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Assessing the link between farming systems and biodiversity in agricultural landscapes: Insights from Galicia (Spain)

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A R T I C L E I N F O

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A B S T R A C T

Agriculture is a major driver of change with manifold impacts on biodiversity and ecosystem services. As social-ecological systems, agricultural landscapes result from the intertwined interaction between farmers and nature, and contribute to several ecosystem services key to human well-being. The social-ecological outcomes of farmlands ultimately reflect the management practices of the dominant farming systems (FS) at the landscape level. However, data-driven research linking agricultural management and biodiversity is still scarce, a knowledge gap limiting our understanding on the impacts of different farming systems on biodiversity at the landscape level.

This research contributes to fill this knowledge gap, by being among the few explicitly exploring the relationship between FS and patterns of biodiversity at the landscape level, using as illustrative case the region of Galicia, northwest Spain. Using data from agricultural policies paying agencies, and protected species and habitats data, the following research questions were pursued: (1) Can farm-level data be used to map and characterize different FS at the landscape-level? and, (2) Is the occurrence of specific FS linked with higher levels of biodiversity?

Results allowed the identification and characterization of seven different FS distributed across Galicia, which dominance allowed to identify seven landscape types. Moreover, besides depicting the dominance of cattle-based farming systems in Galicia, results showed a gradient of management from the most intensive located in coastal lowlands (west) towards less intensive mountain areas (east). Such gradient of decreasing management intensity matched a gradient of increasing nature value of farmlands, reflected as higher habitat diversity and richness for some of the targeted taxonomic groups.

To our knowledge, this research is among the few explicitly addressing the relationship between FS and biodiversity at the landscape level. By highlighting potential links (positive or negative) between specific landscape types and habitats and/or species richness across targeted taxonomic groups, these results constitute a preliminary assessment of the agricultural practices promoting species and habitat richness. Further scrutinizing this assessment can support the identification of farm-level indicators that can be then translated into the design of policies (biodiversity or agriculture-related) fostering biodiversity at several scales of decision making.

1. Introduction

Agriculture is currently a dominant use of the land and a major driver of environmental change and thus agricultural landscapes are key to achieve the United Nations Sustainable Development Goals (SDGs), such as food security and environmental sustainability (DeClerck et al., 2016;

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Landis, 2017; Rasmussen et al., 2018; Rockström et al., 2017). As social-ecological systems, agricultural landscapes reflect the intertwined interaction between humans (farmers) and nature through time (Fischer et al., 2017). The contribution of agricultural landscapes to society goes beyond provisioning ecosystem services (e.g. production of food, forage and fibre). Farmlands can contribute with a wide range of other key ecosystem services to society such as regulating (e.g. climate regulation, pollination) and cultural (e.g. aesthetic and/or touristic values), while providing habitat for biodiversity (Birkhofer et al., 2018; DeClerck et al., 2016; Groot et al., 2018; Power, 2010). However, the social-ecological outcomes of farmlands relate to the characteristics (structure and composition) of supporting landscapes, which ultimately reflect the management practices, i.e. farming systems (FS) prevailing at the landscape level (Birkhofer et al., 2018; Groot et al., 2018; Santos et al., 2020).

Distinct farming systems are characterized by different field- and farm-level agricultural practices, reflecting farmers' decisions on crop selection, livestock management and/or the maintenance of non-crop elements (Martin et al., 2020; Santos et al., 2020; Stoate et al., 2009). Managed under intensive FS, agricultural landscapes contribute mainly to food and fibre production, but at high costs for the natural environment (Rasmussen et al., 2018). Agricultural intensification has been pinpointed as major driver of land use change, causing landscape homogenization, habitat degradation and loss, and the decline of species of conservation interest (Rasmussen et al., 2018; Tapia et al., 2017). Conversely, farmlands managed under low-intensive farming systems, especially those designated in Europe as High Nature Value farmlands (HNVf), have been highlighted for contributing to a wide range of ecosystem services, beyond support to biodiversity (Lomba et al., 2020a; Santos et al., 2020). Characterized by low levels of agrochemical inputs and livestock stoking, minimal mechanization and the rotational use of the land, HNV farming systems maximize the use of territorial resources for agricultural production, while promoting landscape level heterogeneity. Therefore, the maintenance of HNV farming systems has been related to the occurrence of species and/or habitats, among which some of conservation concern (Anderson and Mammides, 2020; Lomba et al., 2020b; Plieninger and Bieling, 2013).

The European Union (EU) Common Agricultural Policy (CAP) has been recognizing the role of agricultural landscapes to meet societal environmental concerns, namely by explicitly defining specific practices (e.g. cross compliance) that farmers' should observe or by supporting low intensity FS fostering the nature value of agricultural landscapes (Lomba et al., 2020b; Pe'er et al., 2020). Overall, CAP instruments align with other EU policy instruments such as Nature Directives (Habitats and Birds Directives) and the EU Biodiversity Strategy, which, among other objectives, aim to include agricultural areas under high-diversity landscape features and organic farming management through uptaking agro-ecological practices for a positive contribution of agriculture to biodiversity and ecosystem services (EC, 2018). Still, while the link between agriculture and biodiversity and ecosystem services has been widely described, data-driven research assessing such relationship at the landscape level across taxonomic groups and services is still scarce.

Data availability is a major limitation to advance knowledge on how farming systems shape biodiversity and ecosystem services at the landscape level (Lomba et al., 2014; Pe'er et al., 2020; Santos et al., 2020; Strohbach et al., 2015). The Integrated Administration and Control System (IACS) database, managed by EU Member States paying agencies to monitor and control CAP payments, has been highlighted as a potential source of information on farmers' practices at the farm-level (Lomba et al., 2017; Pe'er et al., 2020; Uthes et al., 2020). Coupled with the Land Parcel Information System (LPIS), a spatially-explicit identification system for agricultural plots, IACS provide a high spatial (farm-level) and temporal (yearly) resolution dataset integrating several dimensions of agricultural management, such livestock stocking, crops (types and/or cover) and land use (Lomba et al., 2017; Ribeiro et al., 2018). The value of IACS goes beyond the support to assess and monitor the impacts of CAP instruments. This comprehensive source of high-resolution data has been increasingly highlighted for its potential to support data-driven research in agricultural landscapes (Lomba et al., 2017; Pe'er et al., 2020). Examples include mapping HNVf (Lomba et al., 2017; Matin et al., 2020), analysis of crop and landscape diversity (Uthes et al., 2020), land use change (Tomlinson et al., 2018), definition and analysis of farming systems (Santos et al., 2020; Silva et al., 2020), or modelling exercises to assess the impacts of policies on FS and biodiversity (Ribeiro et al., 2018). However, studies using this detailed source of data reflecting agricultural management have seldom been performed to assess and monitor patterns of biodiversity and the delivery of ecosystem services at the landscape level.

