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An applied farming systems approach to infer conservation-relevant agricultural practices for agri-environment policy design

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ABSTRACT

The Common Agricultural Policy (CAP) has shown difficulties in meeting its environmental objectives, namely in supporting biodiversity-friendly farming systems that remain under pressure to intensify or abandon. Proposals to address this have ranged from increasing the focus on highly tailored and targeted agri-environment schemes, to promoting broad-brush policies such as those recently implemented in the Greening of the CAP. Both options have been criticised due to questionable cost-effectiveness. Alternatives based on agri-environment policies oriented to support conservation-relevant farming systems have been suggested, but they have faced operational difficulties related primarily to obtaining the necessary data to define farming system typologies. Here we investigated whether a simplified approach based on a coarse farming system typology built from incomplete data on land-use and livestock, such as that available in CAP paying agencies, could be used to infer on a wider range of conservation-relevant farm management practices and, ultimately, to select the farming systems qualifying for premium payments. Based on data collected by a farm-survey on a High Nature Value farmland area in southern Portugal, we show that some farming systems are consistently associated with conservation-relevant practices related to the use of herbicides, stubble grazing, creation of wildlife plots and early cereal harvest. The traditional system involving the rotational production of cereals and sheep grazing on fallows showed the most favourable balance of land uses and farm management practices with positive conservation effects. Results underlined the potential of farming systems as a framework for developing agri-environment policy.

1. Introduction

A large part of Europe's biodiversity depends on ecosystems provided by traditional and low-input agricultural systems (Bignal and McCracken 1996; Kleijn et al., 2009). These systems are declining due to agriculture intensification or abandonment, which are driven by social, economic and political changes that have occurred during the last decades (Stoate et al., 2009; Latacz-Lohmann and Hodge 2003; Batáry et al., 2015; Lomba et al., 2015), with negative consequences for farmland biodiversity (Donald et al., 2002; Latacz-Lohmann and Hodge 2003; Reidsma et al., 2006). To support the sustainability of these conservation-relevant farming systems, agri-environment schemes (AES) have been implemented under the Common Agricultural Policy (CAP) of the European Union (EU) (European Commission, 2005). Although AES positive outcomes have been documented (e.g. Primdahl et al., 2003; Boatman et al., 2008), their effectiveness seems to be limited due to high transaction costs undermining farmers' voluntary participation, high administrative expenditure, poor environmental performance, and failure in safeguarding high conservation-value farming systems (e.g. Kleijn et al., 2001; Kleijn and Sutherland, 2003; Siebert et al., 2006; Defrancesco et al., 2008; Weber, 2013; Pe'er et al., 2014; Ribeiro et al., 2014; Batáry et al., 2015).

There are essentially two contrasting views to the way agri-environment policies should be designed towards achieving

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greater effectiveness, generally matching CAP Pillars 1 and 2 (European Commission, 2013a; Poláková et al., 2011). On the one hand, Pillar 1 horizontal policy instruments such as the new Green Direct Payments and its Ecological Focus Areas, were recently proposed under the CAP reform 2014–2020 to safeguard and improve farmland biodiversity, and are now mandatory across the EU (European Commission, 2013a; European Commission, 2013b). These broad-scope agri-environment policies offer the advantage of eliminating or significantly reducing transaction costs, but their effectiveness in protecting farmland biodiversity and agroecosystems may be limited, due to poorly specified conservation objectives and low effectiveness of mandatory commitments (Pe'er et al., 2014). They are also more attractive to Member States because they are usually fully funded by the CAP budget, without the need for co-financing.

In marked contrast with these broad-brush policy options, some authors advocate increasing the focus on Pillar 2 agri-environment schemes tailored to meet biodiversity conservation objectives at the local level (e.g., small regions or even individual farms), even at the expense of high administrative costs (e.g. Armsworth et al., 2012). Although the environmental benefits of such complex schemes are potentially high, their sustainability is uncertain due to the high transaction costs involved and the downward trend of the EU budget for Rural Development (Mettepenningen et al., 2011; Weber, 2013), in addition to requiring co-financing by member states. Alternatives are thus needed that conveniently address the trade-offs between scheme precision and administrative costs (Weber, 2015), providing more focused management prescriptions than those achieved by the horizontal policies, while reducing the costs required by local-level schemes (Poláková et al., 2011).

The farming system framework might provide a relatively simple and practical approach to deal with this conundrum, by allowing consideration of groups of farms with similar typology, thereby avoiding the need to tackle the multiple idiosyncrasies of a large number of individual farms (Poláková et al., 2011; Poux, 2013). Farms included in the same farming system type often have similar resource bases, enterprise patterns, livelihoods, and household restrictions (Darnhofer et al., 2012; Ferraton and Touzard, 2009; Keating et al., 2001) and are expected to show common responses to market and policy drivers (Ribeiro et al., 2014). Also, they tend to be associated with specific agricultural practices and land-use patterns to which biodiversity components respond (Bamière et al., 2011; Calvo-Iglesias et al., 2009; Carmona and Nahuelhual, 2010; Ribeiro et al., 2016). Therefore, it is likely that significant benefits could be achieved through an agri-environment policy based on a farming systems selection criteria, whereby only farms operating a farming system considered beneficial to the conservation objectives would qualify for environmental payments.

