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Article — Published Version

Impacts of the EU's Common Agricultural Policy “Greening” reform on agricultural development, biodiversity, and ecosystem services

Applied Economic Perspectives and Policy

Provided in Cooperation with:

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Suggested Citation: Hristov, Jordan et al. (2020) : Impacts of the EU's Common Agricultural Policy “Greening” reform on agricultural development, biodiversity, and ecosystem services, Applied Economic Perspectives and Policy, ISSN 2040-5804, Wiley, Hoboken, NJ, Vol. 42, Iss. 4, pp. 716-738,
<https://doi.org/10.1002/aep.13037>

This Version is available at:

<https://hdl.handle.net/10419/225659>

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SUPPORTING MATERIALS

Impacts of the EU’s Common Agricultural Policy “greening” reform on agricultural development, biodiversity and ecosystem services

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Overview of the study regions

Using the most recently available data at the time of creating the study regions in AgriPoliS, we calibrated GSS using data for 2008 and GMB for 2011 as documented in (Hristov et al., 2017). An overview of the structure of agricultural production in the study regions by the main production activities is provided in table S1. As can be seen the regions are of similar size but GMB has substantially more livestock and grass fodder production, while GSS has a relatively larger area of cash crops.

Table S1. Comparison of agricultural structure in the study regions in 2013

	GMB	GSS
Number of farms	6,447	4,923
Average farm size (ha)	64.1	70.7
Average winter wheat yield (t/ha)	6.3	7.6
Arable land (ha)	310,037	329,060
Cereals (ha)	117,141	179,329
Leguminous plants (ha)	5,122	8,216
Oilseed crops (ha)	23,128	36,293
Sugar beet (ha)	7,138	28,733
Grassland (ha)	134,925	58,998
Pasture (ha)	103,597	18,996
Total agricultural land (ha)	413,634	348,056
Forest (ha)	171,194	63,769
Cattle (No.)	258,927	101,028
Dairy cows	64,795	27,311
Suckler cows	25,551	9,968
Heifers, bulls and steers	87,046	31,002
Calves under 1 year	81,535	32,747
Sheep (No.)	120,435	26,069
Sows (No.)	27,586	38,994
Fattening pigs (No.)	172,023	192,270

Source: Statistics Sweden (2014).

For practical reasons, we model and calibrate geographically coherent sub-regions of the GSS and GMB regions (figure 1 in main article) which allowed us to focus on a contiguous agriculturally dominated landscape. These sub-regions account though for most of the agricultural land in the region.

Landscape heterogeneity index (LHI)

The landscape efficiency hypothesis states that the level of biodiversity benefits depends on the amount and spatial allocation of semi-natural habitats across the landscape (Ekroos et al., 2014). Previous studies have shown an effect of landscape heterogeneity on the efficiency of interventions to enhance biodiversity and biodiversity-based ecosystem services at multiple spatial scales (Benton et al., 2003; Tschardt et al., 2005). Here, regional landscape heterogeneity at the landscape level was measured by a landscape heterogeneity index (LHI). It is calculated as the first principal component (PC1) from a principal component analysis (PCA) of the proportion semi-natural pastures and proportion field border (assuming a field border width of 1 m) from the impact assessment landscapes (black and red in figure 2). Proportion semi-natural pasture was square root transformed prior to analysis to improve linearity between the two. This landscape heterogeneity index has been used in several studies to test the influence of landscape structure on biodiversity and ecosystem services (Andersson et al., 2014; Rader et al., 2014; Stjernman et al., 2019).

Figure S1 displays the calculated landscape heterogeneity index (LHI). GMB is on average a more heterogeneous region than GSS, but there is also a variation in heterogeneity within both regions. Thus, given the landscape efficiency hypothesis we expect different effects from the change in policy in the two regions.

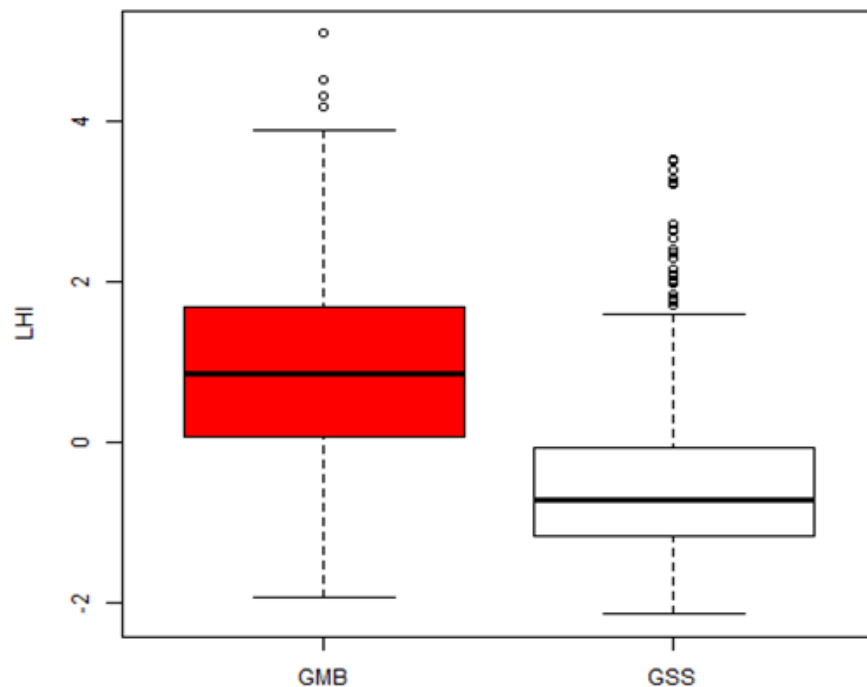


Figure S1. Comparison of landscape heterogeneity between the study regions

The integrated economic and ecological modelling

Figure S2 summarizes the major steps we followed to evaluate the effects of the 2013 reform on biodiversity and ecosystem services at both the farm and regional scales. First, we implemented the main components of the reform in the economic model AgriPoliS to simulate the policy impacts at the farm scale. In particular, this required extending AgriPoliS to model the Ecological Focus Area (EFA) obligation and the different types available in Sweden, these being (SJV, 2015):

