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Abstract

The conservation of biodiversity is one of the aims of the EU's organic farming subsidy programme. We applied an ecological-economic modelling procedure to analyse the impact of organically and conventionally managed meadows on endangered bird and butterfly species in Saxony, Germany. We also analysed the impact of agri-environment schemes (AES) in landscapes with conventional and organic farming. Applying a modelling procedure to assess the impact of organic farming is novel as previous research predominantly relies on field studies. We found that for the species considered the difference in the impact of conventional and organic farming is minor, and both types of farming are unable to conserve a large share of these species. This is because the species require different timings of land use for their reproduction and neither conventional nor organic farming provide this heterogeneity. We also found that in comparison with conventional farmers organic farmers face different opportunity costs when implementing AES measures and are offered different payments for such measures. This influences organic farmers' decisions to take part in AES, which in turn has an important impact on biodiversity conservation. In order to better conserve species it may be necessary to adapt the payment structure of AES with respect to organic farming.

Key words: organic farming, grassland, agri-environment schemes, biodiversity, model, DSS-Ecopay.

Highlights

- We analyse the impact of organic farming on biodiversity by ecol.-econ. modelling
- Organic farming by itself only has a limited ecological impact
- But organic farmers choose different conservation measures if participating in AES
- This is due to their different cost structures and it benefits different species
- These novel findings are essential for the payment design of future AES

1. Introduction

Agricultural intensification is one of the key drivers of biodiversity loss in Europe and other parts of the world (Billeter et al., 2008; Flohre et al., 2011; Kleijn et al., 2011). Especially grassland species such as birds and butterflies are threatened by intensive grassland management (Johst et al., 2015), and the negative trend for such species continues in recent years (Becker et al., 2014). Arguably the most prominent policy instrument to reduce the negative impact of agriculture on biodiversity are agri-environment schemes (AES), where farmers are paid to carry out biodiversity-enhancing farming measures that are beneficial to biodiversity but costly to farmers (Ekroos et al. 2014; Primdahl et al., 2010; Uthes & Matzdorf 2013).

Many authors (e.g. Batáry et al., 2012; Freemark & Kirk, 2001; Lüscher et al., 2016) also consider organic farming an important approach to halt the decline of biodiversity in agricultural landscapes. This view is mirrored in policy documents. For example, the EU justifies its support for organic farming with the argument that it helps to conserve biodiversity in agricultural landscapes (Council Regulation (EC) No. 834/2007). However, studies that investigated the impact of organic farming on biodiversity show mixed results.

While several empirical studies found a positive relationship between organic farming and biodiversity (Batáry et al., 2012; Freemark & Kirk, 2001; Marja et al., 2014; and see Hole et al., 2005 for a review), other studies found no difference between conventional and organic farming (Hiron et al., 2013; Piha et al., 2007; Purtauf, 2005) and in some cases conventional farming even supported a greater biodiversity than organic farming (Weibull et al., 2003). The reasons for these contradicting results are diverse. Fuller et al. (2005) found that some species benefit from organic farming, while others benefit from conventional farming. Moreover, they argued that for some species the impacts of organic and conventional farming become visible locally, while for other species the surrounding landscape at a larger spatial scale is also important. Similarly, Sutherland et al. (2012) found that due to neighbourhood effects species benefit more in larger organically managed regions rather than on single organic farms. Birkhofer et al. (2014) showed that grassy margins on organic fields benefit certain species in comparison to organic fields without grassy margins. Other authors (Freemark & Kirk, 2001; Hiron et al., 2013; Weibull et al., 2003) highlighted that heterogeneous landscapes are often more species-rich and organic farms are more likely to be located in heterogeneous landscapes (Rundlöf & Smith, 2006). Thus, some organic farms may owe their high levels of biodiversity to landscape heterogeneity and not to factors explicitly regulated under organic farming (Taylor & Morecroft, 2009). It has also been shown that increasing landscape heterogeneity may compensate for intensive farm management in terms of biodiversity protection (Tscharntke et al., 2005).

The purpose of this paper is to examine the impact of organic farming on selected endangered bird and butterfly species in the German Federal State of Saxony. We focus on meadows and how they are managed through different mowing regimes. Our research goes beyond existing work by applying an ecological-economic modelling approach, whereas the existing literature predominantly relies on field studies. By using a modelling approach we are able to exclude factors of real landscapes from our analysis that tend to distort the comparison between organic and conventional farming (e.g. landscape heterogeneity). Moreover, the selected modelling procedure enables us to explore two novel aspects. Firstly, the modelling procedure considers the impact of specific aspects of grassland management such as the timing of mowing and the impact of N-fertilizer on butterflies. These specific grassland management aspects partly differ between organic and conventional farming, and we can therefore apply the modelling procedure to assess the impact of these differences. Secondly, the modelling procedure simulates the decision of farmers to participate in an AES based on their costs in relation to the offered payment. Therefore, we are able to analyse how this decision differs between organic and conventional farmers.