Although this idea is potentially attractive, it also has some practical problems that need to be duly considered. An important issue is that developing farming system typologies is a key prerequisite of this approach, but this may be difficult due to the need to identify groups of farms with similar agricultural, economic and sociological characteristics (e.g. Andersen et al., 2004; Pointereau et al., 2010). Typically, the farm-level data needed to develop the typology is obtained through a large number of direct enquiries to individual farmers, but this is costly and time consuming. However, previous studies have shown that operational farming system typologies can be developed from data readily available to CAP paying agencies, derived from farmers' annual subsidy applications (Ribeiro et al., 2014). It is unknown, however, whether such data can capture comparable typologies to that developed from detailed field farm surveys. In particular, it is uncertain whether these broad typologies are associated with particular sets of land-uses and agricultural management practices with conservation relevance, which are usually the target of AES schemes (Batáry et al., 2015).

In this paper we address these issues through a case study developed in cereal-steppe landscapes of southern Portugal, which are representative of a High Nature Value Farmland type that is critical for open farmland birds of European conservation concern (BirdLife International, 2004). In previous studies we used data from the Portuguese CAP paying agency to show that in this region there are at least five main farming systems, which are strongly constrained by biophysical, structural and policy drivers (Ribeiro et al., 2014), and occur under a wide range of landscape conditions (Ribeiro et al., 2016). In here we built on these previous studies, using enquiries to individual farmers to: (i) develop a farming system typology based on farm characterization variables analogous to those available in CAP paying agencies, essentially describing land-uses and livestock husbandry; and (ii) assess how management practices with conservation relevance are associated with particular farming systems. Results were then used to discuss the potential of the proposed farming systems approach as a framework for developing agri-environment policy.

2. Materials and methods

2.1. Study area

The study was conducted in southern Portugal (approx. lat.: 3°42′N; long.: 8°05′W), in an agricultural landscape dominated by rainfed, low-intensity farming systems dedicated to cereal production and livestock grazing. The landscape is characterized by a smooth relief, with altitudes ranging ca. 100–200 m above sea level. The climate is Mediterranean, with hot dry summers and moderately cold and rainy winters. The study area limit was adjusted to include 39 local administrative areas encompassing the Special Protection Area (SPA) of Castro Verde, designated under EU Directive 79/409/CEE (Birds Directive). This SPA covers about 80,000 ha of farmland with high conservation value for several steppe birds of conservation concern, such as the great bustard (*Otis tarda* Linn.), little bustard (*Tetrax tetrax* Linn.) and lesser kestrel (*Falco naumanni* Fleischer) (BirdLife International, 2004). The area benefits from an AES set up in 1995 to support traditional farming systems based on extensive rotation of cereals with long term fallows and grazing sheep (Santana et al., 2014), claimed as main providers of the steppe habitat that led to the classification of this area. In recent years there has been a decline of these traditional systems and their replacement by specialized livestock systems, a trend that is partially attributed to recent CAP reforms (Ribeiro et al., 2014) and whose conservation impacts are largely unknown (Reino et al., 2010).

2.2. Farm characterization

We conducted direct enquiries to farmers from a sample of 199 farms, between March and May of 2013. The sample to be enquired was selected randomly from the overall set of ca. 350 farmers renewing their annual application to agricultural subsidies at the main farmers' association in the region, located at Castro Verde (Associação de Agricultores do Campo Branco), where most farmers deliver their annual declarations. Each farmer was interviewed personally by a technician, using a structured questionnaire aiming to obtain information on land-uses, livestock husbandry and farm management practices. From this questionnaire we derived a set of variables required to establish the typology of farming systems and to characterise agricultural management (Table 1).

Farm characterization variables focused on land-use and livestock husbandry (Table 1), because these are widely available in governmental agencies paying CAP subsidies (Ribeiro et al., 2014), therefore enabling replication in other locations. Land-use vari-

Table 1
Summary statistics of the farm characterization variables, included in the farming system typology, and of the farming practices variables, extracted from the 199 farm questionnaires. See Table S1 in Supplementary information for a description of related impacts on farmland birds. Agricultural base year from October 2012 to September 2013.% UAA = Percentage of the utilized agricultural area. LU = livestock units.

Variable	Code	Description	Mean ± SD (Min-Max)
Farm characterization variables:			
Dry cereals	CEREAL	% UAA with dry cereals	19.9 ± 16.9 (0–100)
Other annual crops	OTHCROP	% UAA with other annual crops	1.0 ± 4.4 (0–55.6)
Permanent crops	PCROP	%UAA with permanent crops	0.8 ± 3.0 (0–20.0)
Fallows	FALLOW	% UAA with fallows	64.4 ± 26.1 (0–100)
Pastures	PPAST	% UAA with pastures	13.9 ± 25.1 (0–100)
Cattle ratio	CRATIO	% of cattle LU in total LU	31.5 ± 43.1 (0–100)
Livestock density	STOCKDENS	LU per hectare of fodder area	0.37 ± 0.44 (0–2)
Farming practices variables:			
Fertilizers	FERTILIZERS	% UAA fertilized	21.4 ± 17.7 (0–100)
Herbicides	HERBICIDES	% UAA treated with herbicides	6.6 ± 13.9 (0–82.6)
Direct drill	DIRCTDRILL	% UAA under direct drill	0.6 ± 5.6 (0–70.8)
Plough	PLOUGH	% UAA ploughed or disked	18.9 ± 18.4 (0–100)
Mechanical operations	N_MECOP	Number of mechanical operations in arable land (typical year)	3.48 ± 1.31 (0–7)
Irrigation	IRRIGAT	% UAA irrigated	1.1 ± 8.4 (0–100)
Stubs not grazed	STUBNGRAZ	% UAA with ungrazed stubbles	3.2 ± 12.4 (0–100)
Improved pastures	PASTPLUS	% UAA with improved pastures	6.4 ± 17.0 (0–100)
Wildlife plots	WLIFEPLOT	% UAA with wildlife food plots	0.8 ± 2.1 (0–17.8)
Conservation buffers	CONSBUFF	% UAA with conservation buffers	7.1 ± 14.6 (0–100)
Stockpiled forages	STOCKFOR	% UAA with stockpiled forages	8.7 ± 13.1 (0–69.6)
Crop rotation	ROTYEARS	Duration of crop rotation (years)	1.82 ± 2.09 (0–5.00)
Early harvest	EARLYHARV	% of the cereal area that is harvested before 31th May	42.0 ± 49.1 (0–100)
Wire fences	WIREFENCE	Meters of wire fences per hectare	31.3 ± 71.6 (0–593.1)