- i) fallow land
- ii) nitrogen-fixing crops (peas and clover)
- iii) under-sown grass with cereals and oilseed rape
- iv) short rotation coppice (willow)
- v) field margins

The equalization of payments and the coupled direct payments could be modelled with existing functionality.

Next we performed a validity check of the simulated EFA areas with data from 2015 (the year of implementation and only available EFA data at the time) as well as validation of the simulated development in the number of farms, land use and livestock numbers with historical data available to 2015. Once we were satisfied that the dynamic baseline simulations adequately reproduced reality, we simulated the impacts of the reform scenario to 2020 as well as the alternative scenarios. The simulated land use changes from AgriPoliS were subsequently used as input to the spatially explicit ecological modelling to determine impacts on biodiversity, pollination and biological control at the landscape scale.

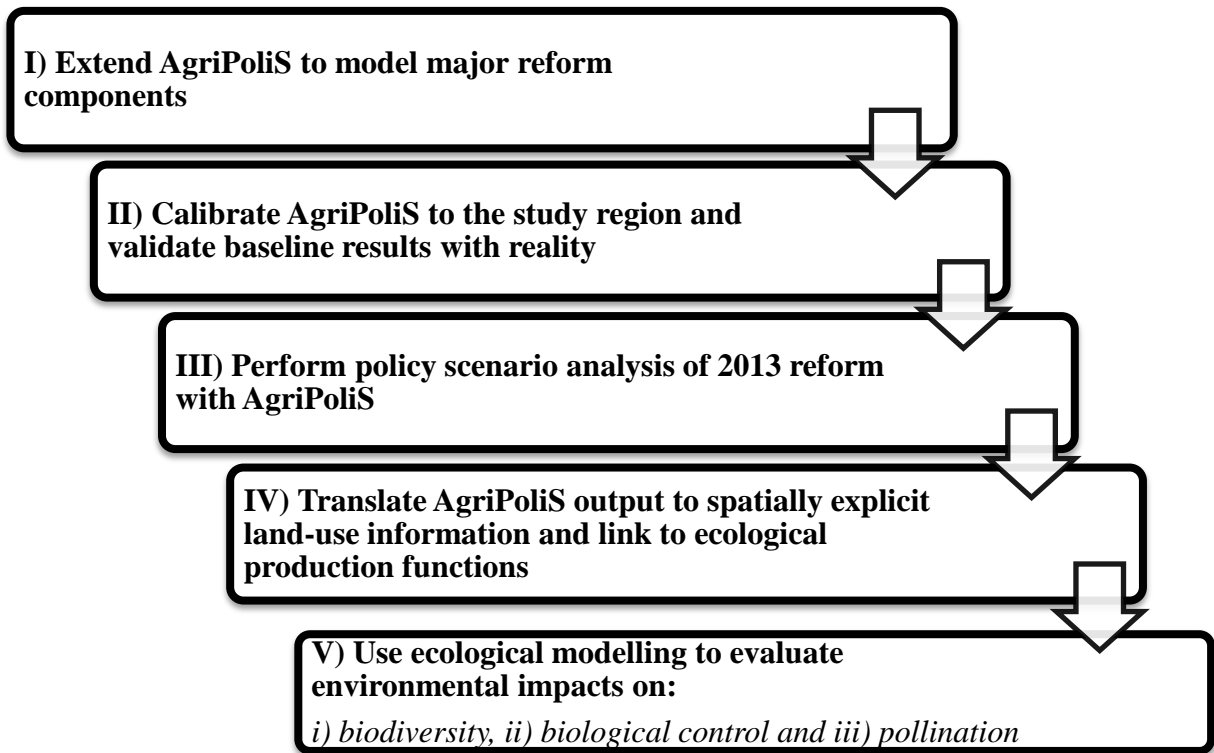


Figure S2. Overview of the integrated economic and ecological modelling

Extend AgriPoliS with Ecological Focus Areas (EFAs)

To model the major components of the 2013 reform—equalization, the greening payment, coupled livestock payments and the EFA requirement—we extended the Mixed Integer Programming (MIP) tableau in AgriPoliS. The new production activities that qualify as EFA and their weighting factors were introduced, as well as the conditions for meeting the EFA requirement and farm-type exemptions.

Table S2 provides an example of how the 5% EFA obligation is modelled for a farm with 100 ha high productive arable land and 100 ha low productive land with four non-EFA crop production activities (winter wheat, spring barley, oilseed rape and sugar beet), and 30 ha semi-natural pasture. The total decoupled direct payment is set to the expected 2019 level when payments will be equalized across Sweden at around 193 €/ha, of which 30% (58 €/ha) is contingent on adopting greening measures and the remaining (135 €/ha) the basic payment. Beside the greening and basic payment support the row "couple livestock support" is used to model the new coupled payment of 91 €/head for cattle over 1 year.

