day periods for suitability and main causes for potential unsuitability. Two types of causes for unsuitability are distinguished: Structure and development of the crop vegetation, and disturbances due to agricultural management. Unsuitable vegetation structure and the growth rate of the crops can refer to crop density and/or crop height. The crop can exceed the required density or height too quickly (⇑, ↑)or achieve the required density or height too slowly (⇓, ↓). The causes for potential unsuitability can occur in combination and in chronological order within one cultivation period of the crop

Crop	Potential feeding habitat suitability															
	Skylark								Corn bunting							
	BP*				AP**				BP				AP			
	Suitability	NPP***	Reason Veg.str.		Suitability	NPP***	Reason Veg.str.		Suitability	NPP***	Reason Veg.str.		Suitability	NPP***	Reason Veg.str.	
			Density	Height			Density	Height			Density	Height			Density	Height
Winter wheat	1	3			1	4			0	–		↑	1	3		
Winter rye	1	1			1	2			0	–		↑	1	1		
Winter barley	1	2			1	3			0	–		↑	1	3		
Triticale	1	2			1	3			0	–		↑	1	3		
Oilseed rape	0	–	⇑	↑	1	4			0	–		↑	1	1		
Maize (grain/ energy/silage)	0	–	⇓	↑	0	–	⇓	↑	0	–		↑	0	–		↑
Summer barley	0	–	⇓	↑	0	–	⇓	↑	1	3			1	3		
Oat	0	–	⇓	↑	0	–	⇓	↑	1	3			1	3		
Sunflowers	0	–	⇓	↑	0	–	⇓	↑	1	2			1	2		
Sugar beets	1	4			1	4			1	4			1	13		
Fodder beets	1	4			1	4			1	4			1	9		
Field pea	0	–		↑	0	–		↑	1	1			1	2		
Potatoes	1	3			1	5			1	7			1	11		
Grassland	1	6			1	11			1	5			1	14		
Pasture	1	6			1	12			1	6			1	15		
Hay meadow	1	5			1	13			1	6			1	15		
Forage grass	1	4			1	9			1	3			1	13		
Grass-clover	1	3			1	7			1	3			1	9		
Alfalfa	1	3			1	7			1	3			1	9		
Alfalfa/grass–clover undersowing	1	3			1	7			1	3			1	9		
Set aside	0	–	⇓	↑	0	–	⇓	↑	1	4			1	8		
Waste land	1	1			1	1			1	4			1	8		
Hemp	0	–	⇓	↑	0	–	⇓	↑	0	–		↑	1	1		

Table 6 (continued)

	Whinchat								Red-backed shrike					
	BP				AP				BP				AP	
	Suitability	NPP***	Reason Veg.str. Density	Height	Suitability	NPP***	Reason Veg.str. Density	Height	Suitability	NPP***	Reason Veg.str. Density	Height	Suitability	NPP***
Winter wheat	0	–	⇑	↑	0	–	⇑	↑	0	–	⇑	↑	1	3
Winter rye	0	–	⇑	↑	0	–	⇑	↑	0	–	⇑	↑	1	4
Winter barley	0	–	⇑	↑	0	–	⇑	↑	0	–	⇑	↑	1	3
Triticale	0	–	⇑	↑	0	–	⇑	↑	0	–	⇑	↑	1	3
Oilseed rape	0	–	⇑	↑	0	–	⇑	↑	0	–	⇑	↑	1	5
Maize (grain/ energy/silage)	0	–	⇓		0	–	⇓		1	3			1	3
Summer barley	1	1			1	1			1	2			1	3
Oat	1	1			1	1			1	2			1	3
Sunflowers	1	2			1	2			1	2			1	3
Sugar beets	1	3			1	3			1	4			1	5
Fodder beets	1	3			1	3			1	4			1	5
Field pea	1	1			1	2			1	1			1	2
Potatoes	1	3			1	3			1	2			1	4
Grassland	1	4			1	4			1	3			1	7
Pasture	1	5			1	5			1	4			1	7
Hay meadow	1	2			1	2			1	2			1	5
Forage grass	1	2			1	2			1	2			1	6
Grass-clover	1	2			1	2			1	2			1	6
Alfalfa	1	2			1	2			1	2			1	6
Alfalfa/grass–clover undersowing	1	2			1	2			1	2			1	6
Set aside	0	–		↑	1	2			1	2			1	11
Waste land	1	1			1	3			1	2			1	11
Hemp	0	–		↑	1	1			1	1			1	3