ables included: dry cereals (CEREAL), mainly rainfed wheat and barley but also forage crops, which were considered together because many farmers often use cereal crop for hay production when it did not develop favourably to grain production; other annual crops (OTHCROP), such as sunflower, sorghum or legumes, whether irrigated or rainfed; permanent crops (PCROP), mainly olive groves; fallows (FALLOW), consisting of arable land that was not sown from one to four years to recover soil fertility, typically within a crop rotation scheme which is often used for stock grazing; pastures (PPAST), grazing areas not cultivated for five or more years, encompassing permanent pastures and long term fallows. Livestock production was characterised from variables reflecting stocking density (STOCKDENS) and the relative importance of cattle versus sheep (CRATIO).

Agricultural management was characterised from 14 variables reflecting farming practices (Table 1), which were selected due to their potential relevance for the conservation of open farmland birds (see Table S1 in Supplementary information). Fertilizers (FERTILIZERS) and herbicides (HERBICIDES) were considered because they have general negative effects on farmland wildlife. Direct drill or no-till operations (DIRCTDRILL) were included due to the positive effects of such techniques, while ploughing and disking (PLOUGH) provide bare soil used by a number of farmland birds, though they also have negative impacts such as soil erosion and carbon loss. The number of mechanical operations involved in farmland cultivation (N_MECOP; e.g. ploughing, disking, seeding, mowing or harvesting) may cause negative impacts on birds (e.g. mortality or disturbance). Irrigation practices (IRRIGAT) are associated with agricultural intensification and major negative impacts on farmland birds. Ungrazed cereal or forage stubbles (STUBNGRAZ) have a positive effect on birds by providing food sources and avoiding the negative impacts of livestock grazing. Improved pastures (PASTPLUS) are associated with negative impacts emerging from high inputs and livestock densities. Wildlife plots (WLIFEPLOT) correspond mostly to crops sown specifically for the benefit of steppe birds, while conservation buffers (CONSBUFF) are strips of cover crops reducing negative impacts of agricultural practices and providing a variety of ecosystem services, including habitat for farmland birds. Stockpiled forages (STOCKFOR) are forage crops that are allowed to grow and accumulate for later grazing during periods of forage deficit, thereby avoiding the negative impacts of grazing such as trampling or nest destruction. Crop rotation (ROTYEARS) is favourable to farmland birds by promoting a complex mosaic of crops and fallows with different ages. The early harvest of crops (EARLYHARV) is associated with nest destruction and chick mortality. Fencing (WIREFENCE) is important as it can cause high bird mortality due to collisions.

2.3. Data analysis

The farming system typology was established considering the seven farm characterization variables reflecting land-uses and livestock husbandry (Table 1). Based on these variables, farms were assigned to groups of farming systems by hierarchical cluster analysis using the Ward's method, which is an agglomerative approach that minimizes the within-group sum of squares, tending to form balanced-sized groups (Borcard et al., 2011; Legendre and Legendre, 1998). The outcome was assessed based on the analysis of the resulting dendrogram and with reference to similar typologies obtained by previous works in the same study area (Ribeiro et al., 2014). We then used one-way ANOVA to identify significant variation among farming systems in the variables characterising land-uses, livestock husbandry and farming practices, applying the Holm's correction on the p-values to account for multiple testing and ensure conservative results (Legendre and Legendre, 1998). To detect where the differences occurred between groups we used Games–Howell (GH) post hoc tests, which allows for heterogeneous variance and uneven sample sizes (Schmitzberger et al., 2005).

To assess whether farming systems could be discriminated in terms of farming practices, we conducted a linear discriminant analysis (LDA). A correlation matrix was computed prior to the analysis to investigate possible collinearity problems between these variables. A stepwise forward Wilk's lambda test procedure was conducted to select those variables that significantly ($p < 0.050$) contributed to group separation (Roever et al., 2014). The accuracy of the prediction was assessed through a confusion matrix, with leave-one-out cross-validation. Since sample sizes were uneven among the farming systems, we used Cohen's weighted kappa to

Table 2
Summary statistics (mean ± SD) of the five farming systems returned by the hierarchical cluster analysis. Variable definition in Table 1. Variables with significant differences ($p < 0.050$) among groups are shaded grey.

Variable	Sheep	Cattle	Traditional	Crops	Intensive grazing[(a)]	ANOVA[(b)]
Number of farms	52	66	31	31	19	-
% UAA	17.2	52.8	12.1	10.8	1.8	-
Average farm size (ha)	155±142	415±288	184±182	164±119	44±60	-
CEREAL (%)	15.2±13.1	20.2±11.8	19.6±25.9	27.9±9.5	19.0±26.7	0.012
OTHCROP (%)	0.5±1.2	0.7±1.7	2.7±10.3	1.5±2.8	0.0±0.0	0.289
PCROP (%)	0.9±3.4	0.2±0.7	0.6±1.5	0.2±0.6	4.0±6.9	0.289
FALLOW (%)	81.8±13.4	66.7±20.4	29.2±23.7	69.6±10.5	57.9±35.6	<0.005
PPAST (%)	1.7±4.0	12.2±19.4	47.9±29.9	0.8±2.6	19.2±36.0	<0.005
CRATIO (%)	0.8±4.2	85.4±21.3	0	0	30.7±43.7	<0.005
STOCKDENS (LU/ha)	0.31±0.19	0.39±0.14	0.15±0.19	0.004±0.02	1.49±0.47	<0.005

(a) System not included in ANOVA.
(b) Holm's adjusted p-values.

correct for agreements occurring by chance between observed and predicted categories, considering both matches in the main diagonal and off diagonal (Titus et al., 1984). Inertia ellipses were added to the LDA plots to help visualizing the distribution of observations within each farming system along the axes, considering the default probability of ca. 66% corresponding to a one standard deviation length. All statistical analyses were implemented in R version 3.2.2 (R Development Core Team, 2015).