Farming systems conceptual and methodological approaches have been pointed as suitable tools to explore the links between farmers' practices and biodiversity (habitats and species) and ecosystem services (Ribeiro et al., 2018; Santos et al., 2020; Silva et al., 2020). Considering farms as systems and units of analysis, a FS includes a set of farms sharing similar characteristics, namely in what concerns land type, labor and means of production, reflected in cropping and livestock subsystems combinations and underlying management decisions such as livestock rates and crop types, or the use of fertilizers. Such characteristics result from farmers' decisions, which are jointly driven by policies (e.g. due to support to specific farming practices), socio-economic factors (e.g. farmer's age and/or education) and by biophysical conditions (e.g. climate, soil). Ultimately, farmers' decisions are reflected as the dominance of a given farming system at the landscape level (Martin et al., 2020; Santos et al., 2020; Silva et al., 2020). Thus, exploring the links between FS and biodiversity and ecosystem services is essential to improve our understanding on the impacts of agriculture on biodiversity in landscapes under different agricultural management.

In this research, we contribute to advance the state-of-the-art, by exploring the link between FS and patterns of biodiversity (habitats and species) at the landscape level. To do that, we used IACS data to identify and characterize the spatial distribution of farming systems in a region in NW Spain (Galicia) and explored the relationships between the composition of FS, and species (amphibians, reptiles, birds, mammals, plants) and habitats richness. More specifically, we aimed to answer the following research questions: (1) Can IACS be used to map and characterize different farming systems at the landscape-level? and, (2) Is the occurrence of specific FS linked with higher levels of biodiversity? Results of the analysis between FS and targeted biodiversity indicators are discussed for the Galician region, and implications drawn with respect to the assessment and monitoring of patterns of biodiversity in agricultural landscapes, including High Nature Value farmlands, across the EU.

2. Materials and methods

2.1. Study area

Our study area covers Galicia, an administrative NUTS 2 region located in North-western Spain, between 41° N and 44° N latitude, and, 9.5° W and 6.5° W longitude (Fig. 1) with a total area of 29,575 km^2. Most of the region is characterized by an oceanic/dry summer climate (Cfb, Csb in the Köppen climate classification; Cardoso et al., 2019; Cunha et al., 2011) and is located in the Atlantic biogeographical region, with only a small area located in the south-east Galicia integrated in the Mediterranean region. Characterized by an elevation ranging from sea level to ~2100 m in the western mountains and a hilly topography, roughly 36% of Galician municipalities have been declared as less-favoured areas (LFAs) according to the Council Directive 75/268/EEC (Corbelle-Rico and Crecente-Maseda, 2014). The biophysical characteristics and historical uses of the land of Galicia are reflected in a considerable natural capital, recognized by the designation of several Natura 2000 areas, including 16 Special Protection Areas (SPAs; designated under the EU Birds Directive) and 59 Special Areas of Conservation (SACs; designated under the EU Habitats Directive). SPAs

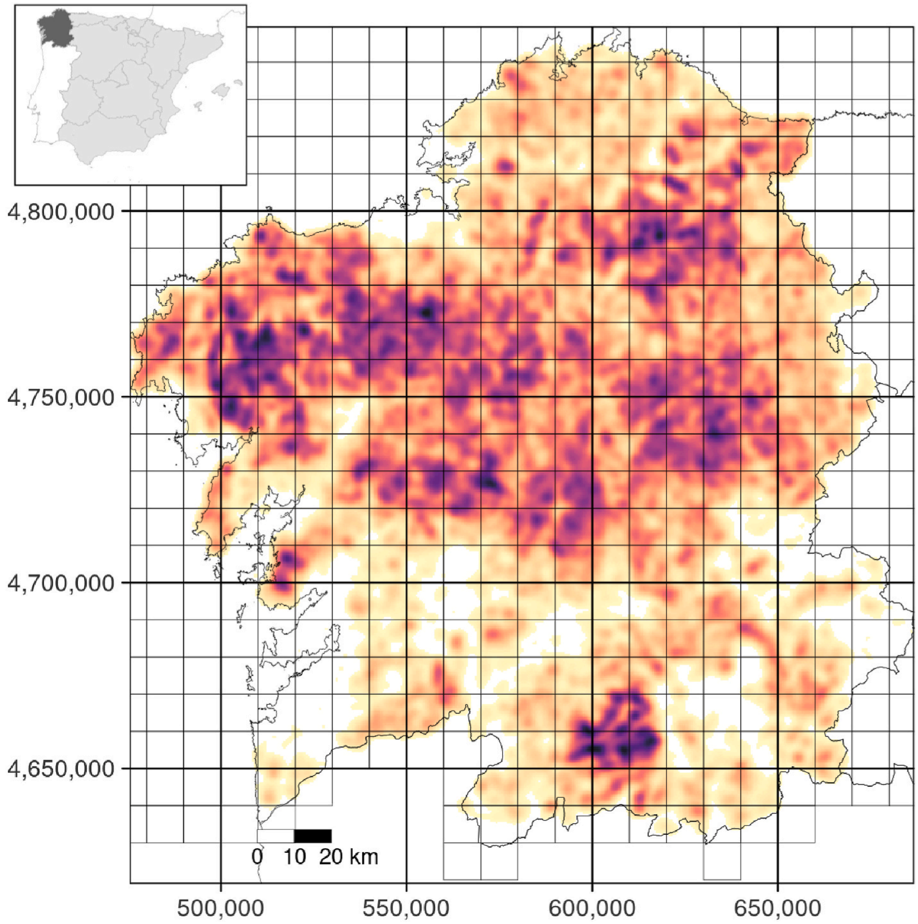

Fig. 1. Location of the study area, Galicia, in the Iberia Peninsula (a) and in Spain (b). The density of farms in the study region is represented, with darker colors depicting higher density of farms. The 10 × 10 km UTM grid utilized in this research is also shown. (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

cover 101,135 ha and SACs 374,435 ha, corresponding to 3.4% and 12.6% of all the area, respectively.

For the last half of the twentieth century, Galicia underwent a polarization between intensification of agriculture and forest activities in the best soils and marginalization of remote, mountainous areas, following the trends observed at the EU scale (Corbelle-Rico and Crecente-Maseda, 2014; Perpiña Castillo et al., 2020; Stoate et al., 2009). The specialization of agriculture targeted mainly dairy production, while in the forest sector focused fast growing species for timber. Thus, despite representing less than 6% of total area in Spain, Galicia currently accounts for about 40% of dairy and 50% of timber production in the country.