The rows and columns “greening_yes>15ha” and “greening_no<15ha” capture the EU exemption from EFA obligations for farms having less than 15 ha of arable land. The next four rows implement the exemption for farms with more than 75% grassland and fodder crops (i.e., rows “greening_yes<75% GL” and “greening_no>75% GL”) and a remaining total arable area of less than 30 ha (row “greening_yes>30ha ALH and ALL”). The EFA exemptions for arable land

and grassland are modelled as integer problems (either 1 or 0) indicated by the rows “greening no<15ha” and “greening no>75% GL”.

The rows “under-sown in fall/spring” indicate which crops are considered as the main crop that is under-sown with grass. Since these two activities indicate how much acreage is under-sown, and use the same area as the main crop, they do not reduce the area available for production, hence these areas are excluded from the “arable land high” and “arable land low” farm area constraints, and the greening exemption row “greening_yes>15ha”; nor are they allocated any basic or greening payment, as this is captured by the main crop.

The row “EFA requirement” is used to model the choice of EFA types as a proportion of the crop production activities as well as to weight the different EFA-options as determined by the Swedish Board of Agriculture (SJV, 2015). Fallow land is valued the most because it is must be sown with grass (i.e., not left bare). Hence, if the “greening_yes>15ha” and “greening_yes<75% GL” rows indicate that the farm must provide EFAs then 5% (0.05) of each ha of winter wheat, barley, oilseed rape or sugar beet should be matched by fallow (0.95). The other EFA activities are weighted relative to fallow land. For example, 1 ha of nitrogen-fixing crops or willow/under-sown crops is counted as 0.7 ha or 0.3 ha EFA respectively. Field margins are accounted for very differently compared to the others, i.e., a 1 m long margin is counted as 9 m² EFA no matter what its width, but must be at least 1 m and no more than 20 m wide (SJV, 2015). Hence we assume farmers adopt the minimum width, as this will be least costly to them. Therefore, according to table S2 a farm with 100 ha arable land (high or low) will be able to meet the 5% EFA requirement, through having either 5 ha fallow land, 7.14 ha (5/0.7) protein plants, 16.7 ha (5/0.3) main crop under-sown with grasses or planted willow, or 0.55 ha (5/9) field margins that are assumed to be 1m wide. However, farmers can choose a mix of different EFA types to achieve the obligation depending on what is optimal.

Table S2. Implementation of EFA in MIP tableau

	Winter wheat	Barley	Oilseed rape	Sugar beet	Semi-nat. pasture	Nitrogen-fixing crops (peas)	Nitrogen-fixing crops (clover)	Fallow land high	Fallow land low	Willow high	Willow low	Under-sown in fall	Under-sown in spring	Field margins high	Field margins low	Cattle prod. activity	Basic payment	Greening payment	Coupled livestock support	Greening yes>15ha	Greening no<15ha	Greening yes<75% GL	Greening no>75% GL	RHS	
Continuous/integer activ.	c	c	c	c	c	c	c	c	c	c	c	c	c	c	c	c	c	c	c	i	i	i	i		
Objective function	GM	GM	GM	GM	GM	GM	GM	GM	GM	GM	GM	GM	GM	GM	GM	GM	1	1	1	0	0	0	0		
Arable land high (ALH)	1		1	1		1		1		1				1										≤ 100	
Arable land low (ALL)		1	1						1		1				1									≤ 100	
Semi-nat. pasture (GL)					1																			≤ 30	
Basic payment	-135	-135	-135	-135		-135	-135	-135	-135	-135	-135			-135	-135		1							≤ 0	
Greening payment	-58	-58	-58	-58		-58	-58	-58	-58	-58	-58			-58	-58			1						≤ 0	
Coupled livestock supp.																-91			1					≤ 0	
Greening_yes>15ha	1	1	1	1		1	1	1	1	1	1			1	1						-∞			≤ 15	
Greening_no<15ha																					1	1		≤ 1	
Greening_yes<75% GL	0.75	0.75	0.75	0.75	-0.25	0.75		0.75	0.75	0.75	0.75			0.75	0.75								-∞	≤ 0	
Greening_no>75% GL																							1	1	≤ 1
Greening_yes>30ha ALH	1		1	1		1		1		1				1									-∞	-30	≤ 0
Greening_yes>30ha ALL		1	1						1		1				1								-∞	-30	≤ 0
Under-sown in fall	-1		-1											1										≤ 0	
Under-sown in spring		-1											1											≤ 0	
EFA requirement1)	0.05	0.05	0.05	0.05		-0.7	-0.7	-0.95	-0.95	-0.3	-0.3	-0.3	-0.3	-9	-9								-∞	-∞	≤ 0
Max. area field margin	-0.04	-0.04	-0.04	-0.04										0.96	0.96									≤ 0	
EFA activity level (ha)						7.14	7.14	5	5	16.7	16.7	16.7	16.7	0.55	0.55										

Note: 1) The weighting factors are set relative to fallow land. Thus, 1 ha nitrogen-fixing crops and under-sown crop or willow are weighted as 0.7 ha and 0.3 ha of fallow land respectively. Field margins are considered to be 1 m wide even though they might be wider in practice but no more than 20 m (SJV, 2015) and the resulting area is multiplied by 9 to obtain the EFA equivalent area. Instead of -∞ we use a large value, i.e., 5 000 in the actual model; c = continuous activities; i = integer activities; GM = gross margin RHS = right hand side constraints.

Note that the modelling of field margins has required some additional assumptions since the width is not definite and the potential length depends on field characteristics (i.e., size and shape). If the parcel is assumed to be square, 1 ha can have a 400 m long field margin (row “Max. area field margin”) if each side has a 1 m wide strip this counts as 9 m² towards the EFA obligation. Hence, a 400 m long strip counts as 3600 m² or 0.36 ha EFA thanks to the weighting factor. More details of the input data and the sources for the modelled EFA's can be found in Hristov et al. (2017).

