Exploring alternative agri-environmental payment schemes for arable land in Scotland

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Summary

We investigate the opportunity to account for both Ecosystem Services (ESS) provision and farmers' opportunity cost to identify target areas for Agri-environmental Schemes, where cost-effectiveness of interventions could be high.

For this we use data on ESS provision for nitrogen retention, soil retention, soil carbon storage, species richness and pollination, as well as data on rotations in place between 2003 and 2007 on more than 90,000 fields in Southeast Scotland. Each land use within a rotation was associated with gross margins values which supported the estimation of the reduction in gross margins (opportunity costs) related to the adoption of agri-environmental measures.

We investigate 3 potential measures: widened field margins, deintensification and integrated farming.

We estimate the opportunity cost of adoption of these 3 measures and simulate the likely adoption patterns at the national scale under different payment scenarios.

We find that wider field margins would most likely be adopted on the most extensive rotations, but that by excluding the most extensive rotations, the fields that would be enrolled are less likely to be those used to grow potatoes and tend to be located in areas with lower soil and nitrogen retention and higher pollination and species richness. The number of fields eligible for the hypothetical deintensification measure is far lower. We see that when the range of variation of opportunity costs of adopting a measure is large, such as for deintensification, flat rate payments set to the average or median opportunity costs of the population are likely to over-compensate farmers beyond their actual opportunity costs. Fields most likely to be enrolled in an integrated farming measure are located in areas with similar characteristics in terms of ESS as in the case of wider field margins. An integrated farming measure yields higher opportunity cost per hectare of field enrolled than other measures (at least within the first rotation of a transition toward integrated farming), making this measure more appropriate for a deep and narrow approach to AECS.

Our results should be interpreted taking into account the limitations of the approach listed in the discussion section.

Without clear clusters of low opportunity costs and high ESS provision, approaches that can lead to a selection of fields enrolled taking into account both the opportunity costs but also the benefits of participation should be investigated, such as result-based schemes and auction mechanisms.

Contents

1. Introduction

It has been proven by many studies that agricultural intensification is clearly connected to the decrease of on-farm biodiversity. There is no doubt that this finding is true for Scotland too. In the literature, two broad approaches responding to this issue might be identified. First approach is land sparing (setting land aside from agricultural use for conservation), another one is land sharing (that "*aims to make existing farmland as hospitable to wild species as possible, by reducing inputs of pesticides and fertilizers and retaining on-farm habitat elements*") (Balmford, Green and Phalan, 2012).

Both approaches are formulated the Scottish Rural Development Programme (SRDP), which operates as a key incentive for economic, environmental and social measures for the benefit of rural Scotland, Agri-Environment Climate Schemes (AECS) being the main schemes targeting environmental protection on agricultural land (Scottish Government, 2017a, 2017b, 2021). AECS include several management options to protect biodiversity in agroecosystems. Examples include payments for the creation of Unharvested Conservation Headlands for Wildlife, Wild Bird Seed for Farmland Birds, and Grass Strips in Arable Fields (Scottish Government, 2017).

We see clear opportunity in further refining the design of Agri-Environment Climate Schemes (AECS) to enhance the provision of Ecosystem Services (ES) by Scottish agriculture. Previous work has helped identify areas with best potential for the provision of ES (e.g. Gimona and van der Horst, 2007, Chan et al., 2006, Crossman et al., 2010, Stallman, 2011, Verhagen et al., 2016). In order to achieve a social optimum in terms of ES provision, not only ES provision target should be achieved through AECSs (effectiveness of the scheme), but these targets should be achieved at the lowest cost for society (cost-effectiveness of the scheme). This is particularly important as AECS rely on public funding, which should be used in such a way that each £ spent in the AECS should provide as much ES as possible. Therefore, we build on previous work on AECS targeting to include an estimate of the opportunity cost of farmers' adoption of AECS measures that could improve the provision of ES.

In addition, AECS relying on voluntary participation of farmers, the spatial distribution of uptake depends on farmers' decision to join the scheme or not. This has been shown to potentially lead to an adverse selection of farmers if farmers only consider their costs as a basis for self-selection (Fraser, 2009, Quillérou, 2010), leading to participation where opportunity costs are low, but not necessarily where the potential provision of ES is highest. We therefore aim to identify areas of high Benefit / Cost ratios, where potentially the cost effectiveness of schemes would be maximized. We then simulate different payment levels for alternative AECS measures and investigate how varying payment levels affect potential participation of farmers, based on the assumption that farmers will join a scheme if and only if the payment offered if larger that their opportunity cost.

We focus on measures that target arable land to improve the provision of ES. We look in particular at 3 measures which could improve the provision of ES: increased width of field margins, deintensification measures and integrated farming options.

Agricultural systems are generally managed to maximize the potential delivery of provisioning ecosystem services. There is no doubt that this has often been at the expense of other ecosystem services (Bert et al., 2017). If we consider fields of arable land not as homogenous units but rather as site-specific and heterogenous pieces of land, then due to the occurrence of diverse natural characteristics, individual parts of fields can provide various types of ecosystem services. Specifically, field margins in agricultural systems have a clear potential for enhanced provision of ecosystem services due to their proximity to semi-natural and natural habitats (Holland et al., 2016). Field margins are generally considered as target areas for enhancing farm biodiversity. A rich set of studies revealed the importance of field margins and non-crop vegetation around arable fields for increased ecosystem biodiversity (Mkenda et al., 2019). Ecosystem services evolving in field margins include natural pest regulation, pollination, nitrogen retention and cycling, reduced offsite erosion and a more climate-positive soil carbon economy. Field margins are therefore considered multifunctional parts of the ecosystem of arable land.

It seems that tackling the loss of on-farm biodiversity tends to be more advanced if a land sharing approach is also materialized. This is especially important as the approach involves the reduction in the use of pesticide and fertilizer inputs. In a metanalysis, Batary et al. (2011) find that species richness and pollinators are most improved in cropland through AES in simpler landscapes. Storkey and Westbury (2007) claim in their study that a whole-field or in-crop approach to protecting biodiversity via agricultural **deintensification** can make on-farm habitat more hospitable to numerous wild species. We can indeed say that plenty of studies stress inverse relationships between fertilizer and herbicide application and arable weed diversity and abundance. In other words, agricultural intensification clearly affects the level of biodiversity (please see e.g., Kleijn and van der Voort, 1997; Squire, Rodger and Wright, 2000; Kleijn and Sutherland, 2003; Kleijn et al., 2009). We are well aware of the positive relation between de-intensification and an increased level of ecosystem services. For example, seeding of the mixtures of specific plant species as a part of agricultural deintensification can especially promote soil-based functions of carbon and nitrogen accumulation. Moreover, the increase in plant diversity has cascading effects on the diversity of organisms in higher trophic levels, including those that provide regulating services such as biological pest control (predators and parasitoids) and pollination (Scherber et al., 2010).

Our main objectives are therefore, for the 3 measures mentioned above, to:

1- Identify hot spots that combine high potential for ES provision and low costs for farmers
2- Simulate likely participation of farmers under alternative payment strategies

2. Methods and data

a. Overview of the approach and data needs

In order to estimate both the potential benefits and costs of alternative measures, we collated data that enabled us to obtain:

- Estimated **opportunity costs of adopting the 3 above-mentioned alternative agri-environmental measures**: for this we worked at the field level and collated data on the rotations in place in a large sample of arable fields in Scotland. From the crops present in the rotations, we were able to derive the current gross margins a farmer would get under conventional practices and use these values as baseline. We then estimate the gross margins at the field level if each of the 3 measures was to be adopted. The opportunity cost of adopting each measure is then derived as the difference between the baseline gross margins and the gross margins under the measures. The sources of data used for the rotations and gross margins are described in the next section.
- In order to characterise the **environmental potential of the different measures**, we allocate to each field the current level of Ecosystem Services (ESS) provision for 5 key ESS: supporting biodiversity (using species richness as a proxy), soil retention, soil carbon, pollination and nitrogen retention. We describe in the next section the ESS data we used.

b. Field rotations data and estimation of opportunity costs

i. Data sources

Field-Level Rotations and Inputs

The field-level rotations associated intensity levels used in the analysis are based on data collated by the Agroecology Group of the James Hutton Institute. The geo-referenced data includes crop rotations and input levels for 95,847 agricultural fields (684,725 ha total) in eastern Scotland from 2003 to 2007 (Squire, Quesada and Begg, unpublished). Each field's crop rotation over the period of five years was gathered from Integrated Administration and Control System of the European Union (European Commission, 2017). Altogether, it considers 21 land use types (see Table 3). The rotations were then categorized in 32 intensity levels from 1 the most intensive rotation to 32 the least intensive. Fields not fitting any of the 32 rotation categories were dropped and the rest of the analysis presented here is based on 90,884 fields representing 620,052 hectares of arable land.

Gross Margins

To estimate the cost to farmers of alternative agri-environmental measures, baseline gross margins were estimated (in 2021 British pounds per hectare) for the 21 land use types considered, assuming conventional agricultural practices. From these estimated gross margins, five-year average gross margins were calculated for the 32 rotation types developed by Squire, Quesada, and Begg. Each field in the sample was assigned an average gross margin according to its rotation type. Gross margins were derived from the following sources. The editions of the Farm Management Handbook (FMH) covering the period from 2017-18 to 2021-22 provide the information about average gross margins based on prices for Scottish production of winter wheat, spring wheat, winter oats, spring oats, winter barley, spring barley, winter oilseed rape, potatoes, and beans and peas for both animal and human consumption. Set aside gross margins are derived from Eurostat data from 2004 on fallow land, while vegetables gross margins are sourced from the Center for Alternative Land Use (CALU) technical notes (CALU 2005).

In field margins, the low values of the FMH were used to account for lower productivity in the field margins. The average loss of productivity over the crops available in the FMH was also applied for other crops (reduction by 46.7% of gross margins).

Gross margins associated with integrated farming systems were collated from the results of the Hutton Center for Sustainable Cropping (CSC) trials (Roberts, Hawes et al., forthcoming), including output value, fertilizer, compost and pesticides costs. They are presented in Table 1. Only a subset of land uses is covered by the CSC data (Winter wheat, winter barley, potatoes, spring barley, beans and winter oilseed rape) so all gross margins for other land uses are assumed to remain constant in integrated farming measures scenarios. In the CSC trial, the same crops were produced under conventional and integrated practices for comparability. We use the CSC gross margins under conventional practices as the baseline gross margin values in the scenarios looking at integrated farming, for consistency with the values of gross margins used for the integrated farming scenario.

All gross margins values are expressed in 2021 GBP (£) using the Agricultural Price Index (API) from DEFRA.