Utilized agricultural area (UAA) occupies about 30% of total area of the region. Holdings are mostly small family farms, considerably smaller (11 ha) than the Spanish average (31 ha; INE, 2020). Moreover, there is a large fragmentation of land property (average land plot is 0.25 ha; DGC, 2020), implying that most farmers manage a rather high number of different plots of land. Thus, despite a trend for agricultural intensification along the last decades, the relatively small scale of farming units and the fragmentation of farm holdings in numerous plots of land contribute to the complexity and heterogeneity of the landscape. Together with a relatively high density of linear landscape elements, these aspects contribute to a High Nature Value linked to the occurrence of cultural landscapes in the area (Lomba et al., 2014; Tieskens et al., 2017).

2.2. Data collection

IACS (Integrated Administration and Control System) and LPIS (Land Parcel Information System) data on farm-level management was provided by the regional managing authority (Fondo Galego de Garantia Agraria, FOGGA; https://fogga.xunta.gal/). Linked to LPIS, IACS provides spatially-explicit information on the geographic location, area and crops produced and the number and type of livestock for all agricultural plots managed by Galician farmers' and declared under the CAP payments. For this study, the dataset contained information for the year 2015 about 1,190,714 parcels, declared by 33, 009 farms (35 land plots per farm, on average). To assure statistical confidentiality, all farms in the dataset are identified by a randomly generated code (anonymization is assured by managing authorities) and as no relation to any farm registration codes.

Information about the distribution of EU Habitats of Community Interest in the region was derived from data available from the previous work of Ramil-Rego et al. (2008a, 2008b). This data is the most up-to-date data source regarding the diagnosis, description and distribution of habitat types listed in Annex I of the Habitats Directive (Council Directive 92/43/EEC) for the study area. Moreover, it constitutes the source of data for the Galician Natura 2000 sites regional Management Plan (*Plan Director de la Red Natura* 2000; Ramil-Rego and Crecente-Maseda, 2012), and for the Standard Data Forms (SDFs) of the designated SACs in the region. While detailed habitat mapping has been carried out exclusively for Natura 2000 sites and their surroundings, records for the presence/absence of habitats in a 10 × 10 km UTM grid (Fig. 1) were available for the whole region from the same project. Here, we considered all terrestrial Annex I habitats listed for the study area (69, of which 19 are considered priority habitats, i.e., habitats in danger of disappearance and whose natural range is within the EU), assuming that agricultural practices may have direct and indirect impacts on their occurrence at the landscape level. We used this information to calculate the total number (richness) of Annex I habitats and the total number of priority (*) habitats recorded per 10 × 10 km grid cell (for detailed information see Supplementary material, Table SM1.1).

The diversity of species of conservation interest was derived from the Biodiversity Data Bank (*Banco de Datos de la Biodiversidad, BDD*) maintained by the Institute of Agrarian Biodiversity and Rural Development (IBADER; www.ibader.gal) of the University of Santiago de Compostela. This data bank is the most updated source regarding species occurrence for Galicia, and includes information about the suitable habitats for each species, according to the methodology proposed by Ramil Rego et al. (2005). Species of conservation interest were selected (see Supplementary Material 1 for more details on the selection of targeted species). Then, and converging with the objectives of our research, we selected only protected species associated with agro-ecosystems (for more detailed information see also Section 2.3 and Supplementary Material 1). Our final dataset included 119 protected species, from which 8 plants, 1 invertebrate, 11 amphibians, 13 reptiles, 80 birds, and 6 mammals (for detailed information on targeted see Table SM1.2). While unbalanced, the final set of species reflects the uneven number of species of conservation interest listed across the targeted taxonomic groups for the study area (e.g. Ramil-Rego et al., 2012). Matching data on habitat richness, species information was available for the whole region with the same spatial resolution (10 × 10 km UTM grid; see Fig. 1 and Figure SM1.1). While the grid is the same used by the Spanish Inventory of Terrestrial Species (MAGRAMA, 2014), the BDD is a distinct data source with more detailed and up-to-date information for the study area.

The most recent Spanish land cover/land use map (1:25.000; SIOSE - *Sistema de Información de la Ocupación del Suelo de España*) was then used to determine the percentage cover of agricultural land per 10 × 10 km grid cell, information used in the modelling exercise to control for the share of farmland within the landscape (see also section 2.3). SIOSE allows an accurate estimation of land cover due to a small minimum mapping unit (about 2 ha for agricultural areas) and because it includes an estimation of the share of a given cover (e.g. agriculture) within each polygon, even if it is not the dominant cover within the polygon.

2.3. Statistical analysis

Overall, the statistical analysis followed three steps. First, we used IACS data to derive a classification of farming systems (FS) for the study area, by applying a cluster analysis to a set of farm-level indicators (e.g. total area, share of different crops, and size and composition of animal stock; see detailed description in section 2.3.1). After identifying FS in the study area, the dominance of different farming systems at the landscape scale was explored using the 10 × 10 km grid used by the Spanish Inventory of Terrestrial Species. We used this 10 × 10 km grid as it allowed the harmonization of FS data with available biodiversity data from a spatial resolution point of view, while granting the possibility of presenting our results according to a system utilized by the administration of our study area. For each 10 × 10 km grid cell we estimated the proportion (percentage; %) of total agricultural area per grid cell that is associated to each FS and then grouped cells into categories applying a cluster analysis. Then, the relationship between biodiversity and FS was assessed assuming two different spatial scales: (i) the landscape level, in which we relate habitat richness and FS dominance; and, (ii) the farming system scale, in which we linked species richness and farming to capture the suitability of different FS to support species associated to agro-ecosystems. Two complementary analysis were performed: we compared species and habitat richness (per grid cell) of different taxonomic groups and types, respectively, across FS; and, modelled habitat and species richness in cells as a function of the proportion of area covered by each farming system.

2.3.1. Classification of farming systems at the regional level

Following the methodology described by Ribeiro et al. (2014), a set of seven variables of management at the farm level were derived from IACS data (see Table 1). We assumed that a farm includes all parcels managed by a farmer, though they may not represent a continuous block of land. Farms were thus characterized regarding the total area declared, share of forage crops, share of other annual crops, share of permanent crops (vineyards), share of fallow land, share of pastures, livestock density and proportion of cattle in total livestock units. This set of variables aimed at capturing the variability of different management practices within the region. Farms that did not manage any land (0.3% of total number of farms) and farms with a stock density higher than 15 livestock units per hectare (feedlots, representing about 0.5% of total number of farms) were considered as outliers and excluded from the dataset. Table 1 presents summary statistics for the set of 33,009 farms included in the dataset.

Variables at the farm level were used to establish a FS typology, by classifying farms into homogeneous groups using the Clustering Large Applications (CLARA) algorithm available in the *cluster* package (Maechler et al., 2019) for R (R Development Core Team, 2020). CLARA is a non-hierarchical partitioning method based on the partitioning around medoids (PAM) clustering algorithm, specifically tailored to overcome time and memory limitations when dealing with large datasets (Kaufman and Rousseeuw, 1990). Overall, in PAM, representative elements of each cluster (medoids) correspond to real observations (in other methods, e.g. k-means, cluster centroids represent simple average values for each variable, not necessarily associated to real observations),

Table 1
Summary statistics of variables included to characterize farms and identify farming systems. Mean, minimum (Min), maximum (Max) and standard deviation (SD) values are presented.