For our analysis we apply an ecological-economic modelling procedure implemented in the software DSS-Ecopay (Mewes et al., 2014; Wätzold et al., 2016). The modelling procedure is able to analyse the impact of over 100 different mowing regimes on 15 endangered bird and 15 endangered butterfly species (Johst et al., 2015). We extended the modelling procedure by adding the option to distinguish between organic and conventional farming. For this, we take into account the differences in the grassland measures between the two farming types and consider both their impacts on biodiversity (Johst et al. 2015) and their costs to the farmers (Mewes et al. 2015).

First, we evaluate the direct impacts of organic and conventional meadow management on bird and butterfly species. Second, we consider that in Saxony organic farmers may receive two types of subsidies: for organic farming itself and for implementing conservation grassland measures in the context of AES; and that these subsidies may be combined. Third, we also consider the different payments offered in the AES regulations for organic and conventional farmers. All of these factors influence the decisions of the organic farmers to take part in AES and to choose certain measures offered compared to conventional farmers. Our modelling procedure is able to analyse this indirect (decision-induced) impact of organic farming on biodiversity.

2. Materials and Methods

2.1. Case study area and its two types of subsidies

Organic farming plays an important role in Saxony as part of rural development strategies. From 1999 to 2014, the area of organically managed land has increased by 187%. While most organically managed land consists of cropland, the share of organic grassland in the total organic area has increased from

32% in 2004 to 39% in 2014, representing an area of 143km² or 7.8% of the total grassland area of approximately 1,842km². Meadows make up 32% of the total grassland area in Saxony (SSUL, 2015a; SSUL, 2015b; Statistisches Bundesamt, 2014). Organic farming in Saxony is regulated according to the Council Regulation (EC) No. 834/2007, and Commission Regulations (EC) No. 889/2008 and No. 1235/2008. Regarding meadows, farmers receive a subsidy of 230€/ha if the meadows are managed organically, which includes limitations on fertilisation (Directive RL ÖBL/2015).

In general, the support of biodiversity-enhancing grassland measures is regulated in the "Agrarumwelt- und Klimamaßnahmenrichtlinie RL AUK/2015" (Agri-environment and Climate Measures Directive). Both conventional and organic farmers can take part in this AES, but organic farmers receive a reduced payment as they already receive financial support for organic farming (SSUL, 2015c).

2.2. Overview of the ecological-economic modelling procedure

We applied an ecological-economic modelling procedure to assess the impact of different mowing regimes on certain grassland species. An overview of the modelling procedure is given below. For detailed information on the model components see Johst et al. (2015) for the ecological model, Mewes et al. (2015) for the economic model, and Wätzold et al. (2016) for the complete ecological-economic modelling procedure. For the purpose of this paper, eight components of the modelling procedure are relevant (Figure 1).

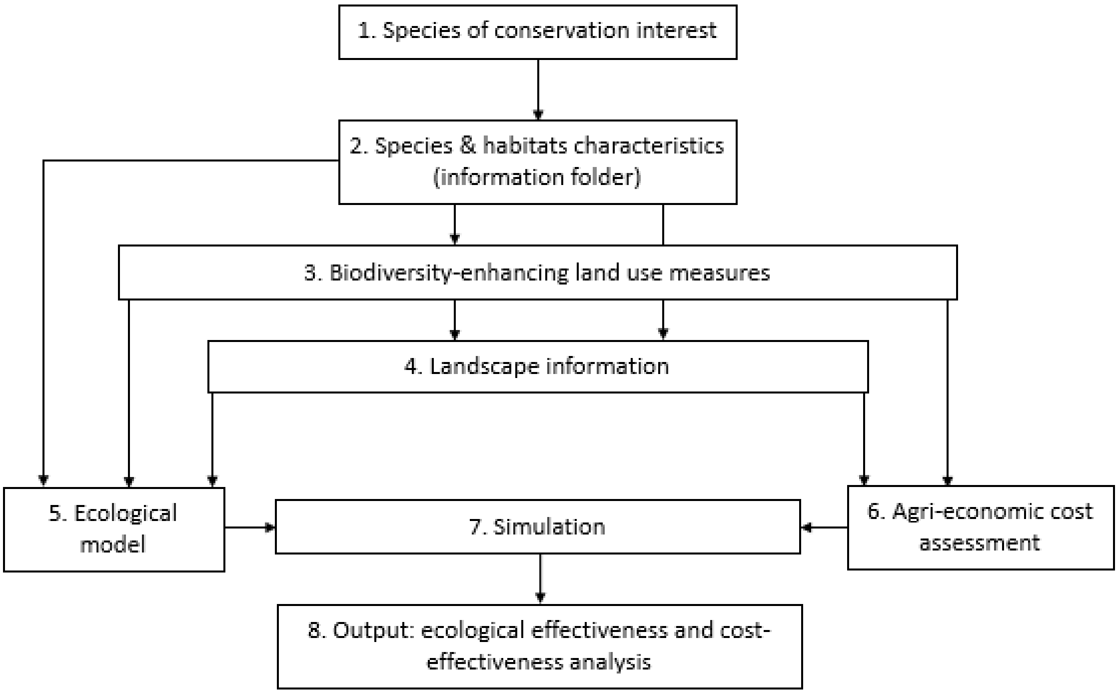


Figure 1: Structure of the modelling procedure; source: adapted from Wätzold et al., 2016