Table 1: Gross margin values for a conventional and an integrated system, from the CSC trial

	GM (£/ha) from CSC trial conventional	GM (£/ha) from CSC trial integrated
Winter wheat	1,226	670
Potato	8,753	7,933
Beans	1,069	838
Spring Barley	1,026	375
Winter Barley	1,346	575
Winter oilseed rape	827	148

Note that the gross margins are considered as fixed for a given land use, not reflecting potential variations in gross margins at the fields level due to the field's characteristics, its location and any specific management practices that could introduce variations in the gross margins obtained around the average values we use.

ii. Descriptive statistics

We work on 90,884 fields, each associated to a rotation, and the corresponding rotation intensity from 1 to 32, 1 being the most intensive rotation (monoculture of Winter Wheat), while 32 is the least intensive rotation. Appendix 1 presents a description of each of the rotation intensity used in the analysis. The average acreage of the fields is 6.82 hectares (standard deviation 6.27 hectares), with fields up to 241 hectares.

A gross margin (in £/ha) was associated to each land use in each rotation, and the average gross margin value over the 5 years of the rotation was associated to each field according to the rotation in place between 2003 and 2007. Table 2 shows the mean and total acreage per rotation type and the associated gross margins. The variable "potato" indicates the presence of potato growing with at least 1 occurrence during the rotation.

Table 2: Gross margins and field acreage per rotation type, ordered from Most intensive (1) to least intensive (32)

Rotation Intensity	Potato	Nb of fields	Mean area (ha)	Total acreage (ha)	Mean GM (£/ha/year)	Mean GM in field margins (£/ha/year)
1	0	259	11.70	3,030.65	1110.83	707.68
2	0	22	14.22	312.94	1077.95	699.12
3	0	67	17.12	1,146.83	1112.06	711.98
4	1	94	12.12	1,138.95	2013.85	1276.68
5	0	314	12.48	3,917.20	1041.49	666.73
6	0	21	12.51	262.74	1045.07	690.57
7	0	23	12.06	277.46	1113.28	716.29

Rotation Intensity	Potato	Nb of fields	Mean area (ha)	Total acreage (ha)	Mean GM (£/ha/year)	Mean GM in field margins (£/ha/year)
8	0	189	11.16	2,109.13	1079.18	703.43
9	1	16	12.93	206.81	1980.97	1268.13
10	1	87	12.44	1,081.93	2015.08	1280.99
11	1	235	11.41	2,682.45	2072.42	1311.71
12	0	461	12.68	5,846.86	993.18	643.66
13	0	708	11.61	8,220.65	976.48	621.18
14	0	23	9.60	220.90	1012.19	682.01
15	0	4	10.82	43.28	1114.51	720.60
16	0	248	11.60	2,875.92	1046.30	694.87
17	0	230	10.26	2,360.55	1080.40	707.73
18	1	210	11.20	2,352.89	1982.20	1272.43
19	1	24	9.17	220.08	1948.09	1259.57
20	1	22	12.60	277.10	2016.30	1285.29
21	1	1,262	11.32	14,287.49	1973.57	1247.93
22	0	4,097	10.66	43,676.31	917.87	589.74
23	1	123	11.54	1,419.40	1950.15	1264.19
24	1	941	10.55	9,927.58	1870.97	1187.31
25	1	1,381	9.46	13,068.95	1871.80	1174.79
26	0	527	10.76	5,672.18	1032.06	693.35
27	0	6,844	9.72	66,522.47	812.51	522.79
28	1	518	10.24	5,305.93	1800.99	1146.65
29	1	2,162	8.01	17,312.22	1703.68	1068.33
30	0	566	10.20	5,771.57	987.41	680.35
31	0	3,958	8.65	34,237.32	757.51	502.63
32	0	65,248	5.58	364,265.65	304.80	231.22
ALL		90,884	6.82	620,052.38	539.62	322.89

Note that more than two thirds of the fields are under the most extensive rotation from the typology (rotation number 32), which is a combination of grassland and set aside, rough grazing, with occasional spring cereals, vegetables, winter oat or beans or peas, but not potatoes or other winter cereals than oat grown.

Table 3 presents the relative importance of each of the land uses over the 90,884 fields included in the analysis.

Table 3: Importance of each land use and associated gross margins (baseline conventional system)

Land Use	Total area (ha)	Mean field area (ha)	SD field area (ha)	Number of occurrences over 5 years	Associated Gross Margin Baseline (£/ha/year)
Winter Wheat	332,521	10.88	7.29	30,559	1,111
Potato	69,356	9.80	6.13	7,080	5,626
Beans - Animal feed	14,197	10.55	6.77	1,346	249
Beans - Human consumption	1,324	9.26	4.46	143	784
Grass under 5 years	625,823	5.02	7.13	124,634	149
Grass over 5 years	773,716	5.52	4.00	140,281	149
Kale Cabbage - Animal feed	2,389	6.47	4.09	369	3,167

Land Use	Total area (ha)	Mean field area (ha)	SD field area (ha)	Number of occurrences over 5 years	Associated Gross Margin Baseline (£/ha/year)
Peas - Animal Feed	5,995	8.25	5.26	727	283
Peas - Human consumption	7,316	10.05	6.08	728	628
Rough grazing	1,533	20.17	27.14	76	-
Spring Barley	779,401	8.14	5.78	95,793	683
Spring Oats	36,132	7.19	5.30	5,028	688
Spring Wheat	13,095	10.30	7.34	1,271	978
Set aside - Oilseed rape	12,435	11.29	6.60	1,101	298
Set aside - Other	72,752	7.95	6.02	9,151	298
Turnips and Swedes - animal feed	18,220	5.50	3.33	3,314	4,823
Turnips and Swedes - human consumption	3,868	10.23	6.24	378	4,823
Vegetable	14,869	9.95	6.90	1,494	4,823
Winter Barley	171,886	9.84	6.72	17,466	946
Winter Oat	19,298	9.90	6.36	1,949	1,052
Winter Oilseed rape	124,136	10.76	7.24	11,532	1,117
Total	3,100,262			454,420	

c. Ecosystem Services data

Ecosystem services (ESS) data used in this project comes from previous research (Gimona et al., (in press); Pakeman & McKeen, 2019). They include soil retention, nitrogen retention, pollination, and carbon storage. We briefly describe the methodology, however for more information refer to Gimona et al., (in press) and Pakeman & McKeen, 2019.

To map soils retention, Gimona et al., (in press), used the InVest sediment retention model (Natural Capital Project undated a) which integrates information on vegetation cover, soil properties, topography, rainfall and climate data to estimate soil erosion from grid cell. Model outputs depend on soil properties, the terrain model and land cover precipitation.

Nitrogen loss and retention maps used the nitrogen retention InVest model (Natural Capital Project undated b) which calculates long-term flow of nutrients assuming a steady state. It uses the amount of nitrogen loaded on each land use type and its retention properties, calculates the annual average water runoff and computes the quantity of nitrogen retained and exported.

Soils Carbon Stocks uses estimates of soil carbon stocks (ton/ha) to 1 m of depth (Poggio and Gimona, 2014). The estimates are based on a spatial model MODIS. Vegetation carbon stocks was not calculated because in Scotland, for croplands and grasslands, these are a relatively minor component compared to the carbon in soil.

To map pollinators an index was used based on 6 species of bumble bee, *namely Bombus lapidarius, B. lucorum, B. muscorum, B. pascuorum, B. pratorum* and *B. terrestris* and for each specie there were 4 main components of floral resources, nesting habitat, spatial (to account for flight distance) and time (to account for flowering of floral resources and queen emergence).

Ecosystem services modelled data were rescaled between 0 and 1, with 1 indicating maximum service or maximum species richness.

All ESS indicators are based on landscape scale modelling that do not account for the heterogeneity of field level management practices (e.g. field margins management, actual use of inputs for a specific field) but are derived from standard input levels. They provide useful information on the type of landscape in which the fields considered is located.

Table 4 presents descriptive statistics of the ESS indicators used:

Table 4: descriptive statistics of Ecosystem Services Indicators data

ESS	N	Mean	St. Dev.	Min	Max
Nitrogen Retention	90,884	0.455	0.396	0	1
Pollination	90,884	0.007	0.016	0	0.652
Soil carbon	90,884	0.107	0.104	0	0.585
Soil retention	90,884	0.027	0.060	0	0.753
Species richness	90,884	15.87	11.70	0	50

Biodiversity

The Botanical Society of Britain & Ireland maintains a database of plant species occurrence records throughout the UK and Ireland (2016). In the present case study, the number of rare arable plant species observed per hectare in eastern Scotland from 2000 to 2009 serves as an indicator of biodiversity and is referred to as species richness in the rest of the document. The hectare within which the largest proportion of each agricultural field fell determined the value of species richness assigned to that field. Summary statistics of species richness are presented in Table 4.

d. Scenarios of adoption of the three AECS measures considered

i. Which agri-environmental measures are we looking at?

We consider the following 3 measures:

- **Increased field margins width** from 1 meter to 3 meters. Buffers around the fields were created on a GIS software to estimate the loss of cultivable land from increasing field margins from the assumed current field margins (1m wide) to 3-meter-wide field margins. The reduction in total gross margins at the field level associated with the reduced cultivable area of the field represents the opportunity cost of farmers who would adopt this measure.
- **De-intensification (or rotation diversification):** all fields with rotation intensity higher than that of rotation 21 (22 for fields where no potatoes are included in the rotation), i.e. rotation types with identifiers lower than 21 (22), would have to switch to rotation 21 (22 if not currently growing potatoes) under a deintensification measure. We choose rotation 21 / 22 as an appropriate compromise to balance food production and farm profitability with ecological objectives. The average 5 years gross margins associated to rotations 21 and 22 are considered to be the new gross margins farmers would get, would they decide to participate in a measure of deintensification. Farmers' opportunity costs of participation are therefore calculated as the difference between the baseline average gross margins associate with the current rotation in place and the new average gross margins, post de-intensification, i.e. the gross margins or rotations 21 or 22. Fields where rotations 21 and 22 are already implemented are assumed to remain in that rotation type. Therefore, the deintensification opportunity cost only assumes a change in rotations (increased rotation diversity), and no change in field management practices, i.e. the same level of input used is assumed for a given land use, hence the same gross margin per land use is kept.
- **Integrated farming (diversification and chemical inputs reduction):** for farmers to adopt an integrated farming system, the first step would be for them to diversify their rotation if their current rotation is classified as intensive. We therefore assume that fields with a rotation intensity higher than rotation type 21 (with potatoes) or 22 (without potatoes), would not only reduce their inputs use as required under an integrated farming system, but also diversify their rotations to include 1 spring cereal and 1 legume (beans). In addition, farmers would reduce their reliance on chemical inputs (fertilizers and pesticides), adapting their field management practices. This would therefore change the gross margins associated with each land use. Therefore, in the scenario in which farmers would adopt integrated farming approaches, we associate for all rotation types, integrated farming gross margins values to each land use to reflect the change in practices. To summarize, the scenario of integrated farming makes 2 assumptions: a diversification of rotations for the most intensive rotation type AND a change

in practices, and therefore gross margins, associated with all land uses for all rotation types. The difference between current average gross margins, and the gross margins obtained after these two changes represent farmers' opportunity costs of adoption an integrated farming system.

ii. What scenarios of adoption of these measures?