Variable	Description and units	Mean	SD	Min	Max
Total area declared (t_area)	Total area of parcels per farm, hectares (ha).	13.36	16.9	0.01	635.49
Forage crops (f_crops)	Proportion of declared land used for forage crops (%): *Dactylo* spp., *Lolium* spp., *Zea* sp., etc.	35.3	32.2	0.0	100.0
Other annual crops (o_crops)	Proportion of declared land used for other annual crops (%): *Triticum* spp., *Solanum* spp., *Phaseolus* spp., *Brassica* spp., etc.	6.4	17.4	0.0	100.0
Permanent crops (p_crops)	Proportion of declared land used for permanent crops (%):*Vitis* sp., *Actinidia* sp., *Vaccinium* sp., *Rubus* sp., etc.	3.2	15.1	0.0	100.0
Fallow land (fallow)	Proportion of fallow land (%).	1.0	6.1	0.0	100.0
Pastures (pastures)	Proportion of declared land used for pastures (%): areas used for grazing by domestic animals, including meadows.	52.8	35.3	0	100.0
Stock density (stockdens)	Livestock units (LU) per hectare of declared land. Livestock units were determined by aggregating animals from different species (cattle, sheep, goats) and ages, using the standard conversion factors.	1.7	4.5	0.0	15.0[a]
Cattle ratio (cattle)	Proportion of cattle LU in the total Livestock Units (%).	71.4	43.5	0.0	100.0

[a] Farms with stock density higher than 15 LU/ha were considered outliers and excluded from subsequent analysis.

meaning that each medoid represents a farm in a cluster, whose average dissimilarity to all other farms in the same cluster is minimal. The optimum number of clusters to be formed was assessed through Silhouette plots (Ribeiro et al., 2014). Clustering results allowed assigning each farm to a given group, based on the assumption that different groups represent different farming systems (Ribeiro et al., 2014).

Coordinates of the centroid of each plot (x and y), were used to estimate the approximate location of each farm as the centroid of all plots that are part of the same farm. This procedure allowed us to produce a spatially-explicit map of the distribution of the different farming systems across Galicia.

2.3.2. Dominance of farming systems at the landscape scale

After deriving the classification of FS, we assessed the relative importance (reflected as the proportion of the total agricultural area) of each farming system in each 10 × 10 km grid cell. To identify areas exhibiting similar composition in terms of farming systems, a hierarchical clustering method (Ward minimum variance) was applied. The optimum number of clusters was determined from an evaluation performed with 30 different indexes available in the R package NbClust (Charrad et al., 2014). This procedure of aggregation of FS information to the 10 × 10km grid cells resulted in the identification of landscape types (LT), i.e. similar combinations of FS at the landscape scale (here a 10 × 10 km grid cell; for more information on cluster analysis results, see Supplementary Material 2). LTS were used to explore the relationship between FS and species and habitat richness.

2.3.3. Linking farming systems and biodiversity at the landscape scale

The relationship between species and habitat richness across farming systems at the landscape scale was first explored through violin plots. Violin plots constitute an adequate method for plotting numeric data across groups, proving summary statistics and a kernel density plot, thus resulting on an overview of the entire distribution of the data being analysed.

After the aforementioned exploratory analysis, we modelled species and habitat richness as a function of the agricultural landscape types and the share of agricultural area per grid cell. As species/habitat number is a count variable, we assumed a Poisson model. As Poisson models assume equi-dispersion in the dependent variable (i.e. the variance of the dependent variable is equal to its mean), we evaluated our independent variables for equi-dispersion to verify that assumption (Cameron and Trivedi, 1998). Results revealed that variables tended to show under-dispersion (mean larger than variance). Fitting under dispersed data through Poisson models results in overestimated standard errors and biased significance levels estimates (Hilbe, 2014). Therefore, we finally used Quasi-Poisson models, as this modelling algorithm does not assume equi-dispersion.

Overall, we fitted seven Quasi-Poisson models for species richness by taxonomic group (M1: amphibians; M2: birds; M3: mammals; M4: reptiles; M5: plants) and for habitat richness (M6: Annex I habitats; M7: priority* Annex I habitats) as dependent variables. Landscape type and the proportion of agricultural land within each grid cell (percent_UAA) were used as independent variables. Because landscape type is a categorical variable with seven possible levels, models need to take one of these levels as the reference, so the models' coefficients for the other levels of the variable reflect changes from the reference level. While the definition of a reference level has negligible impacts on modelling results, they allow more understandable interpretations. Still, we supported the definition of the reference level on data reflecting relevant regional patterns. As a result, LT1 (landscape type dominated by intensive cattle farming system) was thus defined as the reference level assuming that: (i) LT1 consistently relates to the lowest values for richness distribution of most groups (cf. Fig. 4); and, (ii) LT1 is among the most common landscape types in our study area. A statistically significant positive coefficient for any other landscape type indicates a higher species/habitat richness than in LT1. On the other hand, statistically significant negative coefficients indicate lower richness than in LT1, while non-significant coefficients suggest that species/habitat richness in that LT is similar to that of LT1.

3. Results

3.1. Classification of farming systems at the regional scale

Results highlighted three and seven as adequate number of clusters (k) of individual farms (i.e. FS) in our study area (through maximum values of Silhouette width; see Supplementary Material 2, Figure SM2.1 for more detailed results on the cluster analysis). Choosing three clusters (k = 3) resulted in a classification of FS dominated by cattle farms (intensive, intermediate, extensive), whereas selecting seven clusters (k = 7) allowed to capture a wider number of different farming systems, some abundant at the regional scale. As a result, we recognized k = 7 clusters coincident with seven farming systems: three cattle-based FS, one FS dominated by annual crops, one FS dominated by permanent crops, and 2 non-specialized FS.

Overall, cattle-based systems (FS 1, 2 and 3), characterized by a higher proportion of cattle over total livestock units, comprise the vast majority (23,967 farms, 72% of total) of the farms in the dataset and, accordingly, they cover most of the study area (Fig. 2). These three FS reflect a gradient of decreasing intensity, with the share of forage crops decreasing (FS 1: 78%; FS 2: 38%; FS 3: 8%) and the share of pastures increasing from FS 1 to FS 3 (FS 1: 17%; FS 2: 56%; FS 3: 90%). As shown in Fig. 2, cattle-based FS systems seem to follow an east-west gradient (which, in this study area, is associated to a gradient of elevation), with the most intensive FS (FS 1) occurring in western areas, closer to sea level, FS 2 in central areas, and FS 3 (the most extensive) in eastern areas, located at higher elevations.