Veg.str. vegetation structure; **BP* Breeding period; ***AP* Period of bird activity on the fields; ****NPP* Number of potential ten-day periods; *0* Foraging unsuitable; *1* Foraging suitable; ⇑ growth rate too high, vegetation structure too dense; ⇓ growth rate too low, vegetation structure too sparse; ↑ growth rate too high, vegetation structure too high; ↓ growth rate too low, vegetation structure too low

Number of suitable feeding periods of the crops

The number of suitable feeding periods of the crops summed for all investigated farmland birds is presented in Figs. 5 and 6. We found beets, perennial crops, grassland, pasture and hay meadow to be the best feeding and accessible habitats for all investigated bird species. Maize showed a low feeding habitat quality, with only three 10-day periods, and was only suitable for the red-backed shrike. Winter cereals were unsuitable feeding habitats for three of the four bird species. Within the breeding period, winter cereals were only suitable for the skylark. Oilseed rape did not meet the feeding habitat requirements in the breeding period for any investigated species. However, oilseed rape has a moderate habitat quality used for feeding outside the breeding period for three of the four bird species. Summer cereals also served as moderate feeding habitats.

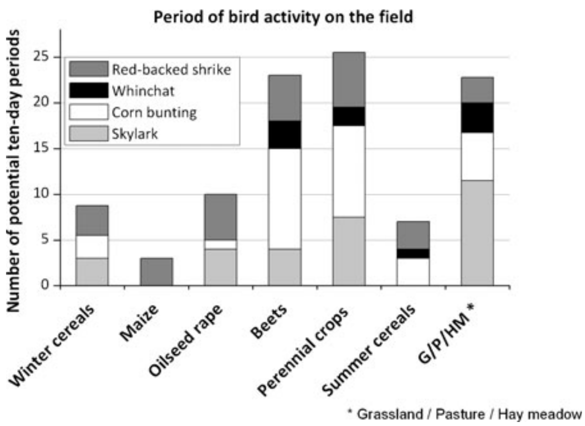

Fig. 6 Number of suitable feeding periods of different crops during the skylark, corn bunting, whinchat and red-backed shrike bird activity periods

Effects of increasing maize cultivation

Potential breeding habitat

The scenario calculations revealed an increase and a decrease in the size of the potential breeding habitat, depending on the bird species (Fig. 7 and Table 7). The area of farmland suitable for skylark breeding and corn bunting declined due to increased energy maize cultivation. The potential breeding habitat area was reduced between 14 % (skylark 1A) and 20 % (corn bunting 1B) in scenario 1 and between 31 % (skylark 2B) and 37 % (corn bunting 2A) in scenario 2 compared to 2003. Comparing the two species, the corn bunting showed a stronger trend. However, the lapwing potential breeding habitat was slightly increased by 9 % (1A) and 7 % (1B) in scenario 1 and greatly increased by 41 % (2A) and 34 % (2B) in scenario 2 relative to 2003. The effects observed in scenario 1 were reproduced in scenario 2. The breeding area of the whinchat was not affected by any of the analysed land use changes.