The basic information necessary for the modelling procedure is a list of (endangered) bird and butterfly species relevant to the conservation target (box 1 in Figure 1; Table A1 provides a complete list of the species). For each species, the software contains an information folder on species-specific characteristics that are relevant for determining the influence of mowing regimes on the species (box 2 in Figure 1). This includes information on the life cycle of the species on grassland and their habitat preferences, e.g. related to grass length.

Over 100 mowing regimes are available as potential conservation measures (box 3 in Figure 1; Table A2 provides a complete list of mowing regimes). A key difference between them is their timing during the season. The temporal scale used to analyse the timing of grassland measures is quarter months (QM): each month is divided into four equal parts and consequently each year is divided into 48 QM.

All relevant landscape information (box 4 in Figure 1) is provided for spatially differentiated grid cells with an area of 250m x 250m = 6.25 ha. For simplicity, each grid cell is assumed to act as an independent farmer. Each grid cell contains land cover information that could influence the species, e.g. grassland and structural elements such as waterbodies, as well as information relevant for the farmer’s choice of grassland measures and their impact, e.g. altitude and grassland productivity. Regarding productivity, each grid cell is categorized into one of four yield classes ranging from “low yield” to “very high yield”.

The ecological model (box 5 in Figure 1) estimates the impact of grassland measures on the species by considering that specific habitat characteristics are necessary for their optimal reproduction (e.g. a certain grass height for clutch protection). Based on the characteristics of the species (box 2 in Figure 1) and the landscape (box 4 in Figure 1), the model assesses the impact of a grassland measure *m* at time t_m on a species *j* for each grid cell *l* by calculating the local habitat quality $q_j^{l,m}(t_m)$. The local habitat quality is a relative measure and can adopt values between 0 and 1, where 0 means that reproduction of a species is impossible and 1 represents the ideal reproductive conditions. The local habitat quality is calculated as follows (Johst et al., 2015):

$$(1) \qquad q_j^{l,m}(t_m) = Q_j^{l,0}\left[\sum_{w=b}^{f} p_j^w \times S_j^{m,w}(t_m) \times Q_j^{l,m,w}(t_m)\right].$$

The first component $Q_j^{l,0}$ of the term contains all factors that influence species reproduction in a grid cell *l* independently of the egg deposition time *w*. This includes soil moisture, structural elements in the landscape, and grassland type. The second component is the sum in the square brackets and describes all factors whose impact depends on the egg deposition time *w*. Egg deposition of a species *j* occurs over a certain time period between QM *b* and *f* in any single QM *w* with probability p_j^w. The survival of the resulting cohort is influenced by the vegetation height ($Q_j^{l,m,w}(t_m)$) and mortality through mowing machines ($S_j^{m,w}(t_m)$). Thus, it depends on the QM *w* in which the cohort is generated in relation to the timing t_m of the measure.

We evaluated the ecological benefit of a grassland measure for a species with the effective habitat area generated. To calculate the effective habitat area A_j^{eff} (equation 2) of species *j* we multiplied the area of all grid cells A^l by their local habitat quality $q_j^{l,m}(t_m)$ and summed them up on condition that: (1) the grid cell lies within a radius r_j that allows a species to reach this grid cell and (2) the local habitat quality $q_j^{l,m}(t_m)$ is greater than a minimum habitat quality necessary for the species to reproduce at all (see Johst et al. (2015) for details). Based on discussions with experts and in line with Wätzold et al. (2016), the minimum habitat quality was set to $q_j^{min} = 0.3$ for birds and to $q_j^{min} = 0.1$ for butterflies.

$$(2) \quad A_j^{eff} = A^l \times \sum_{l(r_j;\, q_j^{l,m} > q_j^{min})} q_j^{l,m}(t_m).$$

The agri-economic cost assessment (box 6 in Figure 1) is used to determine whether a farmer would be willing to implement a grassland measure offered via an AES (Mewes et al., 2015). It is assumed that farmers are profit-maximising and will thus adopt a measure *m* if the sum of their opportunity cost c_m and transaction cost tc_m is smaller than or equal to the payment p_m they would receive for implementing the measure:

$$(3) \quad c_m + tc_m \leq p_m$$

The opportunity cost c_m is the potential profit that is lost after implementing AES measure *m* instead of utilising the land in the most profit-maximising way. It is calculated according to EU requirements (Council Regulation (EC) No. 1698/2005) based on changes in yield, variable costs and labour costs when applying an AES measure. In order to monetise the changes in yield it is assumed that any loss in feed (expressed as net energy content) is substituted with the purchase of concentrated feed, for which a market price is available. Variable costs include seeds, pest management products, fertiliser, hail insurance, use of machines, hired labour, machine rental, ensilage, and other inputs. The transaction cost tc_m covers administrative tasks of the farmer caused by implementing an AES measure. An average annual transaction cost of 40€ per hectare is assumed (Wätzold et al., 2016).