Validate AgriPoliS results with reality

The optimal areas of EFAs chosen by the AgriPoliS farm-agents after the calibration process reproduced adequately the areas observed in 2015, the year of policy implementation, according to statistics obtained from the Swedish Board of Agriculture (table S3). The main difference is that the AgriPoliS farm-agents tended to choose a greater area of fallow than under-sown crops as compared to reality. However, from an environmental perspective fallow has higher value than under-sown crops (Allen et al., 2012), and thus does not risk underestimating the environmental benefits of greening. Under-sown grass does not provide good foraging or overwintering habitat for birds, natural enemies and pollinators. It is also not expected to increase plant diversity under conventional farming practices due to pesticide and fertilizer use (Underwood and Tucker, 2016). In addition, the grass is not assigned any floral quality because when under-sown in an annual crop to be considered as EFA, it is unlikely to flower regularly (Kovács-Hostyánszki et al., 2016). Willow was not chosen at all by the farm-agents, and only marginally in reality due to its low profitability. In addition, it appears that willow has less serious impacts on biodiversity and ecosystems services (Guthrie, 2007).

Table S3. Modelled vs. real EFA areas in the regions in 2015 without weighting

EFA	GMB				GSS			
	SJV		AgriPoliS		SJV		AgriPoliS	
	Area (ha)	%	Area (ha)	%	Area (ha)	%	Area (ha)	%
Fallow land	2,270	21	2,325	33	3,819	22	6,780	42
Nitrogen-fixing crops	3,065	29	4,255	61	7,289	43	8,895	56
Under-sown crop	4,971	47	-	-	5,395	31	-	-
Willow	230	2	-	-	321	2	-	-
Field margins	112	1	400	6	308	2	315	2
Total	10,648	100	6,980	100	17,132	100	15,990	100

Source: (SJV, 2016).

To validate the overall model performance we compared the simulated structural development over the spin-up period (2008-2014) with observed historical trends in land use, numbers of farms and numbers of livestock in both regions.

Table S4 displays a comparison of the actual decline in farms over the period 2008–14 according to official statistics with the simulated decline in farms under the baseline scenario in AgriPoliS (**CAP 2003**). Note that small farms (< 20 ha) are excluded from the validation

because even though these are large in number they manage a small proportion of the total arable area in both GMB and GSS. These farms are also often quasi-commercial (e.g., hobby farms) and therefore problematic to model with precision because of the greater uncertainty about economic parameters such as owners' opportunity costs of labour and investment costs than commercial farms. Consequently, the number of farms in this table differs from the number of farms displayed in table S1. From the table it can be seen that the rate of change in commercial farms simulated by AgriPoliS until 2014 is similar to reality.

Table S4. Comparison of real versus simulated declines in farms 2008–14

	GSS				GMB			
	Real		AgriPoliS		Real		AgriPoliS	
	<i>Nr.</i>	%	<i>Nr.</i>	%	<i>Nr.</i>	%	<i>Nr.</i>	%
2008	2,992		395					
2011	2,860	- 4	388	- 2	3,354		338	
2014	2,684	- 10	372	- 6	3,121	- 7	303	- 10

Source: (Statistics Sweden, 2009, 2012, 2015).

The simulated changes in land use and livestock production also capture very closely the real structural development in the regions. In figure s3 and figure s4 (upper diagrams) it can be seen that the change in the area of arable crops in AgriPoliS has been consistent and following the same trend as in the data from Statistics Sweden for the real regions (lower diagram), over the evaluation period. For example the area of cereal production in both regions as well as grassland (including semi-natural pasture) in GMB, account for the largest proportions in the simulations, and are in line with the real development. Of course, the scale is different between the real data and AgriPoliS but this is because we modelled at the sub-regional level. There is an exception in GMB for fallow land where the simulated area increases faster than the real data. The area of fallow land is though very small relative to the total arable area, thus making it difficult to obtain exact calibration unless it comes at the cost of other (more important) land use categories and indirectly livestock production.

Regarding the different livestock production activities, the lower diagrams of both figures s3 and s4 convey that AgriPoliS also performs well and is able to capture the development visible in the real data. For example, granivore production in GSS follows the same trend in both the simulated and real data, it is declining.

Consequently, it can be concluded that the simulated structural development, land use changes and livestock numbers are consistent with the observed developments over the period 2008–14.