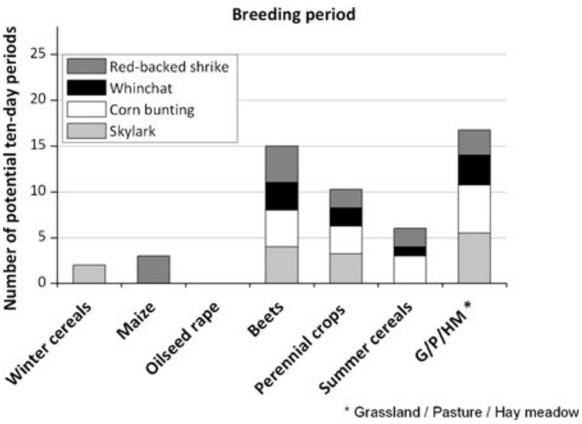

Fig. 5 Number of suitable feeding periods of different crops during the skylark, corn bunting, whinchat and red-backed shrike breeding periods

Potential feeding habitat

The results regarding the potential feeding habitat areas are seen in Figs. 8 and 9 (percent deviation from 2003) and Table 7 (absolute terms). Due to increased maize cultivation and the related decrease of other crops, the feeding habitat area decreased for the skylark, corn bunting and whinchat within and outside of the

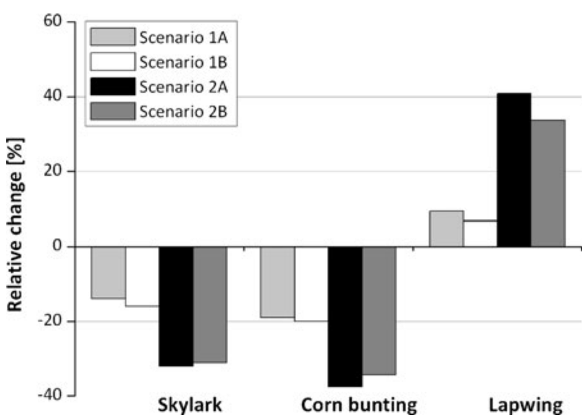

Fig. 7 Suitable breeding areas compared to 2003. Scenario 1 increased maize by 15 %, scenario 2 increased maize by 30 %. **A** Random distribution, **B** aggregated distribution around biogas plants

Table 7 Potential habitat area in hectares

	Potential habitat area [ha]				
	Baseline (2003)	Scenario 1A	Scenario 1B	Scenario 2A	Scenario 2B
Skylark					
Potential breeding habitat	5,407	4,657	4,543	3,675	3,723
Potential feeding habitat (period of bird activity on the fields)	7,373	6,589	6,637	5,526	5,509
Potential feeding habitat (breeding period)	5,280	4,657	4,543	3,675	3,723
Corn bunting					
Potential breeding habitat	1,505	1,219	1,204	941	988
Potential feeding habitat (period of bird activity on the fields)	1,775	1,472	1,456	1,191	1,241
Potential feeding habitat (breeding period)	329	257	259	255	259
Lapwing					
Potential breeding habitat	252	276	269	355	337
Whinchat					
Potential feeding habitat	656	656	656	656	656
Potential feeding habitat (period of bird activity on the fields)	763	698	684	712	692
Potential feeding habitat (breeding period)	710	698	684	712	692
Red-backed shrike					
Potential feeding habitat (period of bird activity on the fields)	5,645	5,654	5,654	5,654	5,654
Potential feeding habitat (breeding period)	1,576	2,052	1,834	2,712	2,620

breeding period; the exception is the whinchat in scenario 2A with a very small increase of 0.3 %. However, the red-backed shrike results differed from the other farmland bird species. The feeding area of the red-backed shrike increased within the breeding period by 16.4 % (scenario B) and 30.2 % (scenario A) in scenario 1, and 66.3 % (scenario B) and 72.1 % (scenario A) in scenario 2. Within the activity period of the red-backed shrike on the fields, we found no change relative to 2003 because all crops were defined as potential feeding habitats for at least one 10-day period within this timeframe. With the exception of the skylark in scenario 2 within the breeding period, the largest potential feeding habitat decrease was calculated for the corn bunting, with a maximum decline of 33 %