The grid-cell based results of the ecological and the economic models are combined in the simulation component (box 7 in Figure 1) to assess the ecological effectiveness and/ or the costs of (1) individual mowing regimes and (2) a complete AES that contains one or more mowing regimes and specific payments that farmers receive if they apply a mowing regime (box 8 in Figure 1). To simulate AES, we assume that farmers choose the most profit-maximising measure (i.e. the measure where the difference between payment and cost is highest for them, see equation 3) or decide not to implement any measure at all if this is profit-maximising.

2.3. Application of the procedure to conventional farming, organic farming and AES

To distinguish between organic and conventional farming we extended the modelling procedure by considering that organically and conventionally managed grasslands generate different yields, differ in terms of fertilisation, and require different cost calculations. The yield and cost data for a profit-maximising grassland use for organic farming and recent data for conventional farming were taken from SLULG (2016). Some data was lacking and we estimated the data based on the information that was available as follows. Our data showed the yield share of each cut. Therefore we could derive what percentage of the total yield was harvested with the first, second and third cut. If, for example, the yield of a meadow mown only twice was missing, we assumed that yield to be equal to the harvest of the first two cuts of a meadow that is mown three times. In order to make the differences between the ecological impacts of conventional and organic farming easy to grasp, we assumed that the whole study area (Saxony) is managed either conventionally or organically.

2.3.1 Basic scenarios: Conventional farming and organic farming

We first simulated the ecological effectiveness and costs of different profit-maximising conventional mowing regimes without AES. Table 1 summarises these land uses. We assumed that conventional meadows are cut three times (SLULG, 2016) and that the timing of mowing differs depending on altitude (Table 1).

Table 1: Mowing regimes characterising conventional and organic farming in our case study for basic scenarios. The timing of land use is given in QM, e.g. the meadow with the timing "19/6/6" is cut for the first time in QM 19, and then two more times with a difference of 6 QM in between.

Management type	Land productivity	Land use intensity	Timing of land use	Altitude
Conventional farming	All yield classes	3-cut mowing	19/6/6	≤500m
			21/6/6	>500m
Organic farming	Medium to high yield	3-cut mowing	19/6/6	≤500m
			21/6/6	>500m
	Low yield	2-cut mowing	19/6/0	≤500m
			21/6/0	>500m

Secondly, we simulated the ecological effectiveness and costs of different profit-maximising organic mowing regimes without AES. Organic meadows have the same altitude-dependant differentiation in the timing of mowing as conventional meadows. Furthermore, following (SLULG, 2016) we considered that for organic meadows on low-yield land the benefit of the third cut is outweighed by the costs of mowing a third time, and consequently assumed that they are cut only twice. Organic meadows are therefore a mixture of two- and three-cut meadows (Table 1).

2.3.2. AES scenarios: "conventional AES" and "organic AES"

Thirdly, we simulated the impact of AES in which the farmers could choose between different AES measures to implement on their meadows. In order to be able to easily identify the ecological impact of an AES for conventional and organic farming, we considered two cases: (1) the whole study area is managed conventionally and an AES is offered to farmers ("conventional AES") and (2) the whole study area is managed organically and an AES is offered to farmers ("organic AES"). In both cases we assumed that all farmers in the case study area could take part in an AES. Thus, the ecological impact of the organic and conventional AES can easily be compared.

In each AES, the farmers could choose between several measures and their respective payment or a land use without implementing a specific measure and no payment. The current Saxon grassland AES offers three measures (GL5a, GL5b, GL5d) in which the timing of grassland use matters and whose impact can hence be assessed with the modelling procedure (Table 2). According to the Saxon AES regulation (cp. Section 2.1), measures GL5a and GL5b (see Table 2) may be implemented either as a two-cut or a three-cut meadow. As the profit-maximising number of cuts depends on the productivity of the grassland (see 2.3.1) we considered both options. Generally, on land with high grassland productivity it is profit-maximising to cut three times whereas on organic land with low grassland productivity a two-cut mowing regime may be profit-maximising (SLULG, 2016). Measure GL5d requires a long usage break and only a two-cut option is offered to the farmers, as the third cut would be too late in autumn.