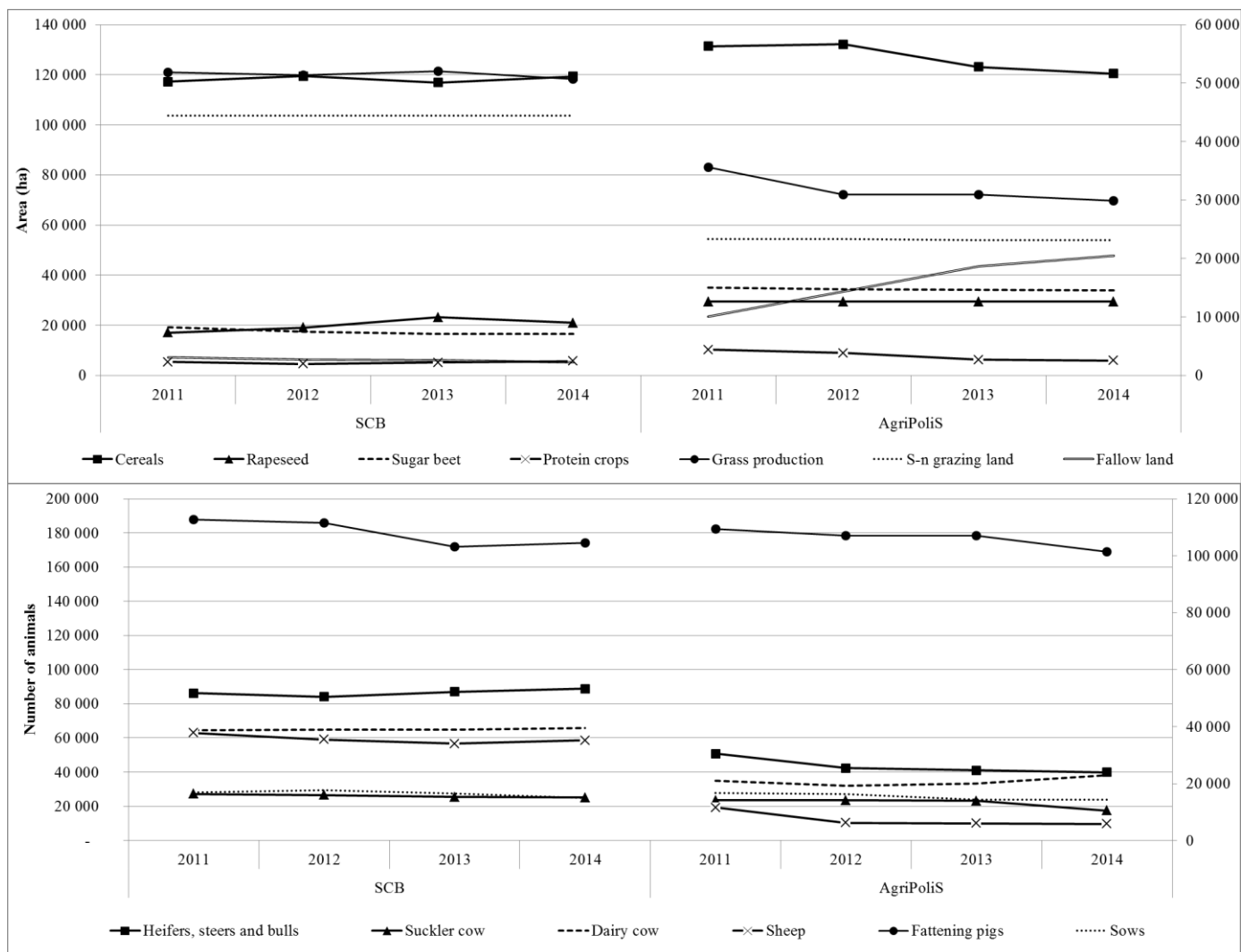


Figure S3. Comparison of real and simulated land use changes (upper diagram) and livestock production (lower diagram) in GMB

Source: (Statistics Sweden, 2009, 2012, 2015).