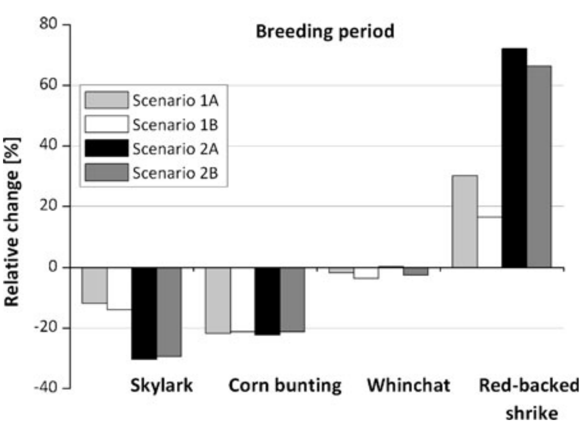

Fig. 8 Suitable areas for foraging during the breeding period compared to the base year 2003. Scenario 1 increased maize by 15 %, scenario 2 increased maize by 30 %. **A** Random distribution, **B** aggregated distribution around biogas plants

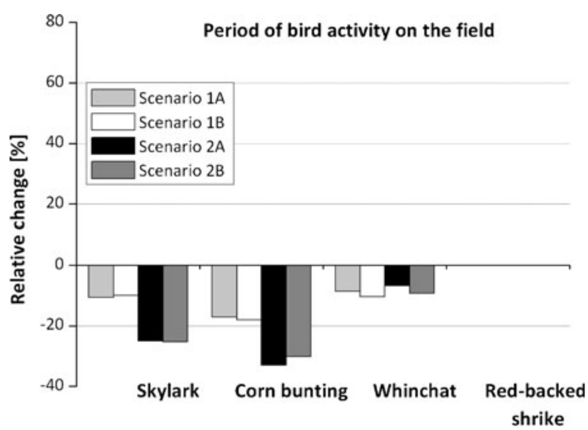

Fig. 9 Suitable areas for foraging during the period of bird activity on the field compared to the base year 2003. Scenario 1 increased maize by 15 %, scenario 2 increased maize by 30 %. **A** Random distribution, **B** aggregated distribution around biogas plants

in scenario 2A over the whole period of activity on the fields. The accessible feeding area of the whinchat was only slightly (no more than 10 %) reduced compared to 2003. We could not identify an amplification of the trend from scenarios 1 to 2 in all cases. The feeding area of the skylark and corn bunting showed a greater decrease in scenario 2 relative to 2003 for the period of bird activity on the fields. Stronger effects in scenario 2 were also obtained for the skylark and the red-backed shrike during the breeding period. However, increasing maize production did not affect whinchat and corn bunting during the breeding period for scenario 2.

Effect of distribution patterns

The potential effects of distribution patterns were determined by comparing scenario A (randomly distributed) with scenario B (aggregated around the biogas plants; see Figs. 7, 8, and 9; Table 7). The spatial aggregation of energy maize production showed a deterioration of habitat quality for lapwing, whinchat and red-backed shrike compared to the spatially random distribution of the maize fields (scenario A). This result indicated a smaller increase of the potential breeding habitat of the lapwing and the potential feeding habitat of the red-backed shrike, and a greater decrease of the potential feeding habitat for the whinchat in every scenario B.

Discussion and conclusion

Birds present numerous advantages as indicators for the condition of landscapes and habitats (Bird Life International 2012; Furness and Greenwood 1993). Environmental changes, which are difficult and expensive to measure directly, can be reflected in the development of bird populations (Bird Life International 2012). Birds are classified near the top of the food chain; thus, bird populations are sensitive to environmental factors affecting any stage of the food chain and represent the biodiversity as a whole (Furness and Greenwood 1993). Furthermore, there is a thorough knowledge of bird ecology and behaviour that can be utilised (Bird Life International 2012). Therefore, wild bird indicators have been adopted by many European countries and by the European Union to measure biodiversity and sustainable development. For instance, the Farmland Bird Indicator has been recognised and included by the EU as an indicator of structural and sustainable development calculated by population-weighted factors for each country and farmland bird species (Butler et al. 2010; Eurostat 2012; PECBMS 2009).