Identification of hot spots of high benefit – Cost ratio

A first scenario would be to look at the total opportunity costs of all farmers adopting each of the 3 measures described above. This enables us to identify areas where opportunity costs of the adoption of such measures would be low. Since we also have values of the local landcape's ES provisions for each field, we are able to generate a benefit / cost ratio for each field by dividing the total sum of the ES indicators (soil retention, soil carbon, pollination and nitrogen retention) by the opportunity cost of adopting the measure. Mapping the weighted average of this B/C ratio for a 100 m x 100 m square grid across Scotland, helps identify potential hot spots where ES have the potential to be high, while the cost of such preservation is low (high B/C ratio).

We also estimate and map the opportunity costs of adopting each measure for the lowest 25 percentile of ES to help target areas, i.e. where the most environmental improvement is required, to help identify where this could be achieved at the lowest cost. Similarly, we estimate and map the opportunity cost of adopting the different measures for the top 25 percentile of ESS provision, to identify areas where conservation of these potentially highly productive (in terms of ESS) land can be achieved at the lowest cost if targeting these areas.

Expected participation under alternative payment levels

However, these measures being associated with a private cost to farmers, under the assumption that farmers are profit maximiser, no farmers would adopt such measures, unless being compensated for their costs. We then also work on scenarios in which farmers would receive a payment, in the form of an agri-environmental scheme, that would compensate the cost of adopting each of these measures. We use different levels of payments and estimate the share of fields that would be enrolled in each measure, assuming that a farmer would enrol a field in such a scheme if the payment offered is strictly higher that the opportunity cost of adopting the measure.

We simulate 2 different payment levels:

- Average opportunity costs of farmers as flat rate payment
- Median opportunity costs as flat rate payment

In the case of increased width of field margins, we also use the current AECS payment levels as a third scenario.

3. Results

a. Relationship between current farming intensity and provision of Ecosystem Services on arable land

We start by analysing the relationship between the 2003-2007 rotation intensity and current levels of Ecosystem Services provision. We report results of correlation test that are significant at the 0.05 threshold. Note that no causality can be inferred form the results of these correlation tests. We analyse separately fields under rotation 32 (most extensive). For other fields, we find that:

- Fields that are under more intensive rotation types tend to be larger in size
- Higher rotation intensity (the closer to rotation type 1) are associated with areas that display higher **Nitrogen Retention scores**. Potatoes being part of the rotation is also positively correlated with a higher **nitrogen retention** score. This is most likely because land located in areas that have higher potential for nitrogen retention is being selected by farmers for more intensive rotations and to grow potatoes, and because the crops in place retain a good proportion of inputs.
- **Soil carbon** scores are not correlated with rotation type, but are higher in areas where fields are used to grow potatoes, as well as in areas with larger fields.

- **Soil retention** is not correlated with the intensity of the rotation type in place either. However, the presence of potato in the rotation is associated with areas that display higher scores in soil retention, while larger fields tend to be located in areas with higher soils retention scores.
- **Pollination** is not significantly correlated with the intensity of the rotation in place between 2003 and 2007. However, the presence of potatoes in the rotation in place between 2003 and 2007 is significantly and negatively correlated with current levels of pollination ESS provision in the areas. Larger fields also tend to be located in areas with higher levels of pollination provision.
- **Species richness** correlates negatively with the presence of potatoes in the rotation but positively with the rotation intensity.

Looking at rotation 32 individually (and compared to all other rotations put together) we find that fields under this rotation is mostly located in areas where:

- **Nitrogen retention** is significantly lower, most likely because of low input needs for the land uses in rotation 32
- **Pollination** is significantly higher, most likely because land uses under rotations 32 are more extensive
- **Soil carbon** is significantly lower
- **Soil retention** is significantly lower
- **Species richness** is significantly lower

These results can be interpreted as rotation 32 being more likely to be adopted in areas where land is of lower agricultural quality.

This reflects underlying patterns in larger regional / geographical pattern of repartition of farming systems, with more intensive land use in the South and lowlands, where fields are larger and have higher soil carbon content, soil retention and nitrogen retention capacity as predicted by the models of ESS provision.

b. Scenarios of payments for increased field margins width

i. Hot spots of potential high benefit – cost ratio

Opportunity costs of wider field margins

Table 5 presents the opportunity costs (£/ha of field margin) of increasing field margins from 1m to 3-meter width, when considering all fields, and then 3 subsets of fields: (i) all fields but those under rotation type 32, i.e. excluding the most extensive fields, (ii) only fields where the sum of ESS scores is within the 25 highest percentile, and (iii) only fields where the sum of ESS scores is within the 25 lowest percentile.

Table 5: Opportunity costs (mean, standard deviation, median and total) associated with the adoption of wider field margins

	n	Mean	Standard deviation	Median	Total opportunity costs assuming 100% adoption
Opportunity cost (all rotation)	90,870 [1]	371.8	322.9	200.0	£ 33,785,466
Opportunity cost (excluding rotation 32)	25,634	729.6	325.4	616.3	£ 18,702,566
Opportunity costs when targeting fields within 25 percentiles of lowest ESS score	38,827	251.19	235.48	149	£ 9,752,954
Opportunity costs when targeting fields within 25 percentiles of highest ESS score	22,721	462.41	365.41	373.86	£ 10,506,418

[1] Note: (14 fields are too small to increase margins' width)

Note that the current payment offered for grass strips or water margins in arable fields is £495.62 per hectare and per year.

Table 5 shows that the mean opportunity cost per hectare of field margins is of £371.8, but this is being pulled down by the fields under the most extensive rotation type (rotation 32) and is estimated to be of £729.6 / ha of field margin when rotation 32 is excluded. The current payment offered to farmers her hectare of field margins is situated between both values.

We also see from Table 5 that targeting areas for the maintenance of ES provision (areas within the top 25th percentile of total ESS provision) or targeting areas for the enhancement of ES provision (areas within the lowest 25th percentile of total ESS provision), leads to a similar level of total opportunity costs, but with a significantly larger number of fields included in the latest target.

What is the geographical distribution of the potential Benefit/Cost ratio?

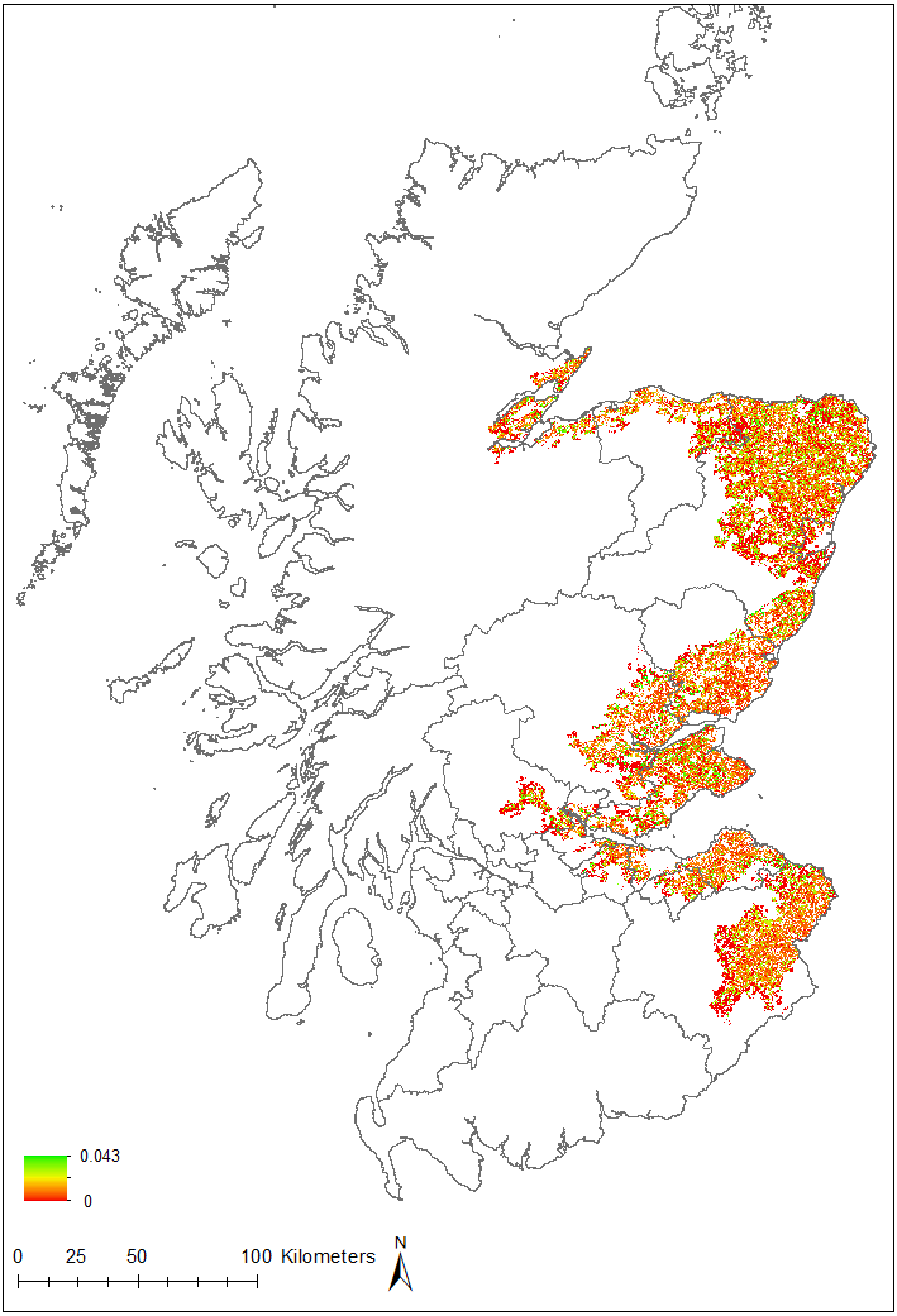

Figure 1: Map of potential benefit / cost ratio of increased field margins width, on a 100 m x 100 m grid

Figure 1 shows the geographical distribution of the ratio: sum of ESS / opportunity costs. It appears that areas with low costs and high potential ESS provision (in green on the map) seem to be scattered across all arable land in Scotland.

We then focus on identifying the least costly areas within the fields belonging to the highest and lowest 25th percentiles of ESS provision. The areas in red in Figure 2 a and b show the areas with the lowest costs if wider margins where to be adopted within the areas with potential to provide the lowest (a.) and highest (b.) 25th percentiles of ESS.