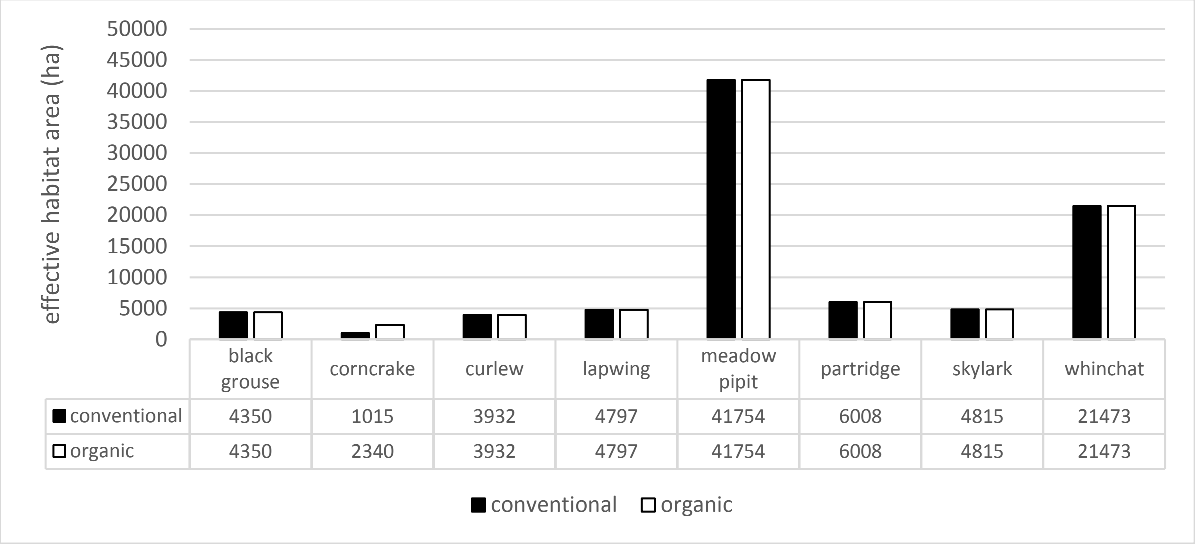
Table 2: Measures and payments offered in the Saxon AES. Measures are from category 5 "specific grassland usage compatible with species protection" of the Saxon Agri-Environment and Climate Measures Directive (SSUL, 2015c). Note that the payments offered to conventional and organic farmers differ: The payment organic farmers are offered is reduced by 230€/ha as the organic farmer already receives 230€/ha organic farming subsidy.

Measure number	**Time-dependent usage criteria**	**Payment offered**	
		Conventional	**Organic**
GL 5a	min. 2 usages per year, 1st usage as mowing but not before 1st of June	330€/ha	100€/ha
GL 5b	min. 2 usages per year, 1st usage as mowing but not before 15th of June	331€/ha	101€/ha
GL 5d	min. 2 mowing usages per year, usage break: first land use until 10th of June, usage break between 11th of June to 31st of August, second land use between 1st of September and 31st of October	359€/ha	129€/ha

3. Results

3.1. Basic scenarios: Simulation of conventional and organic farming

Figure 2 compares the ecological impact of the profit-maximising land use, i.e. the three-cut conventional mowing regime with that of the organic mowing regime, i.e. a mixture of two- and three-cut mowing regimes (cp. Table 1). With both conventional and organic mowing regimes only eight out of the 30 species considered benefit, i.e. have non-zero effective habitat areas. For nearly all species, the impact of organic and conventional farming is identical. Only the corncrake (*Crex crex*) profits from organic mowing regimes to some extent as the two-cut measure on low-yield organically managed land allows the bird to lay its eggs after the second cut during its late breeding period.



	black grouse	corncrake	curlew	lapwing	meadow pipit	partridge	skylark	whinchat
■ conventional	4350	1015	3932	4797	41754	6008	4815	21473
□ organic	4350	2340	3932	4797	41754	6008	4815	21473

Figure 2: Effective habitat area generated from conventionally (3-cut) and organically (2-cut on low-yield areas, 3-cut on medium and higher yield areas) managed meadows. For detailed information on the timing of each land use see Table 1. The scientific names of the species can be found in Table A1.

3.2. AES scenarios: Simulation of conventional and organic AES

The implementation of both organic and conventional AES benefit only eight bird species and no butterfly species (out of the thirty species included in the modelling procedure). When comparing the organic and conventional AES (Figure 3), most species benefit less from the organic than from the conventional AES. However, three bird species (skylark (*Alauda arvensis*), curlew (*Numenius arquata*) and corncrake (*C. crex*)) benefit more from the organic than from the conventional AES. To understand the differences concerning the impact of the two AES, we examine the actual measures adopted under each AES (Table 3) and the species' response to these AES measures (Table 4) in more detail. However, note that one cannot compare the effective habitat area generated in the two scenarios directly, as the "AES scenario" only shows the impact of those farmers implementing AES measures (and not the impact of other farmers who do not participate in the AES), while the "basic scenario" considers all farmers (as none of them are offered an AES measure).