3. Results

3.1. Farming systems characterization

The 199 surveyed farms covered a total of 47,103 ha of UAA. The dominant land-use was fallow (64.4%), followed by cereal crops (19.9%) (Table 1). Permanent pastures and long-term fallows occupied almost the entire remaining area (13.9%). Other annual crops and permanent crops had a marginal expression (1.0% and 0.8% respectively). Sheep were dominant in total livestock (cattle ratio 31.5%), while overall livestock density was 0.37 LU/ha.

The examination of the dendrogram produced by the cluster analysis (Fig. S1 in Supplementary information) led to the selection of a cut-off point defining five groups, which were consistent with the previous typology defined in the same area using data from the Portuguese CAP paying agency (Ribeiro et al., 2014). The five clusters were named according to the distinctive characteristics of each group (Table 2). The Sheep, Cattle and Intensive grazing systems were identified as livestock specialized systems, differing mainly on the type of livestock and grazing density. The Crops system was acknowledged as specialized in annual crop production, with no livestock. The Traditional system was identified as a mixed system, where annual crop production was complemented with low density livestock grazing, dominated by sheep. The average livestock density characterizing the Intensive grazing system was found abnormally above regional standards, probably indicating that these farms feed their animals by resorting to food purchase (hay, silage or concentrate feed) or to rented pastures or stubble crops in neighbouring farms. Consequently, the estimated value is artificial, not representing a true livestock density in the farm. For this reason, and because it occupied a very small area (<2%), this cluster was dropped from further analysis, reducing the sample to 180 observations.

All seven farm characterization variables showed significant differences (Holm's adj. $p < 0.050$) among the four retained farming systems, except for OTHCROP and PCROP (Table 2). The proportion of cereals was significantly higher in the Crops system, relatively to the Sheep and Cattle systems (CEREAL GH post hoc $p < 0.001$ and $p = 0.005$, respectively). The Sheep system had the highest proportion of fallows (FALLOW GH post hoc $p < 0.001$) and the lowest proportion was found on the Traditional system (FALLOW GH post hoc $p < 0.001$). The proportion of pastures and long term fallows was significantly higher in the Traditional system (PPAST GH post hoc

Table 3
Summary statistics (mean ± SD) of the farming systems in terms of farming practices. Variable definition in Table 1 Variables with significant differences ($p < 0.050$) among groups are shaded grey.

Variable	Sheep	Cattle	Traditional	Crops	ANOVA[(a)]
FERTILIZERS (%)	16.0±13.1	20.7±11.6	22.4±27.5	28.7±11.5	0.063
HERBICIDES (%)	5.7±12.0	4.0±8.1	7.1±20.3	15.2±16.3	0.022
DIRCTDRILL (%)	0.0±0.0	0.8±4.4	2.3±12.7	0.0±0.0	0.733
PLOUGH (%)	13.6±13.6	20.1±12.1	20.0±25.9	19.2±19.0	0.733
N_MECOP (count)	3.5±1.2	3.7±1.1	3.1±1.8	3.8±1.2	0.733
IRRIGAT (%)	0.0±0.0	0.4±1.9	2.8±10.9	0.0±0.0	0.273
STUBNGRAZ (%)	0.3±1.6	0.8±3.9	2.7±11.1	7.4±15.5	0.012
PASTPLUS (%)	3.7±13.2	9.3±17.9	3.9±18.0	4.5±14.3	0.733
WLIFEPLOT (%)	0.5±0.8	0.4±0.8	0.5±1.6	2.1±3.6	0.002
CONSBUFF (%)	6.7±12.5	6.2±12.2	7.3±19.8	11.7±16.6	0.733
STOCKFOR (%)	8.4±12.6	11.4±11.1	10.1±16.8	2.7±12.7	0.170
ROTYEARS (years)	1.71±1.95	2.06±2.20	1.52±2.03	2.68±2.20	0.733
EARLYHARV (%)	27.2±44.0	72.0±44.8	29.0±46.1	16.1±37.4	<0.005
WIRFENCE (m/ha)	44.2±87.5	21.0±26.0	12.5±27.9	11.2±21.7	0.090

(a) Holm's adjusted p-values.

$p < 0.001$). The Cattle ratio was significantly higher in the Cattle system (CRATIO GH post hoc $p < 0.001$). Stock density was significantly higher in the Sheep and Cattle systems, compared to the Traditional (STOCKDENS GH post hoc $p = 0.003$ and $p < 0.001$, respectively) and Crops systems (STOCKDENS GH post hoc $p < 0.001$ in both cases).

3.2. Farming practices

The use of fertilizers (FERTILIZERS; 21.4% of UAA) and soil ploughing (PLOUGH; 18.9%) were the most widespread farming practices, while direct drill (DIRCTDRILL; 0.6%), the sowing of wildlife crops (WLIFEPLOT; 0.8%) and irrigation (IRRIGAT; 1.1%) were the least represented (Table 1). The average number of mechanical operations in the arable land was 3.5 and the average crop rotation lasted for 1.8 years. About 42% of the cereal area on the average farm was harvested before the 31th of May.