Other two recognizable groups were FS 4, in which annual crops account for 78% of total crop area, and FS 5, dominated by permanent crops (93% of total crop area). Both FS are not widespread in the region, corresponding to only 4.2 and 2.4% of farms, respectively, and are associated to specific areas (Fig. 2). FS 4 is associated to the farmlands dominated by annual crops farming (*Triticum* spp., *Solanum* spp., *Phaseolus* spp., *Brassica* spp., etc.) in *A Limia*, an administrative region located in the south of Galicia, while FS 5 mainly reflects vineyard holdings associated to productive areas under protected designation of origin. Finally, the two remaining FS are low intensity livestock and non-specialized systems (stocking density ranging between 0.3 and 0.6 livestock units/ha). Farms in these two groups differ by their average size (FS 6: 3.7 ha; FS 7: 7.1 ha) and the share of forage crops and pastures: most area under FS 6 corresponds to forage crops, while pastures occupy most area under FS 7. In terms of number of farms, these two groups represent 8.5 and 12.0% of farms in the region, respectively. FS 6 and FS 7 are distributed across the region, although the first tends to concentrate its presence in the western quadrant.

3.2. Dominance of farming systems at the landscape scale

The analysis of the dominance of FS per 10 × 10 km grid cell resulted in the identification of seven different landscape types (LTs; Fig. 3; see also Supplementary Material 2, Table SM2.1 for detailed results). LTs 1–3 are dominated by cattle farming systems (cattle FS account for more than 75% of agricultural land in each grid cell), although they differ in the distribution of intensive and extensive systems. While landscapes included as LT1 were found to be dominated by intensive cattle FS (FS 1, cattle farms with higher livestock density), LT3 is dominated by extensive cattle FS (FS 3), and LT2 shows a mixture of FS 2 (intermediate) and FS 3. These three agricultural landscape types follow a west-east gradient of decreasing intensity and, overall, they occupy the vast majority of the region. LTs 4 and 5, on the other hand, occupy very specific locations in the region and are dominated by farming systems where annual (FS 4) and permanent crops (FS 5) prevail, respectively. Finally,

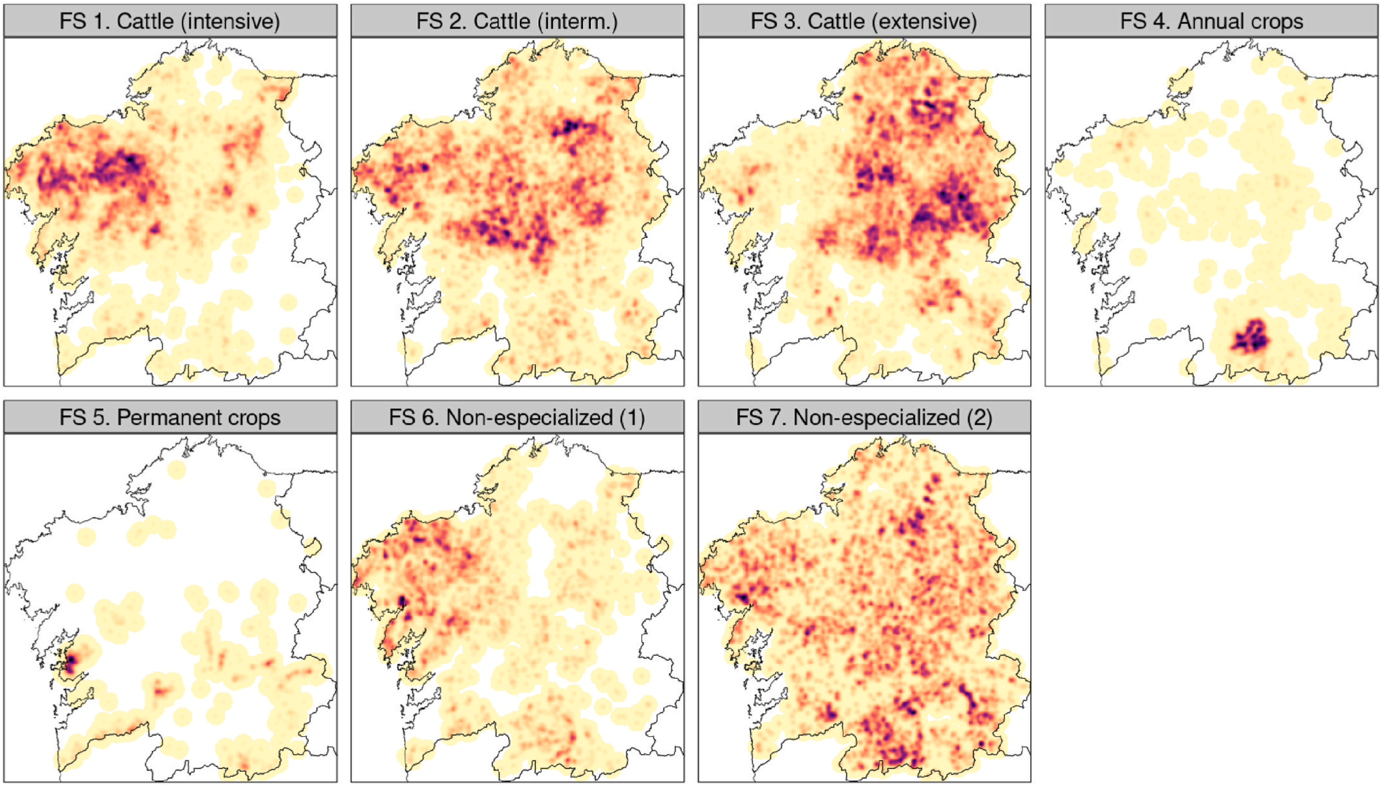

Fig. 2. Spatial distribution of the seven farming systems (FS) identified in Galicia, represented as the kernel density of farms. Darker colors indicate higher density of each specific farming system. (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