Because of their motility, birds can change their breeding or feeding ground relatively easily if the area is no longer suitable. Therefore, negative effects on the environment can be temporarily buffered as bird populations respond more slowly than smaller organisms ("time lag effect") (Bird Life International 2012). Due to the complex spatial interactions and adaptation strategies of farmland birds, it is difficult to measure directly the impact of land use changes on farmland birds. Habitat models allow for comparisons of different crops and crop rotations with the effects of previous crops and different cultivation practices in relation to the potential habitat suitability of birds. Thus, habitat models support the development of strategies for the landscape and regional scale as recommended by Dauber et al. (2010). Therefore, this study contributes to the selection of measures that reduce detrimental effects of agricultural practices on farmland bird species.

Investigations on habitat use by farmland birds show a correlation between crop structure (coverage and height) and the occurrence of birds. Wilson et al. (2005) describe the role of vegetation for successful nesting and foraging and emphasise the key influence of crop structure on farmland birds. The vegetation structure as a significant mechanism of habitat selection for birds is also observed by Bradbury et al. (2005). Toepfer and Stubbe (2001) and Chamberlain et al. (1999) confirm that vegetation coverage and height are important determinants of habitat preference for the skylark in their surveys of Germany and Britain. Other authors describe the effects of vegetation structure on predation risk and food availability. High and dense vegetation protects the birds against predators, but movement is limited, especially for the chicks (Butler and Gillings 2004; Whittingham and Evans 2004). Higher vegetation is associated with a greater abundance and diversity of food resources, but shorter swards improve the visual detection of food and predators (Atkinson et al. 2004; Whittingham and Evans 2004). These results demonstrate that the vegetation structure indirectly influences the habitat quality and the farmland bird population size. The farmland bird species present different requirements for breeding and feeding habitats, but the vegetation structure always plays a decisive role in habitat selection. However, it is not clear if habitat selection of the bird species depends more on crop coverage or crop height, or if both parameters have the same influence on habitat selection. These preferences can differ between species, and investigations are rare or non-existent. Therefore, possible preferences for crop coverage or crop height were not taken into consideration in our model calculation, and the two parameters were treated equally.

The data used in this study regarding the vegetation structure were primarily real survey data. However, data regarding bird requirements on the vegetation structure and breeding period were taken from an expert study based on literature and expert experiences (Fuchs and Matthews 2008). One way to improve the model outlined in this study is to use real survey data (Hoffmann et al. 2012). Moreover, the data relating to breeding period and crop structure requirements were specific to Northeast Germany. However, regional adaptations of the birds are difficult to integrate into the model, and investigations on adaption behaviour are rare. The skylark survey by Wilson et al. (1997) showed that in other parts of Europe, the birds have similar vegetation structure requirements. Wilson et al. (1997) observed regular occurrences of skylark nests in crops between 20 and 50 cm tall in Southern England. The same values were used in the present analysis for Northeast Germany.

The occurrence of bird species also depends on the landscape structure within the habitat. Specifically, neighbouring structures are avoided or preferred for breeding or feeding. For example, the occurrence of red-backed shrike is closely connected to the availability of nest sites such as hedges, shrubs and forest edges (Latus et al. 2004). Because of bird dependence on different landscape elements, it is important to take the landscape pre-conditions into consideration.

In our study, we calculated the potential habitat area for the farmland species. Estimations of the population size, the breeding success of the birds or predation pressure was not included in this study. Therefore, the results do not refer to a realised habitat, and consequently, it would be difficult to validate them. However, it is conceivable to combine these methodological results with an individual-based model such as ALMaSS, which consists of agent-based animal models with a comprehensive and dynamic landscape simulation and calculates the abundance and distribution of different animal species within a certain land use (Topping et al. 2003).

As our results illustrate, increased energy maize cultivation will change the composition of the farmland bird communities. Due to the increased maize cultivation, the habitat area for most of the selected bird species is decreasing. However, lapwing and red-backed shrike showed an increase of their potential breeding and feeding habitats. This result is in accordance with a study by Dauber et al. (2010) that found negative, neutral and positive impacts of biomass crops on biodiversity at the field scale, depending on the respective crop species, the land use replaced, the landscapes or biogeographical context and the group of organisms considered. Measures such as the adjustment of the crop rotation can contribute to reduced conflicts with the regional species inventory and particular endangered or sensitive species in the respective area. However, spatial and temporal variability of the crops and crop rotations is most beneficial for the birds (Benton et al. 2003).