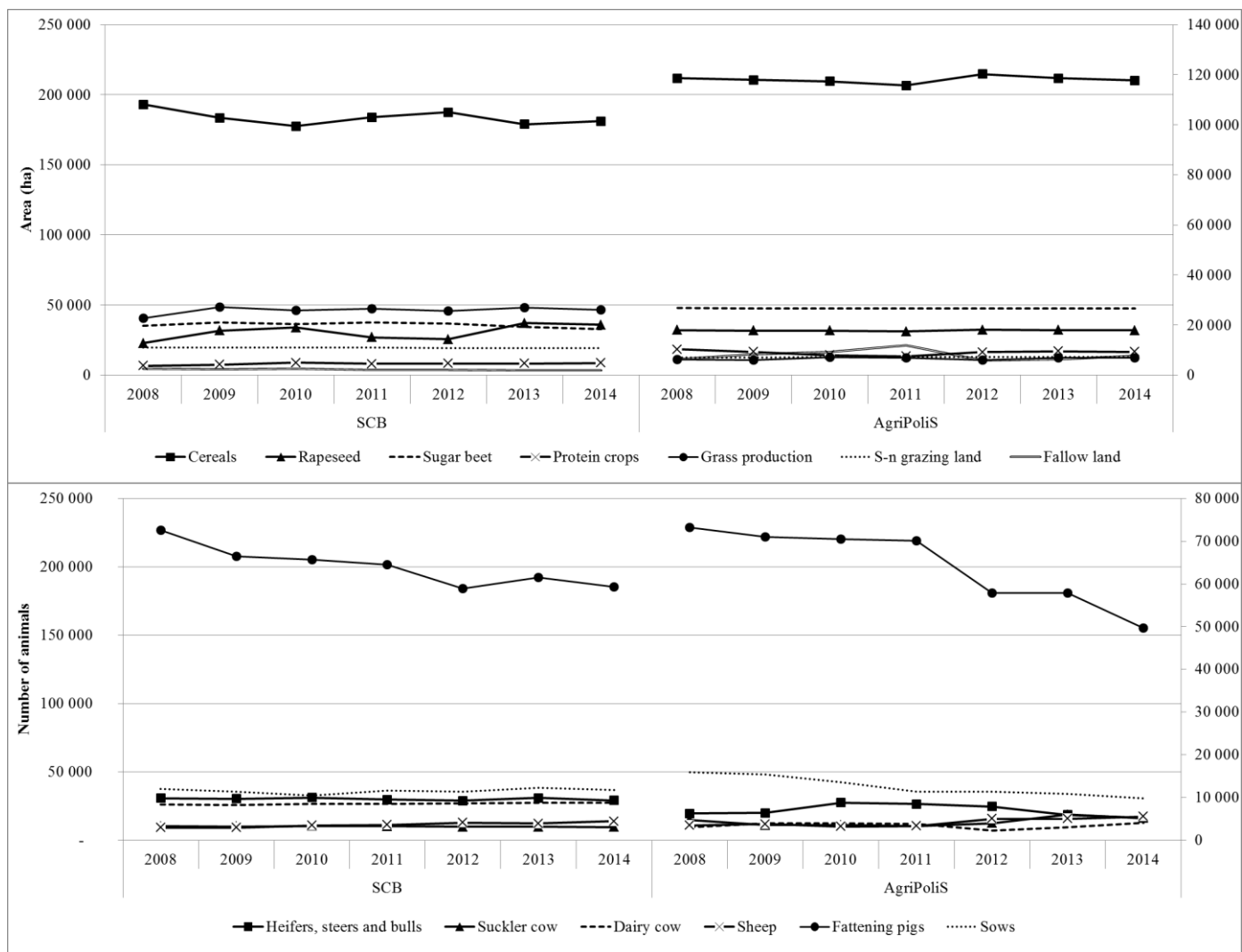


Figure S4. Comparison of real and simulated land use changes (upper diagram) and livestock production (lower diagram) in GSS

Source: (Statistics Sweden, 2009, 2012, 2015).

Perform scenario analysis with AgriPoliS

In table S5 we summarize the assumptions that define the evaluated policy scenarios.

Table S5. Simulated policy scenarios

	Scenario ID	Description
<i>Actual</i>	CAP 2003	Continuation of the 2005-14 Mid-term Review policy.
<i>CAP scenarios</i>	CAP 2013	2013 reform: i) national convergence phased in over 4 years resulting in a uniform area payment of 193 €/ha agricultural land in 2019), ii) coupled cattle payment of 91 €/head cattle over 1 year, iii) 5 % EFA obligation.
		<i>Same structure as CAP 2013 but with:</i>
<i>Hypothetical</i>	EFA15	15 % area obligation including the actual weighting factors.
<i>EFA scenarios</i>	EFA5 (no weights)	5% area obligation and no weighting factors.
	EFA15 (no weights)	15% area obligation and no weighting factors.

Translate AgriPoliS output to spatially explicit land-use information

For each AgriPoliS production activity, one or several corresponding IACS crop categories were assigned. Crop cover changes were implemented by randomly selecting fields with crops predicted by AgriPoliS to decline in cover. The crops in these fields were randomly replaced by crop covers predicted by AgriPoliS to increase under a given simulation. Changes in the amount of field margins were implemented in a second step by randomly selecting edge cells from fields occupied by a crop predicted by AgriPoliS to decrease in cover. To reflect the minimum width of a field margin defined in the policy, a field margin was set to be 25 m long and 1 m wide in each edge cell. Note that the physical landscape structure remains unchanged, i.e. field margins do not change unless the field is abandoned. Information on individual farms obtained from AgriPoliS was used to restrict use of field margins to those farm types that were affected in the model, i.e., specialized field crop and specialized pig farms (holding more than 100 pigs, all ages confounded, and less than 10 bovines).

The set of non-overlapping landscapes in figure 2 in the main article was created by placing a hexagonal lattice of 1 km landscapes such that the number of landscapes included in the two production regions was maximized with the constraint that none of the landscapes should be centred closer than 1 km from production region borders. In this way, the landscapes covered at least 80 per cent of the total land area of the two regions. Only landscapes with at least 40 per cent of their total area comprised of farmland (i.e. >125.7 ha farmland in a 314.2 ha landscape) were included in the impact assessment (black and red in figure 2 in the main article). Such agricultural landscapes are typically observed in both regions, figure 1(b) and (c) in main text, and are the types of landscapes for which the biodiversity and ecosystem service models we use in this study were conceived.

Ecological modelling: biodiversity

As a biodiversity production function we used a statistical model from a study on the effects of agricultural intensification on farmland birds in the same regions (Stjernman et al., 2019). Farmland bird species included in the biodiversity production function were Eurasian Curlew *Numenius arquata*, Lapwing *Vanellus vanellus*, Skylark *Alauda arvensis*, Barn Swallow *Hirundo rustica*, Meadow Pipit *Anthus pratensis*, Yellow Wagtail *Motacilla flava*, Whinchat *Saxicola rubetra*, Northern Wheatear *Oenanthe oenanthe*, Common Whitethroat *Sylvia communis*, Red-backed Shrike *Lanius collurio*, Rook *Corvus frugilegus*, European Starling *Sturnus vulgaris*, Tree Sparrow *Passer montanus*, Linnet *Carduelis cannabina*, and Yellowhammer *Emberiza citrinella*. The 15 bird species and the summarizing index correspond to those used in two indicators, the Farmland Bird Index and the index for the Swedish Environmental objective “A Varied Agricultural Landscape”, both of which are used by Swedish authorities to monitor the fate of biodiversity in farmland.

Therein, farmland bird abundance was related to agricultural land use using a joint species distribution model (JSDM) (Ovaskainen et al., 2010; Pollock et al., 2014). The JSDM is a generalized linear mixed model (GLMM) which jointly models the relationship between abundance and a set of agricultural land use variables for all species simultaneously while also taking residual associations between species abundances into account through the modelling of a residual variance-covariance between species. Agricultural land use was modelled by a set of predictors believed to reflect the major changes in agricultural management that have taken place in recent decades and which in turn should influence farmland birds.