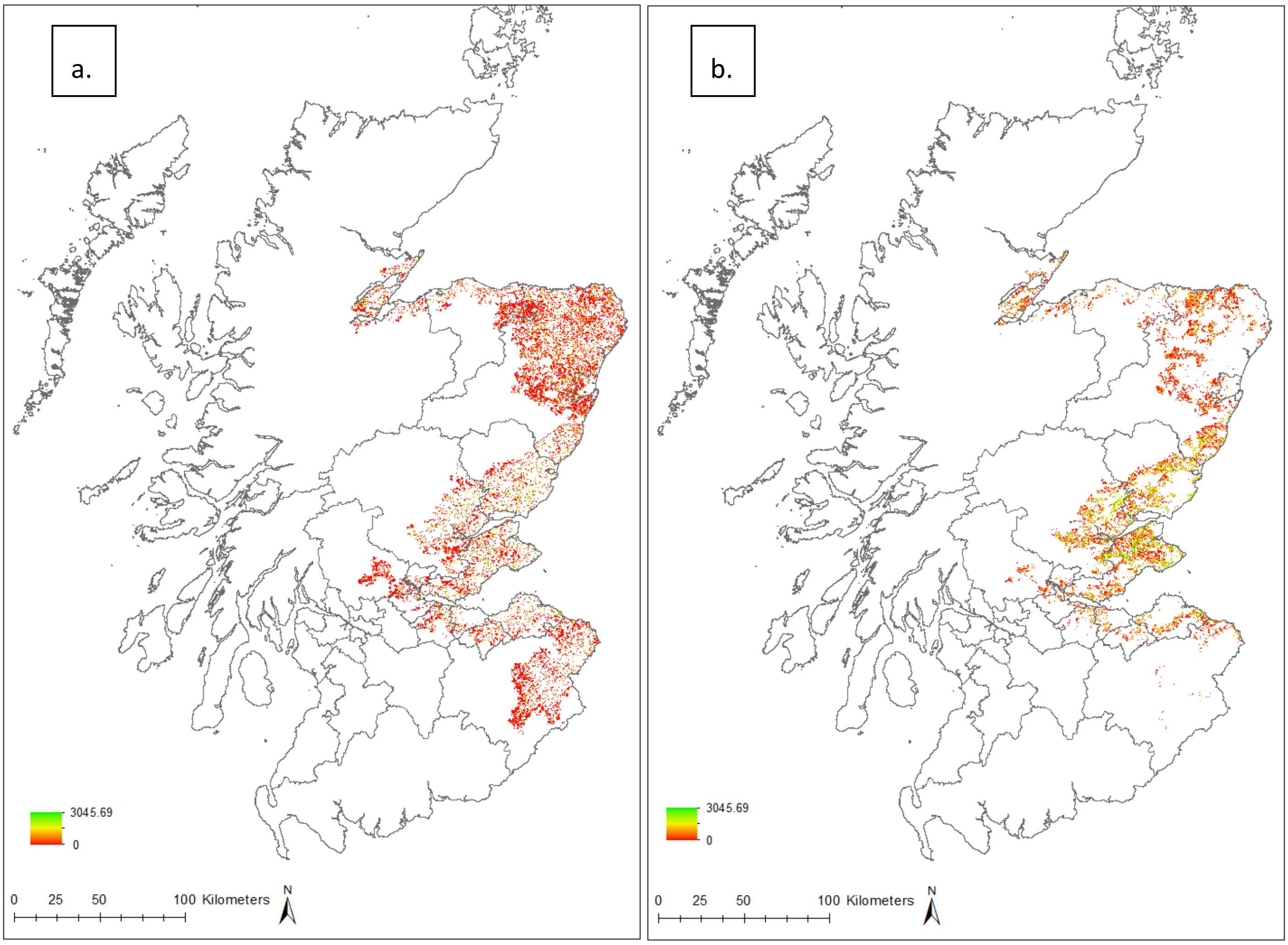

Figure 2 (a and b): opportunity cost of the adoption of wider field margins on a 100-meter x 100-meter grid for the lowest (a.) and highest (b.) 25th percentile of ESS provision

We see on Figure 2 that the areas with lowest opportunity costs (in red) differ when targeting the areas providing the lowest or highest 25th percentiles of ESS. In particular, far fewer fields display low opportunity costs in the Borders (Tweed Valley) when targeting the areas within the highest percentile of ESS provision.

ii. Simulation of participation levels if payment is set to the mean opportunity cost of adoption

Estimated participation rates

Based on the estimated opportunity costs for each field, we estimate the likely enrolment of fields in a scheme that would offer farmers a payment for the adoption of wider field margins (3-meter wider instead of current 1-meter). Here we set the payment level to the mean opportunity costs of this measure (Table 5) and assume that farmers would enrol a field if and only if the payment offered is higher than the opportunity costs for this field. We find that 62.76% of the fields would be enrolled in a scheme paying £371.8/ha of margin to increase field margins size from 1 to 3 meter wide. This drops to 19.39% if we exclude rotation 32 (the least intensive) from the analysis and set the payment level to £729.6 / ha of field margins.

How is participation distributed amongst rotations?

When all rotations are considered, the vast majority of fields that would be enrolled in the scheme (55,456 fields out of 57,035 that would be enrolled) would be those who had a rotation of type 32 between 2003 and 2007, the remainder being under rotation 31 or 27. These being **the least intensive ones**, where field margins are least needed, we run the analysis excluding these most extensive fields (i.e. assuming they would not be eligible).

When excluding fields under rotation type 32, we find that **exclusively fields where no potatoes are grown would be enrolled** (Table 6 below), for a total of 17,620 fields representing 177,485 hectares of arable land, distributed between the rotation types as follows:

Table 6: repartition of expected field enrolment in a scheme of 3-m wide field margins by rotation type – excluding rotation type 32 (most extensive)

rott1_id	potato	Nb fields enrolled Payment = mean	% of fields enrolled Payment = mean	Nb fields enrolled Payment = median	% of fields enrolled Payment = median	Nb fields enrolled Payment = current AECS	% of fields enrolled Payment = current AECS
1	0	259	100%	0	0%	0	0%
2	0	22	100%	0	0%	0	0%
3	0	67	100%	0	0%	0	0%
4	1	0	0%	0	0%	0	0%
5	0	297	95%	57	18%	0	0%
6	0	21	100%	0	0%	0	0%
7	0	23	100%	0	0%	0	0%
8	0	189	100%	0	0%	0	0%
9	1	0	0%	0	0%	0	0%
10	1	0	0%	0	0%	0	0%
11	1	0	0%	0	0%	0	0%
12	0	454	98%	41	9%	0	0%
13	0	647	91%	597	84%	26	4%
14	0	23	100%	0	0%	0	0%
15	0	4	100%	0	0%	0	0%
16	0	248	100%	0	0%	0	0%
17	0	230	100%	0	0%	0	0%
18	1	0	0%	0	0%	0	0%
19	1	0	0%	0	0%	0	0%
20	1	0	0%	0	0%	0	0%
21	1	0	0%	0	0%	0	0%
22	0	3860	94%	2826	69%	757	18%
23	1	0	0%	0	0%	0	0%
24	1	0	0%	0	0%	0	0%
25	1	0	0%	0	0%	0	0%
26	0	527	100%	0	0%	0	0%
27	0	6420	94%	5763	84%	3227	47%
28	1	0	0%	0	0%	0	0%
29	1	0	0%	0	0%	0	0%
30	0	566	100%	0	0%	0	0%

rott1_id	potato	Nb fields enrolled Payment = mean	% of fields enrolled Payment = mean	Nb fields enrolled Payment = median	% of fields enrolled Payment = median	Nb fields enrolled Payment = current AECS	% of fields enrolled Payment = current AECS
31	0	3763	95%	3532	89%	2139	54%
32	0	0	0%	0	0%	0	0%

What are the environmental characteristics of fields that would be enrolled compared to those not enrolled?

When including all rotation types, since enrolment is dominated by rotation type 32, the environmental characteristics of the fields enrolled reflect those of fields under rotation type 32 (as described previously)

When excluding rotation type 32, t-tests between the scores of the 4 ESS for areas within which fields enrolled (vs not enrolled) are located show that, in line with the characteristics of fields in which potatoes are grown:

- ✓ Species richness is significantly higher in areas in which fields would be enrolled
- ✓ Nitrogen retention is lower
- ✓ Pollination is higher
- ✓ There is no difference in soil carbon scores
- ✓ Soil retention is lower

iii. Simulation of participation levels if payment is set to the median opportunity cost of adoption

Estimated participation

When setting the payment to the median opportunity costs, all rotations included, (£200 / hectare of field margins), the total number of fields that would be enrolled drops to 45,327, and all belong to rotation type 32.

If we exclude rotation type 32 and set the payment to £616.3 per ha of field margins, we find that 12,816 fields would be enrolled, distributed amongst the different rotation types, with no enrolment of fields that include potatoes in the rotation and a majority of fields enrolled belonging to lower intensity rotation types (see Table 6).

What are the environmental characteristics of fields that would be enrolled vs not enrolled?

When including all rotation types, since enrolment is dominated by rotation type 32, the environmental characteristics of the fields enrolled reflect those of fields under rotation type 32 (as described previously)

In the scenario where the payment is set to the median opportunity cost within our sample and rotation 32 is excluded, we find (based on t-tests) that the fields that would be enrolled tend to be located in areas that display:

- ✓ Display a higher species richness
- ✓ Have a lower nitrogen retention score
- ✓ Higher pollination score
- ✓ Lower soil carbon content
- ✓ Lower soil retention capacity

These results align with those obtained when the payment level was set to the mean opportunity cost.

iv. Simulation of participation levels if payment is set to current AECS payment

Estimated participation

Our third and last simulated payment level is that of the current payment offered to farmers under the SDRP. We find that mostly fields under rotation 32 (62,121 fields), rotation 31 (2,139), 27 (3,227), 22 (757) and 13 (26), representing 75% of the fields and none of them including potato growing are likely to be enrolled. When removing rotation 32, the enrolment in other rotation types remains constant as the payment level is the same and does not cover the opportunity costs of most famers under more intensive rotation types (with the gross margins values we use). This explains the large reduction in expected participation rate when excluding rotation 32, dropping to 6.8% of the fields being enrolled (Table 7).

What are the environmental characteristics of fields that would be enrolled vs not enrolled?

In terms of provision of ES, comparing fields that would be enrolled to those that would not, when excluding rotation 32 we see that:

- ✓ There is no significant difference in species richness scores
- ✓ There is a slightly lower nitrogen retention score in areas in which fields enrolled are located
- ✓ Pollination scores are higher in areas in which fields expected to be enrolled are located
- ✓ Soil carbon scores are slightly lower
- ✓ As well as soil retention scores

This aligns with the result that field with lower intensity rotations are more likely to be enrolled and the ESS reflect the levels of ESS provided by these fields.

To conclude, it seems that self-selection on opportunity cost, when excluding rotation 32 (the most extensive) would lead to the enrolment of fields located in areas where field margins are likely to be effective (lower nutrient and soil retention, lower soil carbon but higher pollination and species richness likely to support an increase in biodiversity).

v. Comparison of payment strategies

If we summarize the outcomes of the different payment strategies, we see that (Table 7) not including the most extensive rotation types allows to focus enrolment on fields that provide more ESS, including fewer fields, but fields that are being managed more intensively, which is reflected in the higher total opportunity costs to farmers.