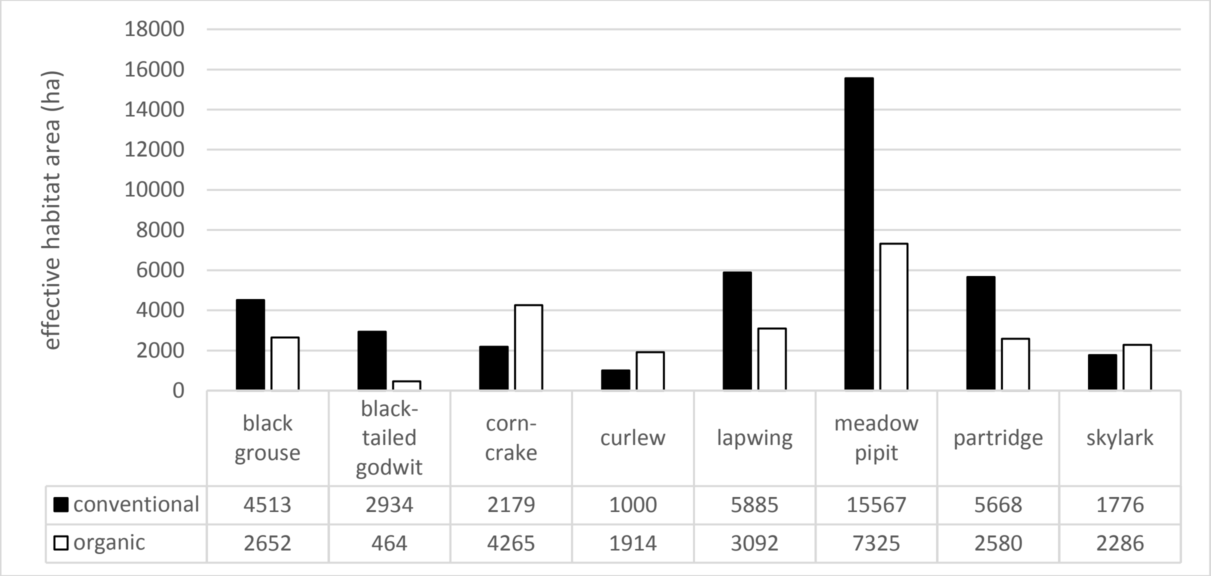


Figure 3: Effective habitat area generated with the conventional and organic AES. The scientific names of the species can be found in Table A1.

Table 3 shows that out of the set of possible AES measures (Table 2) predominantly measure GL5a (and here only the two-cut option) is adopted in the conventional AES, while in the organic AES only measure GL5d is adopted (Table 3). We estimated the ecological impact of each AES measure assuming that this measure (e.g. measure GL5a) was adopted at all possible grid cells and that all grid cells are managed either conventionally or organically (Table 4). These simulations therefore do not take into account the payment offered or the actual grid cells on which each measure is implemented. This implies that the resulting effective habitat area is larger than the effective habitat area generated in the conventional and organic AES. Table 4 thus shows the potential impact of the AES measures on the species.

Table 3: Total area (number of grid cells multiplied with grid cell area) adopting a certain measure offered by AES

Measure	Conventional	Organic
GL 5a (2-cut)	14,012.5 ha	0 ha
GL 5d	3,412.5 ha	8,113 ha
total area	17,425 ha	8,113 ha

Table 4: Potential maximum effective habitat area (in ha) of selected species generated from AES measures, assuming that each measure was adopted in the whole of Saxony. The scientific names of the species can be found in Table A1.

Measure	conventional GL5a	conventional GL5d	organic GL5d
black grouse (ha)	14,103	14,103	14,103
black-tailed godwit (ha)	8,122	8,120	8,117
corncrake (ha)	1,029	28,339	28,338
curlew (ha)	3,952	3,945	3,932
lapwing (ha)	17,942	18,060	18,059
meadow pipit (ha)	47,122	47,122	47,122
partridge (ha)	17,054	17,054	17,054
skylark (ha)	6,491	6,503	6,486

The corncrake (*C. crex*) benefits mainly from measure GL5d and somewhat from measure GL5a (Table 4). This means that although measure GL5a is implemented on large areas in the conventional AES (Table 3), no corncrake (*C. crex*) habitat is generated on those areas as the required minimum habitat is not reached. As in the organic AES measure GL5d is implemented on much larger areas (Table 3), the corncrake (*C. crex*) benefits more from the organic AES than from the conventional AES.