The ANOVA tests with Holm's correction revealed statistically significant differences ($p < 0.050$) among farming systems in four out of 14 farming practices (Table 3), namely in herbicide consumption (HERBICIDES), ungrazed stubbles (STUBNGRAZ), wildlife plots (WLIFEPLOT) and cereal area harvested before the 31th of May (EARLYHARV). Pairwise comparisons showed that herbicide consumption was significantly higher in the Crops system than in the Sheep and Cattle systems (HERBICIDES GH post hoc $p = 0.032$ and $p = 0.004$ respectively), and that the proportion of early harvested cereal was significantly higher in the Cattle system compared to all other systems (EARLYHARV GH post hoc $p < 0.001$). Variables STUBNGRAZ and WLIFEPLOT also showed a significant trend for higher values in the Crops system, although no significant differences were found in the pairwise Games–Howell post hoc tests, probably due to their weak representation in the surveyed farms.

High correlation (>0.70) among farming practices was only found between FERTILIZERS and PLOUGH (0.84), and so we

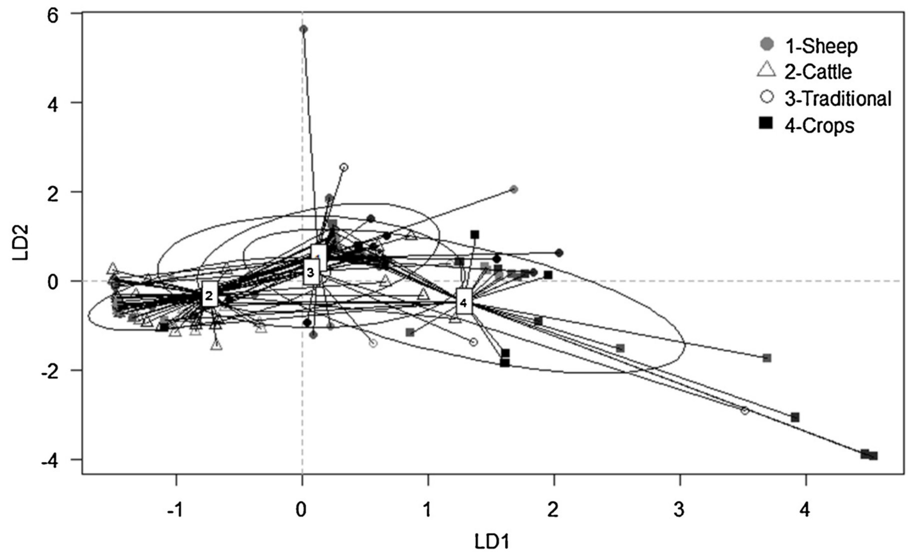

Fig. 1. Scatterplot of the surveyed farms in the first two linear discriminant axis. The centroids and inertia ellipses are provided for each farming system.

discarded the latter from subsequent analysis. In the linear discriminant analysis (LDA), variable selection using Wilk's lambda identified 6 variables contributing significantly ($p < 0.050$) to the separation of farming systems (Table 4). The first linear discriminant axis (LD1) captured 68.1% of the between-group variance and it largely contrasted farming systems with either early harvest (Cattle) or high use of herbicides (Crops) (Table 4, Fig. 1). The Traditional and Sheep systems had an intermediate position in this axis (Fig. 1). LD2 captured 21.3% of the variance and it was mainly related to the joint increase in early harvest and ungrazed stubbles (Table 4). Farming systems were not clearly separated along this axis. LD3 captured the remaining 10.6% of the between group variance, mainly contrasting farms with either irrigation or fencing. The overall prediction accuracy of the LDA, with leave-one-out cross validation, reached 55.6% of success rate, corresponding to an overall Cohen's weighted kappa of 42.5% after correcting for chance agreements, which is still clearly above the random success probability of 25.0% within the four groups. Comparing the prediction accuracy on individual farming systems, the proportions of correct classifications were much higher for the Cattle (72.7%; Cohen's weighted kappa = 44.4%), Sheep (65.4%; Cohen's weighted kappa = 28.5%) and Crops systems (51.6%; Cohen's weighted kappa = 54.6%), than for the Traditional system (6.5%; Cohen's weighted kappa = 3.4%).

4. Discussion

Our results suggest that a farming systems typology built on partial farm-level data, such as that available in CAP paying agencies, can be used to infer key farm management practices of high conservation relevance, and therefore provide relevant information for conservation managers and policy makers. The farming systems showed statistically significant differences in farm characterization variables (land-use and livestock patterns) and farming practices variables with high impact on biodiversity (herbicide consumption, ungrazed stubbles, wildlife plots and early harvest). These differences may help to identify which farming systems have higher conservation value and therefore potentially qualify for financial support through agri-environment schemes.

The Crops and the Cattle systems showed the strongest links with farming practices known to have direct negative effects on farmland birds in the study area (herbicide consumption and the date of cereal harvest, respectively). The Traditional system displayed a moderate stock density and a more varied landscape mosaic, with a balanced distribution of the UAA between cereals, pastures, fallows and small patches of other crops, providing landscape heterogeneity which is a valued feature for farmland biodiversity (Benton et al., 2003) and a landscape mosaic favourable to steppe bird conservation (Delgado and Moreira, 2000; Moreira et al., 2004; Reino et al., 2010). Accordingly, this system was identified as representing the traditional farming system that dominated the local landscape for decades and provided the high valued steppe habitat for several bird species of conservation concern (Ribeiro et al., 2014; Santana et al., 2014), and therefore it could qualify as a prime target for a local conservation program.