Table 7: Comparison of simulated enrolment, budget, ESS provided areas in which fields enrolled are located and total farmers' opportunity costs, under alternative payment options for a 3-m wide field margins scheme

Payment	Number fields enrolled	Total acreage of fields enrolled (ha)	Total budget	Total sum of ESS of areas in which fields enrolled are located	Total farmers' opportunity cost
Mean, all rotations	57,035	306,688	£4,098,573	112,496	£ 1,581,901
Mean, excluding rotation type 32	17,620	177,485	£ 3,446,478	145,649	£ 2,420,717
Median, all rotations	45,327	229,959	£ 1,701,948	63,228	£ 890,705
Median, excluding rotation type 32	12,816	124,171	£ 2,079,289	86,219	£ 1,332,130
Current AECS payment level all rotations included	68,270	400,904	£ 6,823,320	179,081	£ 2,585,542
Current AECS payment level rotation 32 excluded	6,149	54,609	£ 766,885	20,308	£ 288,789

This allows a comparison of the different payment strategies in terms of performance in terms of the sum of ESS targeted by the scheme per unit of budget spent and in terms of over-compensation of farmers' opportunity costs (how much bigger is the budget compared to the actual opportunity costs of farmers).

Table 8 Comparison of the performance of alternative payment strategies for a 3-m wide field margins scheme

Payment strategy	ESS / budget (£ / unit of ES)	Over-payment (budget – opp. cost) / budget
Mean opportunity cost, all rotations	£0.0274	61 %
Mean opportunity cost, excluding rotation type 32	£0.0423	30 %
Median all rotations	£0.0372	48 %
Median opportunity cost, excluding rotation type 32	£0.0415	36 %
Current AECS payment level all rotations included	£0.0262	62 %
Current AECS payment level excluding rotation type 32	£0.0265	62 %

Table 8 shows that, when including all rotations, setting the payment at the median of opportunity costs leads to the lowest level of over-compensation of farmers (payment beyond the opportunity cost) and leads to the enrolment of fields located where the highest level of current ESS are provided per unit of budget spent.

Excluding fields under the most extensive rotation type (32) generally leads to an increase in the level of total sum of current ESS provided in the areas in which fields enrolled are located per unit of budget spent and to a reduction of over-compensation of farmers, but a shown in Table 7 this leads to far fewer fields being enrolled (in our simulations).

c. Scenarios of payments for de-intensification

We now turn to the analysis of a measure of de-intensification, in which the fields under the most intensive rotation categories would adopt a more diversified rotation, that we set as the rotation 21 if the field was used to grow potatoes, and rotation 22 if the field was not used to grow potatoes between 2003 and 2007.

We start by estimating the overall opportunity costs and identify areas of low opportunity costs for deintensification, and link these to the provision of ESS (i). We then move on to simulating 2 different payment strategies for a potential deintensification agri-environmental scheme.

i. Hot spots of high potential benefit – Cost ratio

Opportunity costs of de-intensification

In our data, 3,257 fields have a rotation intensity that is more intense than rotations 21 (with potato growing) or 22 (without potato growing). That is shared between 2,569 fields in which no potatoes are grown and 688 fields in which they are.

The average gross margins over the 5 years of rotation 21 are 1,973.57 £/ha, and those of rotation 22 are 917.87 £/ha. We set these values as the new opportunity costs of all rotations that are currently more intensive than rotation 21 (22) to estimate farmers' opportunity costs of deintensification. We estimate these opportunity costs for all fields, as well as separately for fields including potatoes or not. We also estimate the opportunity costs of targeting deintensification on the fields in areas that currently provide the most or the least ESS. Results are presented in Table 9.

Table 9: opportunity costs of deintensification

	n	Mean (£/ha)	Standard deviation (£/ha)	Median (£/ha)	Total opportunity costs assuming 100% adoption

Opportunity cost (rotations including potatoes)	688	47.80	200.41	8.63	£ 32,886
Opportunity cost (rotations excluding potatoes)	2,569	113.42	179.13	108.68	£ 291,376
Opportunity costs (all)	3,257	99.56	185.74	80.93	£ 324,267
Targeting fields within 25 percentiles **of lowest ESS score**	370	115.62	201.22	107.90	£ 42,779
Targeting fields within 25 percentiles **of highest ESS score**	1,009	120.80	222.55	96.46	£ 121,887

Rotations 11, 13 and 19 display negative opportunity costs showing that farmers would be better-off diversifying their rotations in terms of margins per hectare. For these farmers, AECS measures of deintensification may serve as a habit breaking intervention that may provide an opportunity to farmers to try new practices (Hiedanpaa and Bromley 2014).

Table 9 shows that the total opportunity cost of deintensification in areas producing the least ESS is 3 times less costly, in terms of total farmers' opportunity costs than targeting the areas that currently provide high levels of ESS, because both the opportunity cost per hectare and the number and acreage of eligible fields (fields need to be under an intensive rotation type) are lower in the areas with low provision of ESS.

A deintensification of all fields that were under a rotation type more intensive than rotation 21 between 2003 and 2007 would come at a total cost of £324,267 to society (farmers). Scheme compensating for these costs could therefore be offered to farmers to support their transition to lower intensity farming systems, which we explore in the next section. Given low average opportunity cost for rotations including potatoes, and the low number of eligible fields to a potential deintensification measure (rotation more intense that rotation 21) including potatoes in their rotation, we focus the simulation of payments **on fields that do not include potatoes in their rotations**.

What is the geographical distribution of the potential Benefit/Cost ratio?

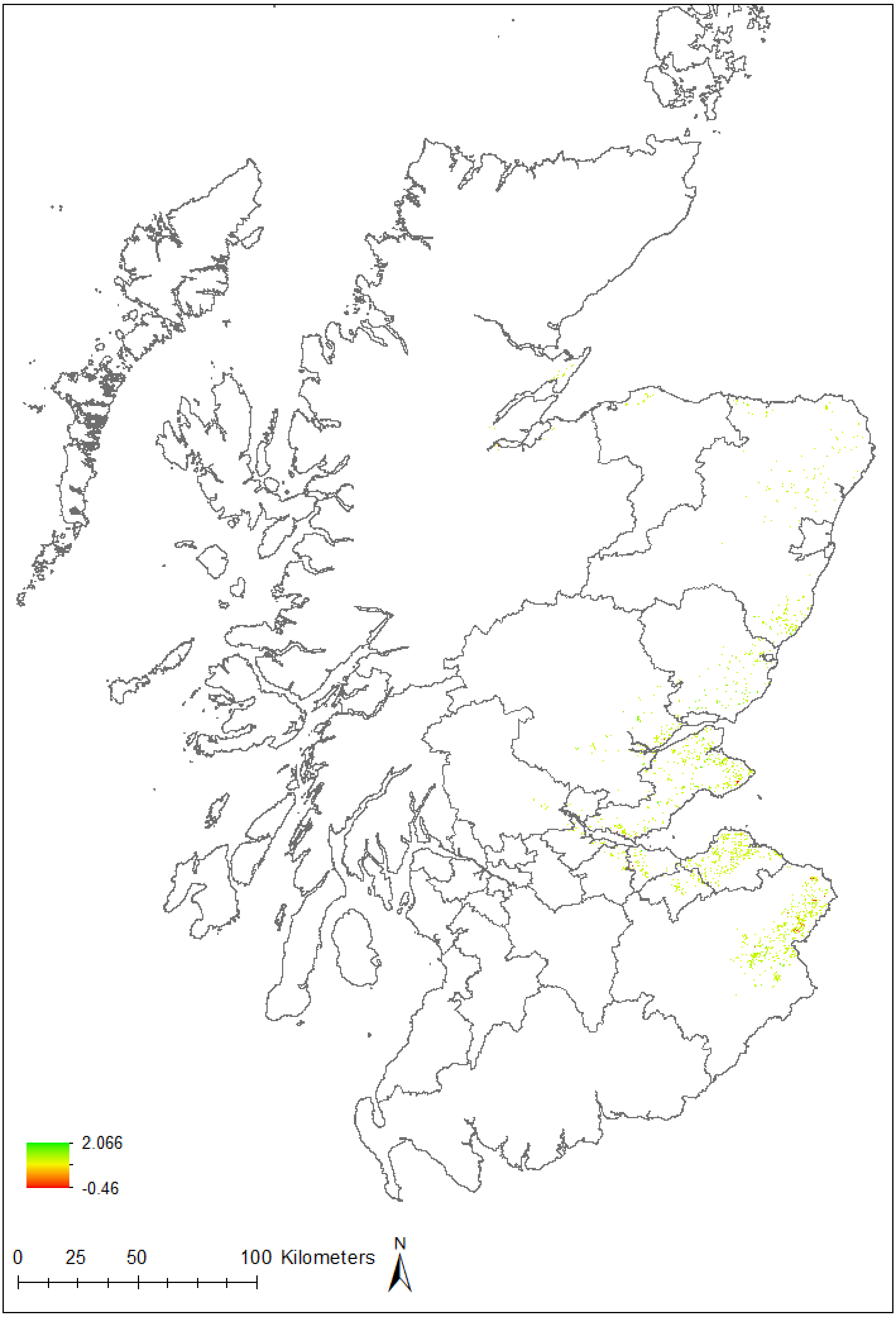

Figure 3: Map of potential benefit / cost ratio of deintensification, on a 100 m x 100 m grid

In a similar way to the case of widened field margins, no obvious geographical cluster of high benefit / cost ratio appear on Figure 3.

Figure 4: opportunity cost of the adoption of deintensification on a 100-meter x 100-meter grid for the lowest (a.) and highest (b.) 25th percentile of ESS provision

Figure 4 (a) shows that the few eligible fields within locate within the 25th lowest percentile of ESS provision seem scattered across all arable land of Southeast Scotland. Potential areas with lower opportunity costs of deintensification see to appear (Figure 4, b) when targeting the highest 25th percentile of ESS provision in Fife, East Lothian (away from coast) and South Aberdeenshire.

ii. Simulation of participation levels if payment is set to the mean opportunity cost of farmers

Estimated participation rates

Reminders: fields including potatoes in their rotation are considered not to be eligible and fields need to have a rotation more intensive than rotation 22 in place between 2003 and 2007. This means that **only 2,569 fields from the total 90,884 fields included in the analysis would be considered as eligible.**

We first set the payment level to the mean opportunity cost of eligible farmers (£113.42 /ha).