Biodiversity predictors

The predictors used in the model were calculated from the IACS crop categories according to the following:

Proportion extensive crops (PE): This predictor is intended to measure the effect of temporally intermixing intensive crop production, characterized by large amounts of inputs and regular disturbance (annual tilling), with more extensive management and is measured by the proportion of ley and fallow on all tillable fields in the landscape. Ley is here defined as grass grown on arable fields and used for fodder production (hay or silage) and/or grazing.

Proportion high quality extensive crops (EQ): The extensive land uses described above may be of different quality for farmland birds. In particular, leys can be managed with varying intensity from highly intensive fodder production with substantial fertilizer input and frequent mowing, to extensive leys only kept for grazing and with minimal inputs. The latter are often characterized by a more diverse grass flora and in the extreme may even resemble semi-natural pastures. These, as well as fallows may therefore provide better habitat for birds than more intensive leys and this was reflected in a predictor calculated as the proportion of fallow and low intensive ley among all ley and fallow.

Crop diversity (CD): Different crops grown on arable fields may provide complementary resources in terms of food and nesting habitats for many farmland birds. Crops differ in both

sward density and structure which will influence availability of insect prey and seeds. Some species prefer to nest on bare ground while others nest in denser vegetation. Hence, a larger diversity of crops on a landscape scale may benefit farmland birds as well as plant and animal biodiversity in general. This is also reflected in that one of the greening requirements is to maintain a minimum level of crop diversity at the farm level. Crops from IACS were divided into 13 groups reflecting both their temporal and structural characteristics (i.e. spring-sown cereals, autumn-sown cereals, spring-sown oilseed rape, autumn-sown oilseed rape, vegetables, potatoes, sugar beets, maize, ley, seed ley, energy crops, flowering crops and fallow). The proportions of each of these groups grown in the landscape were used to calculate the Shannon diversity index (SDI). This index is commonly used to characterize diversity and accounts for both richness (in this case the number of different land uses) and evenness (uniformity of the distribution of the area of different uses) of a set (Olson and Francis, 1995). Shannon diversity was used as a predictor instead of the number of crop groups to also reflect the importance of a more even distribution of crops.

Proportion spring-sown crops (PSS): The timing of sowing will influence how crops are perceived by farmland birds. Spring- and autumn-sown crops differ in several ways as habitat for farmland birds. Timing of cultivation, sward development, and harvest, as well as the presence of stubble are all characteristics that differ between the two sowing regimes and should potentially affect birds. This predictor was calculated as the proportion of spring-sown cereals and oil-seed rape over the sum of all cereals and oil-seed rape in the landscape.

Farmland area (FA): This predictor (measured in hectares) was included as a covariate in the model to control for the fact that farmland birds by definition are strongly dependent on farmland and that study landscapes varied quite considerably in the amount of farmland available.

Landscape heterogeneity index (LHI): One aim of the study from which the statistical model was taken (Stjernman et al., 2019) was to analyse whether the effects of land use were dependent on landscape heterogeneity under the idea that the value of aspects of land management within arable fields vary depending on the availability of (semi-) natural habitats in their surroundings. Landscape heterogeneity was measured by the proportion of semi-natural pastures and field borders within the landscape. The amount of pastures and field borders in study landscapes were used to calculate LHI on the scale of the assessment landscapes.

All predictors were included as main effects in the model together with all two way interactions between LHI and the predictors proportion extensive crops, proportion high quality extensive crops, crop diversity, and proportion spring-sown crops yielding in total 11 fixed effect parameters for each of the 15 species in the model:

$$\log_e Abund = \beta_0 + \beta_1 FA + \beta_2 LHI + \beta_3 PE + \beta_4 EQ + \beta_5 CD + \beta_6 PSS + \beta_7 LHI \times PE + \beta_8 LHI \times EQ + \beta_9 LHI \times CD + \beta_{10} LHI \times PSS$$

In addition, repeated visits to the same landscape were handled by including landscape as a random effect and variation between observers by including observer as a random effect. Abundance was modelled as a negative binomial response variable (log-link, hence the \log_e Abundance in the equation above).

Estimating model parameters

The parameters (land use dependence for the 15 species, 11x15 matrix *Beta* (table S6), and residual variance covariance, 15x15 matrix *Sigma*) of the statistical model were estimated using bird survey data collected in 33 1-km-radius landscapes in GMB and GSS in 2011. In this survey, landscapes were visited twice and at each visit birds were counted for 5 min at 16 points distributed in a 4 by 4 grid (on average 400 m between points) centred in the middle of the landscape (see Stjernman et al. (2019) for details).

The model was fitted to data using the program Stan through R (Stan Development Team, 2016). We used flat normal priors for *Beta*, flat Cauchy priors for random effect variances and a flat inverse-Wishart (IW) prior for *Sigma*. The effect of choice of prior for *Sigma* were evaluated in (Stjernman et al., 2019) and effects on parameters were small to moderate. The IW prior generated slightly more extreme estimates and we chose to use this prior here to maximize predicted effects on biodiversity under the different scenarios.