Our study also showed that it is possible that similar agricultural land-uses entail significant differences in farming practices key for conservation when held under distinct farming systems, which is a rather unexplored issue in the literature with potential implications for policy design. A case in point is that of rainfed cereals which are typically harvested in late June for grain production but, if weather conditions do not favour the growth of the crop, it can be harvested in late May for hay production. As a consequence, harvest may overlap the breading season of farmland bird species of conservation concern that nest in cereal fields, causing nest destruction and chick mortality (Beja et al., 2014). This farming practice was found particularly associated to the Cattle system which is dominant in the study area, thereby implying that most of the cereals area in the region (52%) are affected by this farming practice. Interactions between agriculture and conservation such as these are hardly detectable by conventional landscape analysis

Table 4
Standardized canonical coefficients of the discriminant functions used to separate four farming systems based on practices relevant for bird conservation. Values > 0.50 are in bold. Variable definition in Table 1.

Variable	LD1	LD2	LD3
EARLYHARV	−0.75	**−0.63**	0.19
HERBICIDES	**0.54**	−0.10	0.12
WLIFEPLOT	0.35	−0.33	0.13
IRRIGAT	−0.30	0.26	**−0.82**
STUBNGRAZ	0.30	**−0.58**	0.08
WIRFENCE	−0.02	0.43	**0.59**

techniques often used in AES design (e.g. Batáry et al., 2015; Engel et al., 2008; Fahrig et al., 2011; Ribeiro et al., 2016), which would likely classify all dry cereal area indistinctively and assigned with equal conservation value.

The farming system typology built in this study was consistent with similar typologies produced by a previous study that used data from farmers' annual applications for CAP payments within the same study area (Ribeiro et al., 2014), suggesting that the framework can be easily reproduced on other locations with comparable conservation problems, using similar CAP paying data. Such a framework would potentially improve the cost-effectiveness of agri-environment policies since qualifying farms could be automatically selected on a yearly basis, avoiding the need for contracting long-term subscription agreements with individual farmers, as with many actual AES (Batáry et al., 2015), which would thus be encouraged to remain in the premium paid farming systems. In addition, it is conceivable that the framework would fit under CAP Pillar 1, thereby avoiding co-financing by Member States and relieving funds for Pillar 2 Rural Development policies. Moreover, aside from financing the preliminary studies to identify the farming systems to target, no significant extra-costs should emerge, as the required data to implement the framework is already available in the farm-level databases maintained by the CAP paying agencies in Member States, and also because significant cost-savings could be expected from the inherent simplification of the administrative burden and the easing of field inspections.

Overall, our results suggest that farming systems may be a cost-effective instrument for mitigating tension between development and biodiversity conservation, by providing a comprehensive tool to specify patterns of farmland use, livestock husbandry and farming practices, potentially useful to support the design of selective payment schemes targeted on sustainable farming systems, particularly on areas of special conservation concern. This conclusion tends to support those arguing that the CAP agri-environment policy could be planned based on simpler farm-level eligibility criteria (e.g. Beaufoy and Marsden, 2011; Poláková et al., 2011; Poux, 2013; Schmitzberger et al., 2005), such as operating pre-selected high conservation-value farming systems, as illustrated by the Traditional system in our study area.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.landusepol.2016.07.018.

References

Andersen, E., Baldock, D., Bennett, H., Beaufoy, G., Bignal, E., Brouwer, F., Elbersen, B., Eiden, G., Godeschalk, F., Jones, G., McCracken, D., Nieuwenhuizen, W., van Eupen, M., Hennekens, S., Zervas, G., 2004. Developing a High Nature Value Farming Area Indicator. HNV Farming Project—final Report. Institute for European Environmental Policy.

Armsworth, P.R., Acs, S., Dallimer, M., Gaston, K.J., Hanley, N., Wilson, P., 2012. The cost of policy simplification in conservation incentive programs. Ecol. Lett. 15, 406–414, http://dx.doi.org/10.1111/j.1461-0248.2012.01747.x.

Bamière, L., Havlík, P., Jacquet, F., Lherm, M., Millet, G., Bretagnolle, V., 2011. Farming system modelling for agri-environmental policy design: the case of a spatially non-aggregated allocation of conservation measures. Ecol. Econ. 70, 891–899, http://dx.doi.org/10.1016/j.ecolecon.2010.12.014.

Batáry, P., Dicks, L.V., Kleijn, D., Sutherland, W.J., 2015. The role of agri-environment schemes in conservation and environmental management. Conserv. Biol. 29, 1006–1016, http://dx.doi.org/10.1111/cobi.12536.

Beaufoy, G., Marsden, K., 2011. CAP Reform 2013: Last Chance to Stop the Decline of Europe's High Nature Value Farming. European Forum on Nature Conservation and Pastoralism, Birdlife International European Division, Butterfly Conservation Europe. WWF European Policy Office.

Beja, P., Schindler, S., Santana, J., Porto, M., Morgado, R., Moreira, F., Pita, R., Mira, A., Reino, L., 2014. Predators and livestock reduce bird nest survival in intensive Mediterranean farmland. Eur. J. Wildl. Res. 60, 249–258, http://dx.doi.org/10.1007/s10344-013-0773-0.

Benton, T.G., Vickery, J.A., Wilson, J.D., 2003. Farmland biodiversity: is habitat heterogeneity the key? Trends Ecol. Evol. 18, 182–188, http://dx.doi.org/10.1016/S0169-5347(03)00011-9.

Bignal, E.M., McCracken, D.I., 1996. Low-intensity systems in the conservation of the countryside. J. Appl. Ecol. 33, 413–424, http://dx.doi.org/10.2307/2404804.