2.1 % of all fields (representing 1,309 fields), or **50.9% of eligible fields**, would be enrolled under this scenario, distributed between the rotation types as follows (Table 10):

Table 10: Repartition of expected field uptake of a deintensification measure under 2 alternative payment strategies (mean or median opportunity cost)

rott1_id	potato	Nb fields enrolled	% of fields enrolled	Nb fields enrolled	% of fields enrolled

		Payment = mean	Payment = mean	Payment = median	Payment = median
1	0	0	0%	0	0%
2	0	0	0%	0	0%
3	0	0	0%	0	0%
4	1	0	0%	0	0%
5	0	263	84%	263	84%
6	0	0	0%	0	0%
7	0	0	0%	0	0%
8	0	0	0%	0	0%
9	1	0	0%	0	0%
10	1	0	0%	0	0%
11	1	0	0%	0	0%
12	0	414	90%	396	86%
13	0	609	86%	609	86%
14	0	23	100%	23	100%
15	0	0	0%	0	0%
16	0	0	0%	0	0%
17	0	0	0%	0	0%
18	1	0	0%	0	0%
19	1	0	0%	0	0%
20	1	0	0%	0	0%
Note: fields including potatoes in their rotation are considered not to be eligible, only fields under a rotation intensity higher than rotation 21 are eligible (i.e. rotation type lower than 21)					

What are the environmental characteristics of fields that would be enrolled vs not enrolled?

A two-sample t-test with equal variances was applied to test differences between the groups of fields that will be participating (and these fields who will not) according to the rotation intensity, species richness, nitrogen retention, pollination, soil carbon and soil retention. A total of 1,309 fields would participate, and 89,575 fields would not.

- ✓ In terms of **species richness**, the difference between two groups of fields is significant (Pr(|T| > |t|) = 0.0000). Mean value of species richness for participating fields is higher (19.64) in comparison to non-participating fields (15.81).
- ✓ A similar two-sample t-test with equal variances was carried out for **nitrogen retention**. Also for this variable, two groups of fields differ significantly (Pr(|T| > |t|) = 0.0000). Mean value for nitrogen retention was found to be more than 1.6 times higher for participating fields (0.703) than for non-participating fields (0.452).
- ✓ If we focus on **pollination**, the two groups do not differ significantly (Pr(|T| > |t|) = 0.459).
- ✓ **Soil carbon** was another tested variable. Two groups of fields were found to be statistically significantly different (Pr(|T| > |t|) = 0.0000). Mean value for soil carbon was found to be lower for non-participating field (0.106) than for participating fields (0.146).
- ✓ Another tested variable was **soil retention**. The differences between the two groups of fields are significant (Pr(|T| > |t|) = 0.0000). Slightly higher mean values were found for participating fields (0.037) than for non-participating fields (0.027).

To sum up our findings, **significantly higher mean values for participating fields were found for nitrogen retention (1.6 higher) and soil carbon, as well as for species richness and soil retention to a lesser extent.**

iii. Simulation of participation levels if payment = median opportunity cost

Estimated participation rates

We now set the payment level to the median opportunity cost of eligible farmers (£108.68 /ha).

We estimate that 1,291 fields would be enrolled in such a deintensification measure if payment was set to the median opportunity cost, distributed between rotations as shown in Table 10. These are very similar to the expected enrolment with a payment set to the mean opportunity costs of farmers.

What are the environmental characteristics of fields that would be enrolled vs not enrolled?

Therefore, the environmental characteristics of enrolled fields are also similar to those found in the previous section. Fields that would be enrolled (compared to those that would not) are associated with:

- ✓ A significantly higher species richness
- ✓ A significantly higher nitrogen retention score
- ✓ A similar level of pollination scores (no significant difference)
- ✓ A significantly higher soil carbon score
- ✓ And a significantly higher soil retention score

Indeed, two-sample t tests with equal variation were used to test the differences between the groups of participation and non-participating fields.

Firstly, the **rotation intensity** was tested among the surveyed group. The differences between two groups were found significant (Pr(|T| > |t|) = 0.0000). The value for the group of non-participating fields was 2.7 times lower (30.15) than for the group of participating fields (11.08). This reflects the fact than only fields under rotation intensity higher than that of rotation type 21 are eligible.

In case of **species richness**, the mean value for the group of participating fields is by 20% (19.68) in comparison to non-participating fields (15.81). Also in this case, the differences between two groups were found significant (Pr(|T| > |t|) = 0.0000).

Also for **nitrogen retention**, the differences between two groups were found significant (Pr(|T| > |t|) = 0.0000). Mean value of nitrogen richness for participating fields is higher (0.45) by 36% in comparison to non-participating fields (0.702).

Pollination seems to be a special case. The differences between two groups of fields were found significant (Pr(|T| > |t|) = 0.4806) but with limit values. Although the differences in mean values between two groups are in favour for the group of non-participating fields (0.0073), the value for participating fields is very close (0.0070).

In case of **soil carbon**, where the differences between two groups of fields were found also significant (Pr(|T| > |t|) = 0.0000), we can see mean values for participating fields (0.146) are by 28% higher than for non-participating fields (0.106).

Similar finding is true for **soil retention**, where mean value for participating fields (0.367) are by 27% higher than for non-participating fields (0.27). The differences between two groups of fields were found significant (Pr(|T| > |t|) = 0.4806) but with limit values.

We can say that mean values for the group of non-participating fields are visibly higher for rotation intensity (2.7 times). In case of the group of participating fields visibly higher mean values were detected for nitrogen retention, less for soil carbon, soil retention and species richness (36%, 28%, 27%, 20% respectively).

iv. Comparison of payment strategies

Reminders: fields including potatoes in their rotation are considered not to be eligible, nor fields that currently have a rotation intensity lower than our threshold.

Given the small difference between the mean and median opportunity costs, both payment strategies lead to similar outputs (Table 11) and performance (Table 12).

Table 11: Enrolment levels, total budget, total ESS provided in areas in which fields enrolled are located and total opportunity costs under alternative payment strategies.

Payment	Number fields enrolled	Total acreage of fields enrolled (ha)	Total budget	Total sum of ESS in areas in which fields enrolled are located	Total farmers' opportunity cost
Mean opportunity cost	1,309	15,757	£ 1,787,133	12,228	240,404
Median opportunity cost	1,291	15,535	£ 1,688,365	11,870	208,932

Table 12: Performance of alternative payment strategies for a deintensification measure

Payment	ESS / budget (£ / unit of ES)	Over-payment (budget – opp cost) / budget
Mean opportunity cost	£0.0068	87%
Median opportunity cost	£0.0070	88%

Because there is a large variation in opportunity costs across fields, using the mean or median opportunity costs as levels of payments generate high over-compensation rates of farmers (many farmers have opportunity costs much lower than the payment offered, and even negative opportunity costs).

d. Scenarios of payments for the adoption of integrated farming

i. Hot spots of high potential benefit – Cost ratio

Opportunity costs of integrated farming

First, it is worth noting that 19 farmers have negative opportunity costs, meaning that would have higher gross margins in integrated farming.

For 45,881 farmers the opportunity cost of adopting an integrated farming approach appears as null in the dataset as we do not have values of gross margins under integrated farming for the crop they grow (so the gross margins were kept them constant). It does not mean that they would actually bear no cost, but signals that we do not have the necessary data to estimate what these costs (or benefits) would be. We therefore also generate the opportunity cost descriptive statistics excluding those with a null opportunity cost (opportunity costs different from 0 in Table 13), therefore only keeping in the analysis the fields for which we have CSC data for at least one of the 5 land uses within the rotation. This means that they include at least 1 occurrence of either Inter Wheat (WW), Winter Barley (WB), Spring Barley (SP), Beans, Winter Oilseed Rape (WOSR) or potatoes. Therefore, the opportunity costs generated are a lower bound of the opportunity costs likely to be seen would all farmers adopt integrated farming approaches (assuming these lead to a reduction in gross margins for all land uses). Finally, we generate these same statistics including only rotations for which all gross margins values are available from the CSC data for comparison, i.e. fields with rotations relying on no other crops than: WW, WB, SP, Beans, WOSR or potatoes.

Table 13: Opportunity costs of farmers adopting an integrated farming approach

	n	Mean (£/ha)	Standard deviation (£/ha)	Median (£/ha)	Total opportunity costs assuming 100% adoption
All fields included	90,884	233.56	271.39	0	£ 21,226,867
All fields included, opportunity costs different from 0	44,984	472.16	189.27	520.39	£ 21,226,867

Only fields under rotations with CSC crops	17,095	657.59	47.54	650.49	£ 11,241,501
Targeting fields within 25 percentiles **of lowest ESS score (opp cost >0)**	10,029	413.20	200.12	390,29	£ 4,143,983
Targeting fields within 25 percentiles **of highest ESS score (only fields with full data) (opp cost >0)**	14,864	481.70	183.49	520.39	£ 7,159,989

What is the geographical distribution of Benefit/Cost ratio?

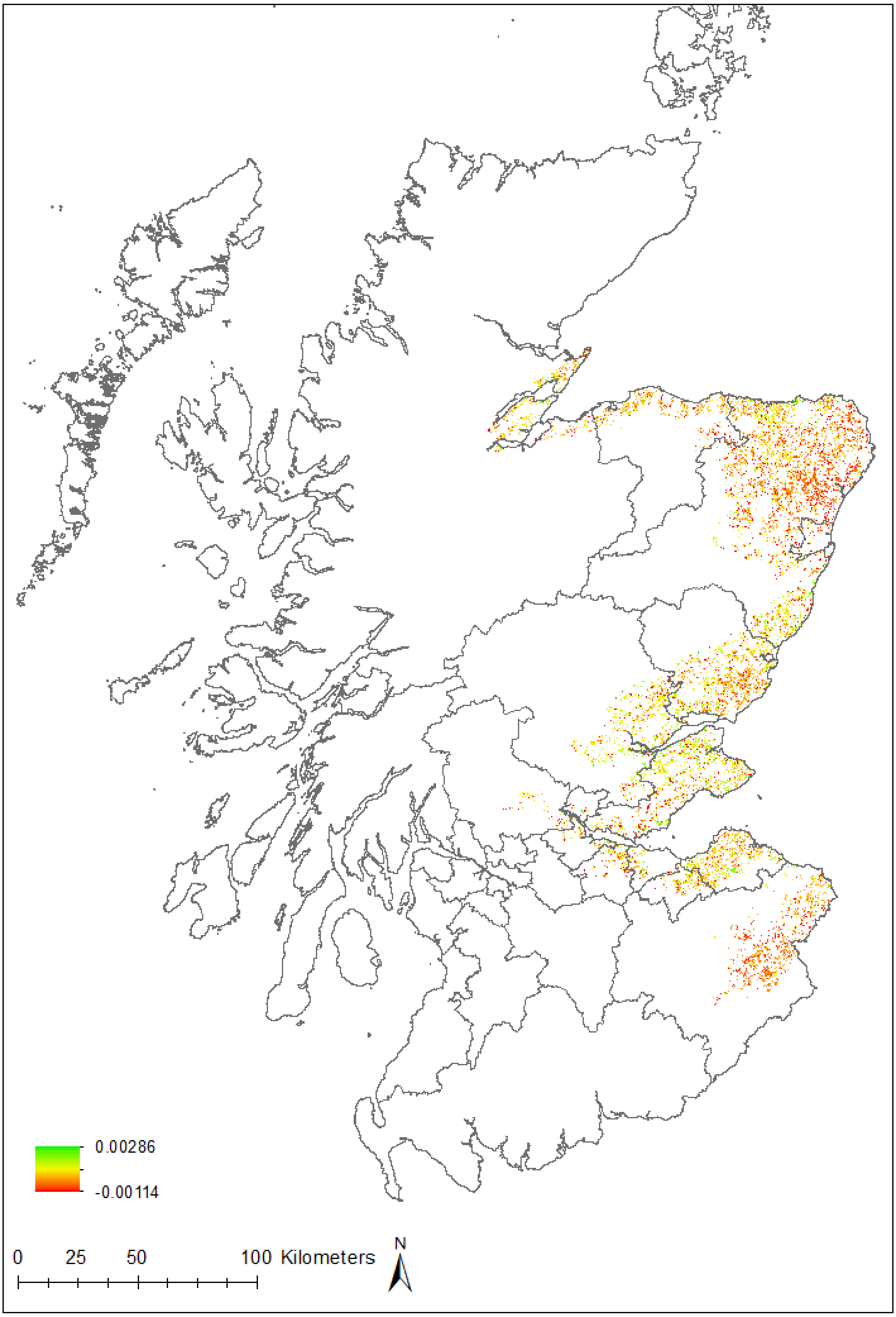

Figure 5: Map of potential benefit / cost ratio of integrated farming, on a 100 m x 100 m grid

Note that the maps presented here only consider fields for which with full data on gross margins under integrated farming are available. Higher concentration of fields with high Benefit / cost ratio (in green on Figure 5) can be observed in the very North and very South Aberdeenshire, Fife and South of East Lothian.