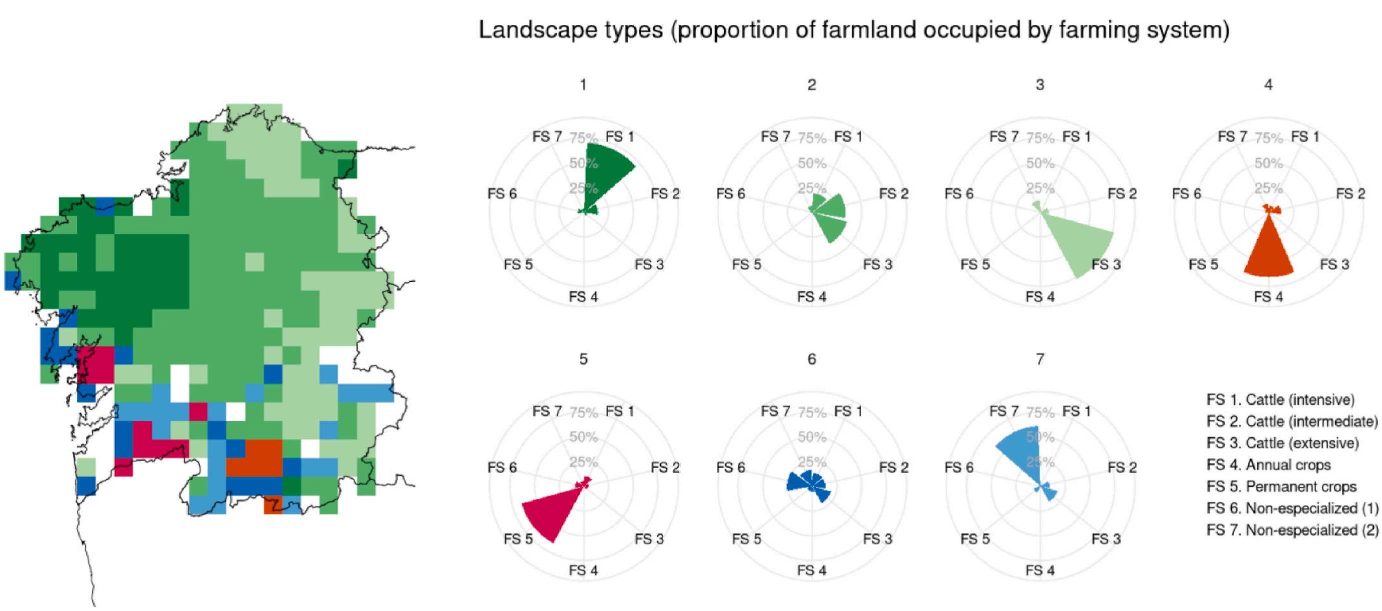

Fig. 3. Distribution of landscape types (1–7) in Galicia and their composition in terms of the area occupied by each farming system (FS) identified in the study area.

in LTs 6 and 7 non-specialized farming systems (FS 6 and FS 7) prevail, with a higher presence of forage-based farms (FS 6) in LT6 and of pasture-based farms (FS 7) in LT7.

3.3. Linking farming systems and biodiversity at the landscape scale

Overall, an increasing number of protected species and habitat richness was found to be associated to decreasing levels of agricultural intensity observed from LT1 to LT3 (Fig. 4; see also Supplementary Material 3, Table SM3.1 for detailed results). This pattern was observed for birds, mammals and reptiles, which show a trend to increase as the prevalence of more intensive farming systems in the landscape decreases. For example, the average number of birds was 39.8 for LT1 (dominated by FS 1, intensive cattle farming), 41.2 for LT2 (intensive/extensive) and 42.4 for LT3 (dominated by FS 3, extensive cattle farming). Similarly, the average number of reptile species was 4.6 for LT1, 4.7 for LT2 and 5.4 for LT3. A similar gradient was observed for the number of Annex I habitats, with an average number of habitats of 14.8

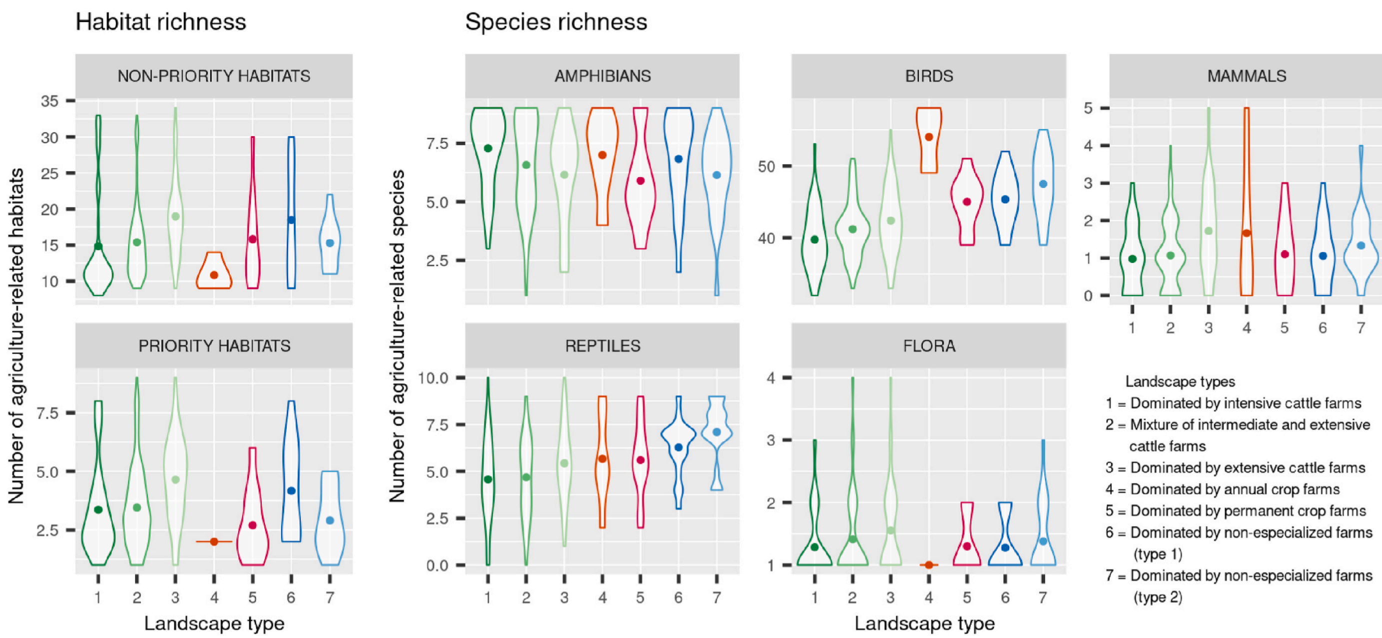

Fig. 4. Violin plots representing species richness and number of habitats across landscape types for the study area. In the violin plots, dots indicate average (mean) values for each taxonomic group considered for analysis. Kernel density plots are presented as colorful lines outlining the boxplot, with colors reflecting the identified landscape types. (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

for LT1, 15.4 for LT2 and 19.0 for LT3. Contrastingly, the richness of amphibians presented higher values in LT1 compared to LTs 2 and 3.

The gradient of decreasing intensity of FS also matches a gradient of decreasing share of farmland, with LT4 (dominated by annual crops) presenting an average of 38% of farmland per grid cell, followed by LT1 (intensive cattle, 30%), LT2 (intensive/extensive cattle, 26%), LT5 (permanent crops, 23%), LT3 (extensive cattle, 16%), LT6 (non-specialized, 20%) and LT7 (non-specialized, 9%).