BirdLife International, 2004. *Birds in the European Union: a status assessment*. Wageningen, The Netherlands: BirdLife International.

Boatman, N., Ramwell, C., Parry, H., Bishop, J., Gaskell, P., Mills, J., Dwyer, J., 2008. A review of environmental benefits supplied by agri-environment schemes. Land Use Policy Group.

Borcard, D., Gillet, F., Legendre, P., 2011. Numerical Ecology with R, Use R!. Springer, New York, http://dx.doi.org/10.1007/978-1-4419-7976-6.

Calvo-Iglesias, M.S., Fra-Paleo, U., Diaz-Varela, R.A., 2009. Changes in farming system and population as drivers of land cover and landscape dynamics: the case of enclosed and semi-openfield systems in Northern Galicia (Spain). Landsc. Urban Plan. 90, 168–177, http://dx.doi.org/10.1016/j.landurbplan.2008.10.025.

Carmona, A., Nahuelhual, L., 2010. Linking farming systems to landscape change: an empirical and spatially explicit study in southern Chile. Agric. Ecosyst. 139, 40–50, http://dx.doi.org/10.1016/j.agee.2010.06.015.

Darnhofer, I., Gibbon, D., Dedieu, B., 2012. Farming systems research: an approach to inquiry. In: Darnhofer, I., Gibbon, D., Dedieu, B. (Eds.), Farming Systems Research into the 21st Century: The New Dynamic. Springer, pp. 1–26.

Defrancesco, E., Gatto, P., Runge, F., Trestini, S., 2008. Factors affecting farmers'participation in agri-environmental measures: a northern Italian perspective. J. Agric. Econ. 59, 114–131, http://dx.doi.org/10.1111/j.1477-9552.2007.00134.x.

Delgado, A., Moreira, F., 2000. Bird assemblages of an Iberian cereal steppe. Agric. Ecosyst. Environ. 78, 65–76, http://dx.doi.org/10.1016/S0167-8809(99)00114-0.

Donald, P.F., Pisano, G., Rayment, M.D., Pain, D.J., 2002. The common agricultural policy, EU enlargement and the conservation of Europe's farmland birds. Agric. Ecosyst. Environ. 89, 167–182.

Engel, S., Pagiola, S., Wunder, S., 2008. Designing payments for environmental services in theory and practice: an overview of the issues. Ecol. Econ. 65, 663–674, http://dx.doi.org/10.1016/j.ecolecon.2008.03.011.

European Commission, 2005. Agri-environment Measures—Overview on General Principles, Types of Measures, and Application. Directorate General for Agriculture and Rural Development.

European Commission, 2013a. Overview of CAP Reform 2014-2020, Agricultural Policy Perspectives Brief No. 5.

European Commission, 2013b. Regulation (EU) No 1307/2013 of the European Parliament and of the Council of 17 December 2013 establishing rules for direct payments to farmers under support schemes within the framework of the common agricultural policy and repealing Council Regulation. European Parliament and of the Council.

Fahrig, L., Baudry, J., Brotons, L., Burel, F.G., Crist, T.O., Fuller, R.J., Sirami, C., Siriwardena, G.M., Martin, J.-L., 2011. Functional landscape heterogeneity and animal biodiversity in agricultural landscapes. Ecol. Lett. 14, 101–112, http://dx.doi.org/10.1111/j.1461-0248.2010.01559.x.

Ferraton N., Touzard I., 2009, Comprendre l'agriculture familiale: diagnostic des systèmes de production, Quae. ed. Les presse agronomique de Gembloux.

Keating, B.A., McCown, R.L., 2001. Advances in farming systems analysis and intervention. Agric. Syst. 70, 555–579, http://dx.doi.org/10.1016/S0308-521X(01)00059-2.

Kleijn, D., Sutherland, W.J., 2003. How effective are European agri-environment schemes in conserving and promoting biodiversity? J. Appl. Ecol., 947–969.

Kleijn, D., Berendse, F., Smit, R., Gilissen, N., 2001. Agri-environment schemes do not effectively protect biodiversity in Dutch agricultural landscapes. Nature 413, 723–725, http://dx.doi.org/10.1038/35099540.

Kleijn, D., Kohler, F., Báldi, A., Batáry, P., Concepción, E.D., Clough, Y., Díaz, M., Gabriel, D., Holzschuh, A., Knop, E., Kovács, A., Marshall, E.J.P., Tscharntke, T., Verhulst, J., 2009. On the relationship between farmland biodiversity and land-use intensity in Europe. Proc. Biol. Sci. 276, 903–909, http://dx.doi.org/10.1098/rspb.2008.1509.

Latacz-Lohmann, U., Hodge, I., 2003. European agri-environmental policy for the 21 st century. Aust. J. Agric. Resour. Econ. 47 (1), 123–139.

Legendre, P., Legendre, L., 1998. Numerical ecology. In: Developments in Environmental Modelling, 2nd Englis. ed. Elsevier, Amsterdam.

Lomba, A., Alves, P., Jongman, R.H.G., Mccracken, D.I., 2015. Reconciling nature conservation and traditional farming practices: a spatially explicit framework to assess the extent of High Nature Value farmlands in the European countryside. Ecol. Evol., 1–14, http://dx.doi.org/10.1002/ece3.1415.

Mettepenningen, E., Beckmann, V., Eggers, J., 2011. Public transaction costs of agri-environmental schemes and their determinants—analysing stakeholders' involvement and perceptions. Ecol. Econ. 70, 641–650, http://dx.doi.org/10.1016/j.ecolecon.2010.10.007.