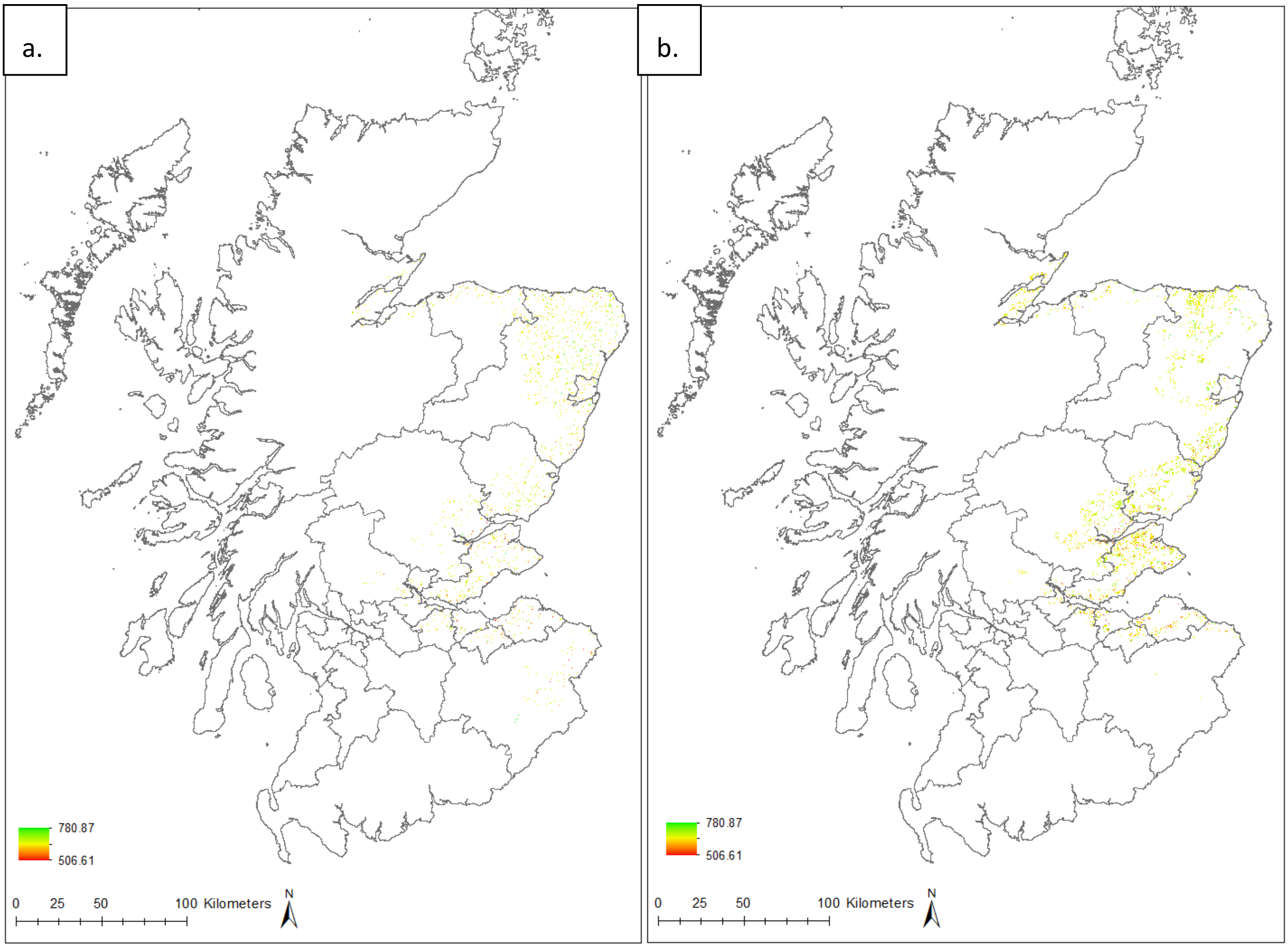

Figure 6: opportunity cost of the adoption of integrated farming on a 100-meter x 100-meter grid for the lowest (a.) and highest (b.) 25th percentile of ESS provision

In the case of an integrated farming measure, the range of variation of opportunity costs is a lot narrower than for other measures. Figure 6 shows that no clear geographical pattern exist in the location of low opportunity cost fields within the areas producing the lowest or highest 25th percentiles of ESS.

ii. Simulation of participation levels if payment is set to the mean opportunity cost

Estimated participation

We only run the payment simulations for those fields for which we have full gross margins data availability (i.e. fields with rotations relying on no other crops than: WW, WB, SP, Beans, WOSR or potatoes). Indeed, when including others, we are most likely under-estimating the actual opportunity cost of adopting integrated farming practices, since we assume null cost for these land uses. This would lead to a large over-estimation, and therefore very biased, estimate of participation rates, with fields for which less data is available being less more likely to be wrongly found as likely participants, since their opportunity costs will artificially be lower than the payment offered.

With a payment set at the **average** opportunity cost, we find that 10,168 fields out of the 17,095 for which we have full gross margins data available could be expected to join a AECS for integrated farming. This would be distributed across rotations as follows (Table 14):

Table 14: Repartition of expected field uptake of an integrated farming measure, by rotation type, under 2 alternative payment strategies (mean or median opportunity cost)

rott1_id	potato	Nb fields enrolled Pay = mean	% of fields enrolled Pay = mean	Nb fields enrolled Pay = median	% of fields enrolled Pay = median
1	0	259	100%	259	100%
2	0	22	100%	22	100%
3	0	67	100%	67	100%
4	1	94	100%	94	100%
5	0	104	100%	104	100%
6	0	21	100%	21	100%
7	0	23	100%	23	100%
8	0	189	100%	189	100%
9	1	0	0%	0	0%
10	1	0	0%	0	0%
11	1	84	100%	84	100%
12	0	167	100%	167	100%
13	0	160	100%	160	100%
14	0	0	0%	0	0%
15	0	4	100%	4	100%
16	0	0	0%	0	0%
17	0	230	100%	230	100%
18	1	210	100%	210	100%
19	1	0	0%	0	0%
20	1	22	100%	22	100%
21	1	565	89%	282	44%
22	0	1221	98%	1221	98%
23	1	0	0%	0	0%
24	1	6	1%	6	1%
25	1	14	2%	14	2%
26	0	0	0%	0	0%
27	0	1282	50%	1166	46%
28	1	1	0%	1	0%
29	1	15	2%	15	2%
30	0	0	0%	0	0%
31	0	163	10%	0	0%
32	0	5245	100%	8	0%

What are the environmental characteristics of fields that would be enrolled vs not enrolled?

In terms of environmental characteristics of areas where fields are likely to be enrolled, we find that, compared to those where fields are less likely to be enrolled, these tend to:

- ✓ Have slightly higher species richness (p-value < 0.01)
- ✓ Provide slightly higher levels of pollination (p-value < 0.01)
- ✓ Provide slightly lower levels of nitrogen retention (p-value < 0.01)
- ✓ Display slightly lower levels of soil carbon (p-value < 0.01)
- ✓ Not differ in terms of soil retention services.

These results are similar to those obtained for the widened field margins measure.

iii. Simulation of participation levels if payment is set to the median opportunity cost

Estimated participation

Again, and for the same reasons as in the previous sections, we only run the payment simulations for those fields for which we have full gross margins data availability (i.e. fields with rotations relying on no other crops than: Winter wheat, Winter Barley, Spring Barley, Beans, Winter oilseed rape or potatoes).

With a payment set at the **median** opportunity cost, we find that 4,369 fields out of the 17,095 for which we have full gross margins data available could be expected to join a AECS for integrated farming, which is less than half the participation rate found under a payment set at the average opportunity cost, while the 2 payment levels are actually very close. Participation would be distributed across rotations as shown in Table 14. The drop in participation is mostly driven by a large reduction in participation in the most extensive rotation types (rotation id 32), meaning that under this scenario, the fields that would be enrolled are on average under more intensive rotation types than those that would not be enrolled.

What are the environmental characteristics of fields that would be enrolled vs not enrolled?

In terms of environmental characteristics, we see that the fields most likely to be enrolled, on average are located in areas that:

- ✓ Have higher levels of species richness (t-test p-value <0.01), but do not differ on average in terms of pollination
- ✓ Have higher levels of nitrogen retention (t-test p-value <0.01)
- ✓ Have slightly higher Soil carbon levels
- ✓ Do not differ in terms of soil retention levels (p-value> 0.05)

iv. Comparison of payment strategies

Table 15: Enrolment levels, total budget, total ESS provided in areas in which fields enrolled are located and total opportunity costs under alternative payment strategies for an integrated farming scheme

Payment	Number fields enrolled	Total acreage of fields enrolled (ha)	Total budget (2021 £)	Total sum of ESS in areas in which fields enrolled are located	Total farmers' opportunity cost (2021 £)
Mean opportunity cost	10,168	95,261	62,642,501	73,418	54,423,057
Median opportunity cost	4,369	47,953	31,193,214	35,673	23,882,971

When focussing the analysis on fields for which all gross margins data available, we see that a small decrease in the payment level (i.e. median instead of mean opportunity costs) leads to a large decrease in participation rates as most fields have an opportunity cost within a narrow range of opportunity costs.