The curlew (*N. arquata*) and the skylark (*A. arvensis*) benefit almost equally from AES measures GL5a and GL5d. Although the total area adopting AES measures is larger in the conventional AES, the species benefit more from the organic AES. This is due to the small area of very high quality habitat generated in the organic AES in comparison to the larger area of low-quality habitat generated in the conventional AES (Equations 1 and 3).

4. Discussion and conclusions

We applied and extended an ecological-economic modelling procedure to analyse the impact of organically and conventionally managed meadows with and without additional AES measures on endangered bird and butterfly species in Saxony, Germany. Applying a modelling procedure to assess the impact of organic farming is novel as previous research predominantly relies on field studies. The application of the modelling procedure enabled us to detect two novel aspects that enhance our understanding of how organic agriculture affects biodiversity.

First, we found only small differences between the direct impact of organically and conventionally managed meadows on endangered birds and butterflies. The reason for this finding is that the focus of the modelling approach lies on analysing the timing and frequency of cuts of mowing regimes, which are largely identical under conventional and organic farming. While previous research addressed the ecological impact of temporal aspects of grassland use (Johst et al. 2002), our study is the first addressing these temporal aspects in relation to organic farming. Interestingly, we found that only eight species out of thirty benefit. These species benefit from organic farming as well as conventional farming. As both conventionally and organically managed meadows are cut in very similar ways, and many endangered species require different cutting regimes (Johst et al., 2015) only few and the same species benefit. It is interesting to note that the whinchat (*Saxicola rubetra*) only benefits when no additional AES measures are implemented. This is due to the species' early reproduction time. The slightly delayed cut in the AES measures thus impacts the whole cohort of that year, while the slightly earlier cut in the basic scenario leaves the last eggs of that year without any impact, highlighting the importance of specific mowing regimes for certain species.

The literature shows mixed results regarding the direct impact of organic farming in comparison with conventional farming. Batáry et al. (2012) found organic farming to benefit biodiversity, Hiron et al.

(2013) found no difference and Weibull et al. (2003) even found conventional farming to benefit biodiversity more than organic farming under certain conditions. Rundlöf and Smith (2006) suggest that the interactions between landscape heterogeneity and management type may be the reason for these mixed results, as heterogeneous landscapes are beneficial for many species and organic farms are more likely to be located in a heterogeneous landscape. Thus, the benefit for species may be caused by landscape heterogeneity rather than organic farming. By applying a modelling approach our study eliminates the impact of unknown interaction effects such as those caused by landscape heterogeneity and focuses completely on specific aspects that differ between conventional and organic meadow management.

However, our analysis suggests that organic farming may provide benefits for particular species. These benefits result from a less intensive land use that may become profit-maximising on organic farms due to the lower yield in comparison to conventional farms. In our case study area, a two-cut meadow is likely to be profit-maximising for organic farms in areas with low grassland productivity (SLULG 2016). Unlike for conventional farms, the profit from the additional yield of the third cut is outweighed by the cost of this cut. Considering the grassland productivity in our case study area, these impacts were limited, and only small areas of land are cut twice. Nonetheless, we found that the corncrake (*C. crex*) was positively affected by the two-cut land use on organically managed land of low grassland productivity. In other regions with a higher share of less productive areas these impacts may be more pronounced.

Our second key finding is that organic farming also has an indirect impact on endangered species because organic farmers have different incentives than conventional farmers regarding participation in AES. They have different opportunity costs when implementing AES measures and are paid differently for implementing AES measures. Thus, organic farmers select different AES measures which in turn has an impact on biodiversity.

In our case study, when implementing AES measures most species benefit more from conventional farming than from organic farming (Figure 3). This is due to the relatively small number of grid cells, respectively farmers, taking part in the organic AES, which is caused by the lower payment offered to organic farmers in comparison with conventional farmers (Table 3). However, three species benefit more from the AES implemented on organically managed land. This is caused by the different AES measures selected by organic and conventional farmers from the set of measures available in the AES, as these measures affect different species differently depending for example on their breeding periods. The key factor influencing this differing selection of AES measures is the different cost structures of organic and conventional farms, differing in the payment offered for implementing measures and the opportunity costs arising when implementing such measures. Due to the differing cost structures, the implementation of AES measures by organic farmers in our case study showed that they may implement AES measures that are only scarcely adopted under conventional farming and vice versa.

Obviously, our approach has limitations. Firstly, organic agriculture has other influences that have not been included in this analysis. For example, because the use of pesticides is restricted (Commission Regulation (EC) No 889/2008), certain weeds and insects are present that are important in the food chain of some bird species (Hallmann et al., 2017; Shennan, 2008). Moreover, bird and butterfly species other than those included in this analysis may be impacted differently by the mowing regimes modelled, as their impacts vary greatly with each species' specific reproductive behaviour (Johst et al. 2015). The impact of the AES also depends largely on the AES measure options available. Only three AES measures have been included in this analysis. When including more options, the results will inevitably vary. Furthermore, the quality of the results of the modelling procedure depends on data input. While we used official data that is also used for the design of AES in most cases, certain costs and yields had to be estimated. Moreover, even the official data only represents approximations of reality.