In our calculations, the doubling of energy maize cultivation from scenarios 1 to 2 did not always result in a proportional decrease or increase of the potential habitat area. We could not identify an amplification of the trend for the feeding habitat of the whinchat and the corn bunting (breeding period) in scenario 2. This result may be due to the additional energy maize in scenario 2 replacing crops that have already been defined as being unsuitable feeding habitats, for example, winter cereals as a feeding habitat for the corn bunting during the breeding period. The results depend on the type of agricultural land use being replaced by the energy crops. Anderson et al. (2004) also emphasise the importance of the type of land use replaced by the energy crops. Moreover, Gevers et al. (2011) found that increasing the cultivation of energy maize had significantly fewer negative effects on skylark, partridge and hare, if other crops were displaced by maize instead of set aside.

The skylark has a long breeding period, starting in the middle of April and ending in the middle of August, with the potential for several broods each year (Table 2). Crops with tall and dense vegetation are avoided for breeding (Toepfer and Stubbe 2001; Chamberlain et al. 1999). Winter cereals, beets and perennial forage crops are preferred because they provide sparse and low vegetation structures during the skylark breeding period. At the beginning of the breeding period, oilseed rape is already too dense and high for breeding. Summer cereals provide an insufficient vegetation cover and grow to unsuitable stand heights, and there are only approximately 10 days when the vegetation coverage and height meet the requirements of the skylark. However, this narrow window may stimulate the skylark to breed in the crop, and the subsequent rapid height increase could lead to an abandonment of nests, causing an ecological trap described by Schlaepfer et al. (2002). Our results are not completely consistent with the findings of Toepfer and Stubbe (2001), who found breeding skylarks in winter cereals, but also in summer cereals and oilseed rape. Fuchs and Matthews (2008) confirmed perennial forage crops as being potential breeding habitats for the skylark. However, they also documented summer cereals as suitable habitats.

Compared to the skylark, the corn bunting has a shorter and later breeding period, from the end of May to the end of July. Its breeding habitat requirements differ from the skylark primarily in the need for a dense and high crop structure (Table 2). Crops such as winter cereals and oilseed rape meet these structure requirements within the breeding period of the corn bunting. However, late sown crops such as maize and summer cereals do not reach the required coverage fast enough. Perennial forage crops (alfalfa, grass–clover, forage grass) as well as pasture, hay meadow and grassland were unsuitable breeding habitats because the time of cutting coincides with the breeding period of the corn bunting. However, if cuttings were delayed, perennial crops could be suitable breeding habitats for the corn bunting (Fuchs and Stein-Bachinger 2008).

Our results reveal a positive effect of increased energy maize cultivation on the lapwing, with an increase of up to 41 % of the potential breeding habitat area within the landscape. Earlier studies by Dziewiaty and Bernardy (2007) and Kooiker and Buckow (1997) also described maize as a well-suited breeding habitat. However, Dziewiaty and Bernardy (2007) also considered maize as an ecological trap (Schlaepfer et al. 2002): Lapwings start their breeding in maize, which initially provides favourable conditions, but the fast growth of the crop and a lack of available food for chicks make it difficult for the lapwing to successfully complete its brood. However, if we consider the initial values of the base year, the potential breeding area of the lapwing only comprises a small part of the study area, which agrees with the Red List of Brandenburg state by Ryslavy and Mädlow (2008), who noted small lapwing breeding populations. In 2003, the potential breeding habitat was only 0.9 % of the total study area (2.52 km^2), and the maximum increase in breeding area observed in scenario 2B with 3.37 km^2 only comprises 1.2 % of the total study area. Thus, the relative numbers are high, but the absolute numbers are not. The lapwing prefers special habitat conditions that include moist or wet soils for breeding and feeding (Kooiker and Buckow 1997; Milsom et al. 2002; Eglington et al. 2008).