Table 3 shows the results for six models fitted with the Quasi-Poisson approach. For all models, landscape type 1 (dominated by intensive cattle) was defined as the reference level (see Methods for information on the definition of the reference level). Therefore, coefficients for other groups reflect changes in relation toLT1, with significant changes marked as bold. A statistically significant negative coefficient suggests that a given landscape type is likely to hold less species of a given taxonomic group than LT1. Conversely, a statistically significant positive coefficient suggests that a LT type is likely to hold more species than LT1 (the reference level). Model 1 (M1) results highlighted that all LTs except for 4 and 6 (annual crops, non-specialized farming; Table 2) are associated to lower numbers of endangered amphibian species when compared with LT1. M2 results showed that the richness of endangered bird species is higher in all other LTs than in LT1 (coefficient values showing the highest richness in LT4 –annual crops, followed by LTs 7, 6 and 5) but also suggested that it is likely to be higher in cells where farmland occupies a larger proportion of the total landscape. Conversely, the effect of the proportion of area occupied by farmland seems to be negative for mammals (M3) and reptiles (M4), while not significant for amphibians (M1) and flora (M5). Both M3 and M4 showed higher values of species richness (mammals and reptiles) in LT4 when compared to the reference (LT1), with M3 (mammals) showing also a positive effect associated to LT3 (extensive cattle). Finally, results suggested that the number of endangered plants is similar across all LTs, with the only exception of LT3, associated to higher richness of species of this group.

Table 2
Characterization of the farming system (FS) identified in the study area, reflected as average (mean) values for each considered variable. *n*, number of farms; ha, hectares: %, percentage; LU/ha, livestock units per hectare of declared land.

Variable	FS 1 Cattle (intensive) n = 6751	FS 2 Cattle (interm.) n = 6779	FS 3 Cattle (extensive) n = 10,437	FS 4 Annual crops n = 1399	FS 5 Permanent crops n = 827	FS 6 Non-specialized (1) n = 2829	FS 7 Non-specialized (2) n = 3987
Total area declared (t_area) (ha)	16.5	15.3	16.7	9.4	2.8	3.7	7.1
Forage crops (f_crops) (%)	78.9	38.0	7.8	8.3	2.3	77.8	15.8
Other annual crops (o_crops) (%)	2.8	4.1	1.4	78.5	1.3	7.2	4.9
Permanent crops (p_crops) (%)	0.4	0.9	0.6	1.0	93.1	1.7	1.9
Fallow land (fallow) (%)	0.8	0.5	0.1	8.7	0.6	1.0	2.3
Pastures (pastures) (%)	17.0	56.1	90.0	3.4	1.6	11.9	66.3
Livestock density (stockdens) (LU/ha)	2.4	1.8	1.6	0.1	0.0	0.3	0.6
Cattle ratio (cattle) (%)	98.5	97.6	97.3	1.6	0.0	1.4	1.7

Table 3
Results of Quasi-Poisson models (M) fitted to the species and habitats richness across landscape types (LT). Coefficient values for LTs 2–7 reflect the relative effect by comparison to LT1 (reference group). Estimated coefficients are shown, with standard error values presented within parentheses. *n*, number of observations, i.e. total number of 10 × 10 km grid cells in the study area. Significance levels; 0 '***'; 0.001 '**'; 0.01 '*'; 0.05 '.'; 0.1 '' 1. Significant coefficients are highlighted as bold text.

Landscape type (LT)	Amphibians (M1)	Birds (M2)	Mammals (M3)	Reptiles (M4)	Plants (M5)	Annex I Habitats (M6)	Priority (*) Annex I Habitats (M7)
LT2	**−0.104****	**0.033***	0.067	−0.012	0.091	0.016	0.002
	(0.051)	(0.018)	(0.157)	(0.072)	(0.088)	(0.062)	(0.087)
LT3	**−0.174*****	**0.045****	**0.443*****	−0.007	**0.172***	**0.130***	**0.191***
	(0.062)	(0.021)	(0.170)	(0.083)	(0.101)	(0.071)	(0.097)
LT4	−0.035	**0.323*****	**0.644****	**0.370****	−0.235	−0.212	−0.401
	(0.127)	(0.039)	(0.314)	(0.163)	(0.246)	(0.178)	(0.272)
LT5	**−0.213***	**0.116*****	0.068	0.131	0.004	0.016	−0.272
	(0.109)	(0.034)	(0.300)	(0.133)	(0.176)	(0.121)	(0.189)
LT6	−0.068	**0.116*****	−0.018	**0.181***	−0.020	0.131	0.113
	(0.083)	(0.028)	(0.248)	(0.105)	(0.144)	(0.094)	(0.131)
LT7	**−0.179****	**0.146*****	0.108	0.150	0.042	−0.159	**−0.362****
	(0.087)	(0.028)	(0.233)	(0.104)	(0.141)	(0.100)	(0.147)
percent_UAA	−0.043	**−0.164*****	**−1.076****	**−1.546*****	−0.153	**−1.001*****	**−1.148*****
	(0.173)	(0.057)	(0.477)	(0.235)	(0.278)	(0.201)	(0.282)
Constant	1.998***	3.730***	0.278	1.950***	0.295***	2.978***	1.532***
	(0.066)	(0.022)	(0.190)	(0.089)	(0.110)	(0.078)	(0.108)
n				293			

Models based on habitat richness (M6 and M7, Table 3) did not highlighted significant differences between LTs, other than depicting higher values for LT3 (extensive cattle) and lower values for priority habitat richness in LT7 (dominated by non-specialized farms). On the other hand, both models (M6 and 7) resulted in lower habitat richness in cells where the proportion of total area occupied by agriculture is higher.