Table 16: Performance of alternative payment strategies for an integrated farming scheme

Payment	ESS / budget (2021 £ / unit of ES)	Over-payment (budget – opp cost) / budget
Mean opportunity cost	£0.0012	13%
Median opportunity cost	£0.0011	23%

Again, since the range of variation of opportunity costs between fields is small, we see on Table 16: Performance of alternative payment strategies for an integrated farming scheme that whichever payment strategy used leads to relatively low levels of overcompensation of farmers.

4. Discussion

Our results rely heavily on the assumption that farmers will only join a scheme if the payment offered at least compensates them for their opportunity cost. We know from many previous studies that farmers are assumed to be profit maximisers, however undoubtedly, many behavioural factors are also at play (Pedersen et al., 2020, Dessart et al. 2019), when making decisions about how to focus their farming activities. A rich variety of behaviour factors such as aversion to change, risk aversion or, loss aversion as well as altruism and pro-environmental preferences may also affect farmers decision to join an AECS. Application of the Theory of Planned Behaviour might be a hint of how better to understand farmer´s behaviour. In short, the theory claims that behavioural intentions of an individual are formed by interplay between attitudes, subjective norms and perceived behavioural control. Drivers leading to the change of attitudes towards more pro-environmental preferences of farmers seem to be of immense importance (Senger et al., 2017), however heterogeneity of these factors is frequently highlighted. Not taking behavioural factors into account is an obvious limitation of our approach. However, Dreschler (2021) argues that deviations from the standard assumption of farmers being "*rational, perfectly informed and self-interested homo oeconomicus*" may not have large effects on the cost-effectiveness of agri-environmental schemes.

Other assumptions and associated limitations of the work include that we calculate the same gross margins values for all fields in which a same rotation is in place and do not take into account the heterogeneity in performance between fields within a same rotation, that may be due to fields' characteristics or the management in place. In addition, in the particular case of the gross margin values for integrated farming measures, these rely on the results of a field trial, over 1 single rotation and do not reflect the potential improvements in yields likely to arise from best integrated farming management practices in following rotations. Similarly, we do not account for field level management practices in the estimates of ESS provision, which rely on landscape scale modelling.

Future work could look at increasing the range of ESS included in the analysis to provide a more comprehensive analysis of the trade-offs and synergies. A further step would be to model the outcomes in terms of ESS provision from the adoption of the simulated measures to be able to simulate the environmental impact of alternative payment and adoption scenarios.

5. Conclusion

We argue that ES provision and costs should be accounted for when targeting AESs. We illustrate how farmers' opportunity costs can be used in the targeting and payment choice of 3 measures: widened field margins, de-intensification and integrated farming.

It appears that areas with low costs and high potential ESS provision seem to be scattered across all arable land in Scotland in many cases. Targeting may not always be the most suited approach to favour the selection of fields that have low opportunity costs jointly with high potential for the provision of ESS. Other screening (or selection) mechanism may therefore be more suited to increase the cost-effectiveness of AECS, and could be used in conjunction with targeting based on ESS potential only. Two of these mechanisms are result-based schemes and auction mechanisms described below.

When looking at a measure of widened fields margins, we find that the fields under the least intensive rotations are most likely to be enrolled, and growing potatoes appears as a strong factor limiting the adoption of such a measure in our simulations. This leads to the likely enrolment of fields located in areas with higher species richness and pollination services, but lower soil and nitrogen retention scores and lower soil carbon stocks.

Results of simulations for a de-intensification measure show that the number of eligible fields would be much lower than for a field margins measure. It is worth noting that the simulation results show that some fields could generate higher gross margins under a less intensive rotation, which highlights the potential role of AECS as habit breaking interventions that can provide farmers with a chance to try new practices (Hiedanpaa and Bromley 2014). The results also show that fields in areas with higher species richness, soil carbon stocks, soil and nitrogen retention ES provision are most likely to be enrolled in such a measure. This analysis also illustrates that when there is a large heterogeneity in the opportunity costs of a measure, the schemes are more likely to over-compensate participating farmers when payments are set as flat-rate payments based on the mean or median expected opportunity cost of the population.

Finally, when looking at a measure supporting the adoption of an integrated farming approach, we see that the opportunity costs per hectare of such a measure are higher than for the other two, this measure being therefore more suitable for a deep and narrow approach to AECS, providing higher levels of payments to fewer eligible farmers. Targeting areas with most potential for the provision of ESS is even more important in this setting, and in that regard the mapping of areas with the lowest opportunity costs in the top and lowest 25th percentile of ESS provision can be useful in increasing the cost-effectiveness of AECSs.

Looking beyond flat-rate practice-based payment schemes, two scheme designs that would allow for both costs and benefits to be accounted for in the selection of participating farmers in AECSs are: result-based schemes and auctions. In auction mechanisms, farmers propose their own "bid" (or proposal) associating practices and a required payment. Bids are then selected based on a scoring of their bid that factors in both the benefits and the costs of the bid, typically in the form of a Benefit/Cost ratio. However, very little is known still about how farmers decide to join result-based scheme and then which practices they would implement to achieve the required environmental objectives, which hindered our ability to associate opportunity costs and a participation decision to each field, and therefore to include such a scheme design in our simulated scenarios. Both approaches, however, would very likely raise farmers' attention not only on the opportunity cost of participation but also on the potential environmental benefits, in order to be able to achieve the environmental results required to either be selected into the scheme or to receive the result-based payment. These approaches come with design challenges and potential drawback that still require further investigation.

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Appendices

Appendix 1: Description of rotation types, from 1 (most intensive) to 32 least intensive

Rotation	Occurrence of crops			Rotation used for integrated farming scenario
1	Winter wheat (5)			WW(3) SB(1) Beans (1)
2	Winter wheat (4) +	Winter barley (1)		WW(2) WB(1) SB(1) Beans (1)
3	Winter wheat (4) +	Winter oilseed rape (1)		WW (2) WOSR (1) SB(1) Beans (1)
4	Winter wheat (4) +	Potato (1)		WW(2) Potato (1) SB(1) Beans (1)
5	Winter wheat (4) +	Beans or Peas (1) or Grass or set aside (1) or Spring cereals (1) or Vegetables (1) or Winter oat (1)		1 occurrence of winter wheat is replaced by Beans
6	Winter wheat (3) +	Winter barley (2)		WW(2) WB(1) SB(1) Beans (1)
7	Winter wheat (3) +	Winter oilseed rape (2)		WW (2) WOSR (1) SB(1) Beans (1)
8	Winter wheat (3) +	Winter barley (1) +	Winter oilseed rape (1)	WW1 WOSR1 WB1 SB1 Beans1
9	Winter wheat (3) +	Potato (1) +	Winter barley (1)	WW1 Potato1 WB1 SB1 Beans1
10	Winter wheat (3) +	Potato (1) +	Winter oilseed rape (1)	WW1 Potato1 WOSR1 SB1 Beans1
11	Winter wheat (3) +	Potato (1) +	Beans or Peas (1) or Grass or set aside (1) or Spring cereals (1) or Vegetables (1) or Winter oat (1)	1 occurrence of winter wheat is replaced by Beans
12	Winter wheat (3) +	Winter barley (1) or Winter oilseed rape (1)	+ Beans and Peas (1) or	1 occurrence of winter wheat is replaced by Beans

			Grass or set aside (1) or Spring cereal (1) or Vegetables (1) or Winter oat (1)		
13	Winter wheat (3) +	(2) amongst: Beans and Peas and/or Grass or set aside and/or Spring cereal and/or Vegetables and/or Winter oat			Unchanged
14	Winter wheat (2) +	Winter barley (3)			WW1 WB2 SB1 Beans1
15	Winter wheat (2) +	Winter oilseed rape (3)			WW1 WOSR2 SB1 Beans1
16	Winter wheat (2) +	Winter barley (2) +	Winter oilseed rape (1)		WW1 WOSR1 WB1 SB1 Beans1
17	Winter wheat (2) +	Winter barley (1) +	Winter oilseed rape (2)		WW1 WOSR1 WB1 SB1 Beans1
18	Winter wheat (2) +	Potato (1) +	Winter oilseed rape (1)	+ Winter barley (1)	WW1 Potato1 WOSR1 WB1 Beans1
19	Winter wheat (2) +	Potato (1) +	Winter barley (2)		WW1 Potato1 WB1 SB1 Beans1
20	Winter wheat (2) +	Potato (1) +	Winter oilseed rape (2)		WW1 Potato1 WOSR1 SB1 Beans1
21	Winter wheat (2) +	Potato (1) +	Winter barley (1) or Winter oilseed rape (1) or Grass or set aside (1) or Spring cereals (1) or Vegetables (1) or Winter oat (1)	+ Beans and Peas (1) or Grass or set aside (1) or Spring cereals (1) or Vegetables (1) or Winter oat (1)	Unchanged
22	Winter wheat (2) +	(2) amongst: Winter barley and/or Winter oilseed rape and/or (Grass or set aside or Spring cereals or Vegetables or	Beans and Peas (1) or Grass or set aside (1) or Spring cereals (1) or Vegetables (1) or Winter oat (1)		Unchanged

		Winter oat)			
23	Winter wheat (1) +	Potato (1) +	Winter barley (1 or 2 or 3)	+ Winter oilseed rape (0, 1 or 2)	Unchanged
24	Winter wheat (1) + Winter barley (1) or Winter oilseed rape (1) or Winter oat (1)	Potato (1) +	(1 or 2) occurrences of either Winter barley or Winter oilseed rape or one of each	+ (1 or 2) amongst: Beans and Peas or Grass or set aside or Spring cereals or Vegetables or Winter oat	Unchanged
25	Winter wheat (1) +	Potato (1) +	(3) amongst: Beans and Peas or Grass or set aside or Spring cereals or Vegetables or Winter oat		Unchanged
26	Winter wheat (1) +	Winter barley (1 to 4) +	Winter oilseed rape (0 to 3)		Unchanged
27	Winter wheat (1)	(3) amongst: Winter barley and/or Winter oilseed rape and/or (Grass or set aside or Spring cereals or Vegetables or Winter oat)	(1) amongst: Beans and Peas or Grass or set aside or Spring cereals or Vegetables or Winter oat		Unchanged
28	Potato (1) +	(1 to 4) amongst Winter Barley and/or Winter Oilseed Rape	(0 to 3) amongst: Beans and Peas or Grass or set aside or Spring cereals or Vegetables or Winter oat		Unchanged
29	Potato (1 or 2) +	(3 to 4) amongst: Beans and Peas or Grass or set aside or Spring cereals or Vegetables or Winter oat			Unchanged

30	Winter barley (1 to 5) +	Winter oilseed rape (0 to 4)	Unchanged
31	(1 to 4) amongst winter barley and/or winter oilseed rape	(1 to 4) amongst: Beans and Peas or Grass or set aside or Spring cereals or Vegetables or Winter oat	Unchanged
32	5 amongst: Beans and Peas and/or Grass or set aside and/or Spring cereals and/or Vegetables and/or Winter oat and/or rough grazing		Unchanged

Note: only 7 fields have 5 occurrences of Rough grazing

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