Table S6. Estimates of beta parameters of the biodiversity production function. Shown is the mean of the posterior distribution for each parameter

	β_0	β_1	β_2	β_3	β_4	β_5	β_6	β_7	β_8	β_9	β_{10}
Whinchat	-3.514	0.156	0.637	0.037	-0.049	0.005	0.288	-0.174	-0.102	-0.051	-0.060
Yellowhammer	-1.789	0.198	0.500	0.020	-0.038	-0.270	0.285	-0.205	-0.084	0.125	-0.023
Yellow wagtail	-2.576	-0.074	0.191	0.108	-0.026	0.050	0.303	-0.281	-0.068	0.365	-0.005
Linnet	-1.600	0.047	0.146	0.088	-0.034	-0.102	0.308	-0.233	-0.075	0.166	0.038
Barn swallow	-0.979	0.106	0.315	0.118	-0.042	0.130	0.305	-0.103	-0.107	0.050	-0.026
Tree sparrow	-0.330	0.004	-0.070	0.117	-0.047	-0.018	0.332	-0.158	-0.110	-0.170	-0.097
Rook	-0.640	0.037	0.076	0.186	-0.046	0.370	0.301	-0.239	-0.056	-0.134	-0.075
Starling	-0.793	0.143	0.391	0.064	-0.100	0.143	0.268	-0.235	-0.102	0.024	-0.025
Skylark	0.115	-0.026	-0.123	0.013	-0.024	0.122	0.323	-0.181	-0.070	-0.234	0.028
Curlew	-4.595	0.096	0.133	0.087	-0.064	0.124	0.319	-0.250	-0.062	0.078	-0.062
Wheatear	-3.913	0.119	0.266	0.077	-0.084	0.010	0.326	-0.223	-0.071	-0.108	-0.036
Red-backed shrike	-5.098	0.197	0.353	0.091	-0.043	0.040	0.308	-0.210	-0.062	-0.058	-0.038
Lapwing	-2.046	0.089	0.318	0.070	-0.005	0.223	0.334	-0.192	-0.051	-0.256	-0.006
Greater whitethroat	-0.539	0.169	0.091	-0.101	0.000	-0.088	0.288	-0.162	-0.063	0.068	0.029
Meadow pipit	-4.220	0.081	-0.006	0.201	0.031	0.381	0.318	-0.251	-0.052	-0.051	0.064

Predicting bird abundances in assessment landscapes

Bird abundances (on the log-scale) were predicted for each species in the assessment landscapes under all scenarios using the estimated parameters from the JDSM. In particular, we predicted log abundance by applying *Beta* to the downscaled land use in each landscape for each scenario. Residual associations between species were included by simulating final

log abundance from a multivariate normal distribution with the calculated log abundance as the mean and *Sigma* as variance-covariance. The biodiversity index was then calculated as the mean log abundance over the 15 farmland-bird species.

Ecological modelling: biological control

The biological control production function uses the landscape composition in circular buffers surrounding cereal fields to predict the abundance of predators, their effects on aphid population development, and potential crop damage in the focal field. The model was parametrized for spring barley and the aphid *Rhopalosiphum padi* for Swedish conditions, and assumes a high and constant initial pest pressure (number of initial aphid colonizers) in each field based on numbers published in Östman et al. (2003). In this model, biological control potential is positively associated with the proportion of non-cropped area and pasture at various distances from cereal fields (Jonsson et al., 2014). In terms of EFAs, we assume that fallows are perennial and contribute to the proportion of non-cropped area, whereas field margins are assumed to be annually tilled and occupy a small area, thus we did not include these in the proportion of non-cropped area when deriving the landscape variables. The area of cereals in each landscape was used to study changes in the demand for biological control services. The biological control indicator (*B*) used in the analyses is the predicted proportional reduction in crop damage compared to the value expected in the absence of aphid mortality due to natural enemies:

$$B = \frac{1 - ((1 - \mu_c) \times \exp^{rT} \times r^{-1})^{0.66}}{\left(\frac{\exp^{fT}}{f}\right)^{0.66}}$$

where μ_c is the mortality rate due to predation after the colonization phase, f is aphid fecundity (maximum reproductive rate under no predation), r is the population growth rate (fecundity minus mortality due to predation in that phase) and T the number of days for the exponential growth phase (set to be 14 days). Prior to analysis, this variable was transformed ($x^{2.4}$) to satisfy model residual distributional assumptions, and then z -transformed.

Ecological modelling: pollination

Pollination is an essential ecosystem service that contributes to more than one third of global food production through animal-mediated (insects, birds and mammals) pollination (Klein et al., 2007). Each of the land-use classes in the rasters was assigned a floral quality (Q) on a scale from 0 to 20, and a floral cover (C) between 0 and 1, by expert judgment, and also assigned a nesting quality index (Olsson et al., 2015). We assumed that the pollinators' energy intake rate (A) while foraging in a patch i (map pixel) was linearly related to quality but by a decelerating function to cover: $A_i = 0.65 Q_i C_i^{0.4}$.

Intake rate in a patch will together with the distance between the nest and the patch, τ_i , determine the fitness related value for the pollinators of visiting a patch (D) as:

$$D_i = \tau^* + \frac{\omega}{A_i} - \tau_i,$$

where τ^* is the farthest distance the pollinators would fly to a patch of infinite quality, and ω is a coefficient (<0) which describes the trade-off between distance and patch quality (Olsson and Bolin, 2014; Olsson et al., 2015). These parameters are mainly different between species, but will also vary between rich and poor environments. As shown by Olsson et al. (2015) expected visitation rate of pollinators (V) in a pixel is then proportional to:

$$V_i = \sum_{j=1}^n \left[N_j \left(D_{i,j} - \frac{kT}{M_j} \right) \right],$$

where N_j is an indicator variable, which is 1 if the pixel j is a suitable nest site and 0 otherwise, n is the number of potential nesting pixels surrounding the foraging pixel i , $-kT$ is the fitness overhead cost of not foraging and M_j is the number of foraging pixels visited by workers from nest j . Pollination service was assumed to be proportional to pollinator visitation rate.

These variables were $\log_e(x+1)$, and then z -transformed prior to analysis.

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