Moreira, F., Morgado, R., Arthur, S., 2004. Great bustard Otis tarda habitat selection in relation to agricultural use in southern Portugal. Wildl. Biol., 251–260.

Pe'er, G., Dicks, L.V., Visconti, P., Arlettaz, R., Baldi, A., Benton, T.G., Collins, S., Dieterich, M., Gregory, R.D., Hartig, F., Henle, K., Hobson, P.R., Kleijn, D., Neumann, R.K., Robijns, T., Schmidt, J., Shwartz, A., Sutherland, W.J., Turbe, A., Wulf, F., Scott, A.V., 2014. EU agricultural reform fails on biodiversity. Science 344, 1090–1092, http://dx.doi.org/10.1126/science.1253425.

Pointereau, P., Doxa, A., Coulon, F., Jiguet, F., Paracchini, M.L., 2010. Analysis of Spatial and Temporal Variations of High Nature Value Farmland and Links with Changes in Bird Populations: A Study on France JRC Scientific and Technical Reports. Joint Research Centre of the European Commission.

Poláková, J., Tucker, G., Hart, K., Dwyer, J., Rayment, M., 2011. Addressing Biodiversity and Habitat Preservation Through Measures Applied under the Common Agricultural Policy, Report Prepared For DG Agriculture and Rural Development Contract No. 30-CE- 0388497/00-44. Institute for European Environmental Policy.

Poux, X., 2013. Biodiversity and Agricultural Systems in Europe: Drivers and Issues for the Cap Reform. Institut du développement durable et des relations internationales.

Primdahl, J., Peco, B., Schramek, J., Andersen, E., Oñate, J.J.J., 2003. Environmental effects of agri-environmental schemes in Western Europe. J. Environ. Manag. 67, 129–138, http://dx.doi.org/10.1016/S0301-4797(02)00192-5.

R Development Core Team, 2015. R: A language and environment for statistical computing. [WWW Document]. R Found. Stat. Comput. URL http://www.r-project.org (accessed 12.26.11.).

Reidsma, P., Tekelenburg, T., van den Berg, M., Alkemade, R., 2006. Impacts of land-use change on biodiversity: an assessment of agricultural biodiversity in the European Union. Agric. Ecosyst. Environ. 114, 86–102, http://dx.doi.org/10.1016/j.agee.2005.11.026.

Reino, L., Porto, M., Morgado, R., Moreira, F., Fabião, A., Santana, J., Delgado, A., Gordinho, L., Cal, J., Beja, P., 2010. Effects of changed grazing regimes and habitat fragmentation on Mediterranean grassland birds. Agric. Ecosyst. Environ. 138, 27–34, http://dx.doi.org/10.1016/j.agee.2010.03.013.

Ribeiro, P.F., Santos, J.L., Bugalho, M.N., Santana, J., Reino, L., Beja, P., Moreira, F., 2014. Modelling farming system dynamics in High Nature Value Farmland under policy change. Agric. Ecosyst. Environ. 183, 138–144, http://dx.doi.org/10.1016/j.agee.2013.11.002.

Ribeiro, P.F., Santos, J.L., Santana, J., Reino, L., Leitão, P.J., Beja, P., Moreira, F., 2016. Landscape makers and landscape takers: links between farming systems and landscape patterns along an intensification gradient. Landsc. Ecol., http://dx.doi.org/10.1007/s10980-015-0287-0.

Roever, C., Raabe, N., Luebke, K., Ligges, U., Szepannek, G., Zentgraf, M., 2014. Package klaR: Classification and visualization [WWW Document]. URL http://www.statistik.tu-dortmund.de.

Santana, J., Reino, L., Stoate, C., Borralho, R., Carvalho, C.R., Schindler, S., Moreira, F., Bugalho, M.N., Ribeiro, P.F., Santos, J.L., Vaz, A., Morgado, R., Porto, M., Beja, P., 2014. Mixed effects of long-term conservation investment in natura 2000 farmland. Conserv. Lett. 7, 467–477, http://dx.doi.org/10.1111/conl.12077.

Schmitzberger, I., Wrbka, T., Steurer, B., Aschenbrenner, G., Peterseil, J., Zechmeister, H.G., 2005. How farming styles influence biodiversity maintenance in Austrian agricultural landscapes. Agric. Ecosyst. Environ. 108, 274–290, http://dx.doi.org/10.1016/j.agee.2005.02.009.

Siebert, R., Toogood, M., Knierim, A., 2006. Factors affecting european farmers' participation in biodiversity policies. Sociol. Ruralis 46, 318–340, http://dx.doi.org/10.1111/j.1467-9523.2006.00420.x.

Stoate, C., Báldi, A., Beja, P., Boatman, N.D., Herzon, I., van Doorn, A., de Snoo, G.R., Rakosy, L., Ramwell, C., 2009. Ecological impacts of early 21 st century agricultural change in Europe–a review. J. Environ. Manag. 91, 22–46, http://dx.doi.org/10.1016/j.jenvman.2009.07.005.

Titus, K., Mosher, J.A., Williams, B.K., 1984. Chance-corrected classification for use in discriminant analysis: ecological applications. Am. Midl. Nat. 111, 1, http://dx.doi.org/10.2307/2425535.

Weber, A., 2013. How are public transaction costs in regional agri-environmental scheme delivery influenced by EU regulations? J. Environ. Plan. Manag., 1–23, http://dx.doi.org/10.1080/09640568.2013.776950.

Weber, A., 2015. Implementing EU co-financed agri-environmental schemes: effects on administrative transaction costs in a regional grassland extensification scheme. Land Use Policy 42, 183–193, http://dx.doi.org/10.1016/j.landusepol.2014.07.019.