Nonetheless, according to our results considering the different cost structures of organic and conventional farmers is of key importance, as it influences their adoption of AES measures. In general, a greater variety in the timing of land use caused by a greater variety of AES measures benefits more species (Johst et al., 2015). However, for more diverse AES measures to be implemented, the AES has to be designed in a way to support this. In our case study, for example, only very few organic farmers implement AES measures with the current payment and many endangered species are not protected at all.

This result suggests important management implications for the design of AES in general. In order for an AES to effectively protect species and make use of the potential offered by different cost structures, it is necessary to adapt the payments to the different cost structures of organic and conventional farmers when designing an AES. By taking into account the different opportunity costs of organic and conventional farmers one can design measures and payment structures that lead to cost-effective solutions (Wätzold & Schwerdtner, 2005). Future research may analyse the necessary payment structure to reach cost-effective results that consider the different cost structures of conventional and organic farmers in order to maximise biodiversity conservation.

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Appendix

Table A1: Bird and butterfly species of Saxony included in the modelling procedure, information about protection status according to Landesamt für Umwelt, Landwirtschaft und Geologie (2007, 2015) and adapted from Wätzold et al., 2016

Scientific name	**English name**	**Red list Saxony**[1]	**Legal Protection Grasslands Types Directive**[2]	**BNat SchG**[3]
Butterflies				
Coenonympha glycerion	Chestnut Heath	3		§
Cupido minimus	Small Blue	G		
Erebia medusa	Woodland Ringlet	2		§
Erynnis tages	Dingy Skipper	V		
Euphydryas aurinia	Marsh Fritillary	1	Annex II	§
Hesperia comma	Silver-spotted Skipper	2		
Lasiommata maera	Large Wall Brown	3		
Lycaena hippothoe	Purple-edged Copper	2		§
Maculinea alcon	Alcon blue	0		§
Maculinea nausithous	Dusky Large Blue	*	Annex II, IV	§§
Maculinea teleius	Scarce Large Blue	1	Annex II, IV	§§
Melitaea cinxia	Glanville Fritillary	2		
Polyommatus amandus	Amanda’s Blue	*		§
Polyommatus semiargus	Mazarine Blue	2		§
Zygaena trifolii	Five-spot Burnet	-		§
Birds			**Birds Directive**[4]	
Alauda arvensis	(Eurasian) skylark	(V)		§
Anas querquedula	Garganey	1		§§
Anthus pratensis	Meadow Pipit	-		§
Crex crex	Corncrake	1	Annex I	§§
Galerida cristata	Crested Lark	2		§§
Gallinago gallinago	(Common) snipe	2		§§
Limosa limosa	Black-tailed godwit	0		§§
Numenius arquata	(Eurasian) curlew	1		§§
Perdix perdix	Partridge	2		§
Philomachus pugnax	Ruff	-		§§
Saxicola rubetra	Whinchat	3		§
Tetrao tetrix	Black Grouse	1	Annex I	§§
Tringa totanus	(Common) redshank	1		§§
Upupa epops	Hoopoe	1		§§
Vanellus vanellus	(Northern) lapwing	2		§§

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[1] Red list of threatened species- 0: extinct; 1: critically endangered - extremely high risk of extinction; 2: endangered - high risk of extinction; 3: vulnerable - high risk of endangerment, V: near threatened - likely to become endangered in the near future; G: endangerment is assumed; ∗: least concern.

[2] Habitats Directive: Council Directive 92/43/EEC on the Conservation of natural habitats and of wild fauna and flora adopted in 1992; it aims to protect some 220 habitat types and approximately 1,000 species listed in the Annexes. Annex II species require designation of Special Areas of Conservation, Annex IV species are in need of strict protection

[3] BNatSchG=Federal Nature Conservation Act: § = specially protected, §§ = strictly protected

[4] 3Birds Directive: Council Directive 2009/147/EC on the conservation of wild birds adopted in 2009 in replacement of Council Directive 79/409/EEC of 2 April 1979; It aims to protect all European wild birds and the grassland types of listed species.

Table A2: Overview of the 140 mowing regimes differentiated according to parameters (QM= quarter month, year divided into 48 consecutively numbered QM, e.g. QM19= 15th to 22nd of May). Source: adapted from Wätzold et al., 2016

Characteristics	**Number of measures**
Time of first cut (QM 19-30): 12 Interval from first to second cut (0,4,6,8,10 QM): 5 N-Fertilizer (reduced/no): 2	12∗5∗2=120
Only one cut after QM 30, time (QM 31-40): 10 N-Fertilizer (reduced/no): 2	2∗10=20
Sum	**140**

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