We found that the spatial aggregation of energy maize resulted in a negative effect on breeding and feeding habitats for lapwing, whinchat and red-backed shrike, while the other bird species showed no effect. One reason for this specific reaction may be that these three bird species need specific physical habitat structures that are not evenly distributed over the area within or adjacent to the crop fields. The lapwing breeds in habitats with wet features (Milsom et al. 2002; Eglington et al. 2008); therefore, only soil types such as gleys, clay soils or luvisols provide a habitat for this species. Whinchat and red-backed shrike depend on hedges, shrubs or similar structures for perching and marking their territory by singing (Bastian and Bastian 1996) and breeding (Latus et al. 2004), respectively. Thus, these species are more dependent on landscape pre-conditions, making it more difficult to switch to another area to avoid negative conditions or to take advantage of positive conditions. Skylark and corn bunting are less restricted to specific landscape pre-conditions and are therefore less affected by the aggregated distribution of specific crops. The spatial clustering of single crops will affect species limited in distribution and spread and will favour species with unspecific habitat demands. Wretenberg at al. (2006) previously documented that farmland bird species with specialised requirements are more sensitive to land use intensification than generalists. Concentrating a single crop cultivation (e.g., maize) around biogas plants might accelerate typical processes of biocoenosis simplification (Bellamy et al. 2009). Anderson et al. (2004) also confirmed the importance of the geographical distribution of the crops and their spatial arrangement within the landscape. However, to avoid the negative effects of crop clustering on less mobile species, fixed minimum distances between the maize fields could be implemented.

The observed effects of spatial clustering of energy maize were less than expected. This finding might be due to the fact that biogas plants within the study area were distributed evenly. This means that distances between the biogas plants were large enough so that there was no overlapping of the energy maize aggregation areas. Thus, the energy maize aggregations were covering a large part of the study area. If the biogas plants were clustered closer together, we may have observed a more pronounced effect. The methodology in this study could be used to make impact assessments of the location of biogas plants (clustered or equally distributed) within a regional planning context.

The expansion of renewable energies such as biomass production for biogas is promoted by current political bodies due to its contribution to CO2 reduction strategies (Cornelissen et al. 2012; Gustavsson et al. 2007). Every change in land use or management will affect environmental goods and will therefore potentially conflict with alternative land use strategies or demands (e.g., biodiversity strategies). Our results clearly indicate that the effects of land use change are less dependent on the type of land use but on the species inventory, landscape pre-conditions and the amount as well as the spatial configuration of land use changes. These results refer to the current discussion on thresholds for extensive land use elements to be integrated in agro-environmental policies of the EU (Zeijts et al. 2011). Our results stress the need for regionalised analysis with tools and data inputs like those used in this study.

Currently, energy cropping in Germany is in conflict with a biodiversity conservation scheme (BMU-Federal Ministry for the Environment, Nature Conservation and Nuclear 2007). Energy plant cultivation provides many opportunities to adjust the land use, including a reduced use of pesticides and well-considered selection of crop rotations, which offers the possibility of diversification based on new and old crops as well as mixed cultivations. However, these opportunities need to be seized by farmers. To provide farmers with alternatives, new cultivation systems must be investigated and assessed ex ante to make conclusions about the habitat suitability and how biodiversity-friendly crops and crop rotations are. Biodiversity assessment must become part of an obligatory, strategic landscape planning, and standards must be formulated to support sustainable biogas production and to prevent a heavy species loss (Dauber et al. 2010). Ex ante assessments only work with model-based evaluations. Therefore, this research provides a good basis for policy and landscape planning to improve the evaluation of energy cropping systems. Tools such as those presented in this study may contribute to identifying and defining regional standards to support a sustainable biogas production and to reduce ongoing species loss (PECBMS 2009). Furthermore, these tools can help to identify biodiversity-friendly energy cropping systems through the comparison of different cropping opportunities.

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