4. Discussion

In this research, we analysed the relationship between farming systems and biodiversity at the landscape level, using farm-level data on farmers' practices and available biodiversity data. Overall, our analysis resulted in the identification of seven different FS distributed across Galicia: three cattle-based farming systems, one dominated by annual crops, one where permanent crops prevailed, and two non-specialized FS (cf. Fig. 2 and Table 2). Based on farm-level data from the IACS/LPIS dataset, which includes data on farmers' management reported under CAP payments, we characterized each individual FS in what concerns their spatially-explicit distribution and respective farming practices, in line with previous research performed in other social-ecological contexts (Lomba et al., 2020b; Ribeiro et al., 2016; Santos et al., 2020). Cattle-based FS were found to prevail in Galicia (72%), followed by Non-specialized FS (8% and 12%, respectively). While the prevalence of livestock –based farming in Galicia was previously reported (Alvarez et al., 2014), our study discriminated three Cattle-based FS based on a decreasing gradient of intensity from the most intensive (FS 1) in the west, intermediate (FS 2) in the central area, to less intensive farms (FS 3) located in eastern Galicia (cf. Fig. 2). Such gradient of decreasing intensity, depicted by decreasing levels of livestock density and shares of forage crops, and increasing shares of pastures, seem to relate to an increasing number of biophysical constraints to agricultural practices, namely increasing altitude, slopes and remoteness (Eliasson et al., 2010; García-Feced et al., 2015; Perpiña Castillo et al., 2020). The biophysical characteristics, along with farmers' decisions mainly driven by agricultural policies, have been acknowledged as major drivers of FS occurrence (Santos et al., 2020; Silva et al., 2020). Without a relevant expression in the region, FS dominated by annual and permanent crops (FS 4 and 5, respectively) were found to have restricted distributions. FS 4, dominated by annual crops, was found in the deep soils and mild slopes of the region of *A Limia* (South Galicia; Fig. 2), whereas FS 5, dominated by permanent crops (mainly vineyards), was found on productive lowlands located close to the sea or in the valleys of rivers, under Protected Designation of Origin (Cardoso et al., 2019). Finally, two non-specialized FS were found widespread across the whole study area and depicting low-intensity small farms owning a low number of livestock and producing mainly forage (FS 6 and 7, respectively; cf. Table 2). The occurrence of small family farm holdings within complex mosaics and parcels was previously reported for Galicia and related to the failure of land consolidation programmes in a region characterized by the occurrence of biophysical constraints limiting agricultural land use (Crecente et al., 2002; Guiomar et al., 2018; Perpiña Castillo et al., 2020).

Farming systems approaches based on spatially-explicit farm-level data allow identifying areas sharing a set of similar agricultural management practices e.g. Ribeiro et al. (2016); Santos et al. (2020). An analysis of FS at the landscape scale (the 10 × 10 km grid cells) allowed pinpointing seven types of landscapes (LTs) mostly coincident with the seven referred FS, and thus, as expected, exhibiting similar characteristics and distribution patterns across the region, with the exception of LT 2, characterized by a mosaic where FS 2 and FS 3 co-occur. This fact stems from changing the scale of analysis from farm to landscape level, which allowed capturing transition landscape types, specifically reflecting the co-occurrence of intermediate (FS 2) to extensive (FS 3) cattle-based FS along the western-eastern gradient of decreasing intensity. Nevertheless, the coherence between results obtained at the regional and landscape scales highlight the suitability of IACS and LPIS datasets to support the assessment and monitoring of the impacts of farming practices on the environment at multiple scales of decision (Lomba et al., 2017; Pe'er et al., 2020).

The relationship between the occurrence of species and habitats, including those of conservation concern, and specific farming systems, has been previously advocated (Halada et al., 2011; Lomba et al., 2020b). An increasing number of habitats (including priority habitats) was found associated to a gradient of decreasing intensity (depicted by decreasing shares of forage and increasing shares of pastures) from LT1 to LT3 (i.e. from cattle-based farms located in the coast to low-intensity cattle farms located in the mountains; cf. Fig. 4). Higher values of total habitats richness were also recorded within LTs dominated by non-specialized (LT6) and permanent crops (LT5). Still, no significant differences between LTs were found when modelling habitat richness across LTs (cf. Table 3), except for landscapes dominated by non-specialized farms (LT7) and dominated by annual crop farms (LT4), for which lower values of total and priority habitats richness were observed, respectively. In both cases, lower richness of habitats was coincident with landscapes where the area occupied by farming is higher. Our results are partially supported by Rotchés-Ribalta et al. (2021) that recently reported increasing richness of semi-natural habitats with decreasing levels of farming intensity when analyzing two agricultural landscapes in Ireland. In a European study, García-Feced et al. (2015) also reported higher abundance of semi-natural habitats in Northern Spain in marginal farmlands in mountain areas under less intensive farming practices.

Landscapes dominated by low-intensity farming systems have been shown to support higher levels of protected species diversity when compared to farmlands under intensive management (Anderson and Mammides, 2020; Lomba et al., 2020b). Overall, increasing richness of protected species was observed for birds, reptiles, and mammals along the western-eastern gradient of decreasing agricultural intensity, in line with the results achieved for habitat diversity (total and priority; cf. Fig. 4). Our results are in line with previous research. Maskell et al. (2019), observed higher diversity of birds of conservation concern in areas exhibiting higher habitat diversity. Gentili et al. (2014) found a decrease of small mammals' diversity with increasing agricultural intensification and resulting loss of landscape naturalness and complexity in farmlands in northeastern Italy. Biaggini et al. (2015) reported low diversity of reptile assemblages in landscapes dominated by intensive agriculture located in Central Italy. Contrastingly, trends for increasing amphibian richness were observed across a gradient of increasing intensity, from landscapes dominated by extensive cattle farms in the east to intensive cattle farms in the west (cf. Fig. 4). Still, such patterns relate to global patterns of their distribution in the territory (Galán, 2005), where higher amphibian richness is observed in western coastal areas and nearby mountains and are related to higher levels of rainfall and lower thermal amplitudes. Relevant differences were detected when modelling richness across cattle dominated LTs, showing higher bird, mammal, flora and habitat richness (but lower amphibian richness) in landscapes dominated by extensive cattle farms (cf. Table 3).

Bird richness was also found to be significantly higher in landscapes where annual and permanent crops and non-specialized farms prevail when comparing with cattle-based FS (FS1 – FS3; cf. M3, Table 3). Significant differences were also observed within cattle-based LTs, with the higher richness associated to extensive farming. The observed pattern may be related to lower intensity of agricultural management of non –specialized farms (LTs 6 and 7; lower cattle ratio and lower farmland shares), reflected by higher landscape heterogeneity due to natural and/or semi-natural areas and uncultivated patches occurrence embedded in the agricultural matrix e.g. see (Mäkeläinen et al., 2019; Wretenberg et al., 2010). The significant association between higher bird richness and LTs dominated by annual crops (LT4; cf. Table 3) relates to their specific location: *A Limia* (LT4). *A Limia* is characterized by the occurrence of continental wetlands and coincides with an area designated for conservation of bird diversity - the SPA ES0000436 '*A Limia*'. Thus, the observed pattern is likely due to the coexistence of farmland and the wetland system, rather than to the occurrence of the farmland itself. In fact, farmlands in the area resulted from the process of land reclamation of wetlands that occurred in the late 1950s (Fernández Soto et al., 2011). Still, significant remnants of the wetland system exist, allowing the occurrence of very vulnerable steppe birds (Villarino et al., 2017). Finally, modelling results depicted decreasing richness of mammals and reptiles (but higher richness of birds) with increasing shares of farmland area (cf. M2, 3, 4; Table 3). Such results are in line with previous studies reporting a link between higher shares of farmland area and species diversity through increased crop field sizes in more intensively managed and less heterogeneous landscapes e.g. see Martin et al. (2020).

Overall, our results suggest that the natural value of agricultural landscapes in our study area increases from the lowlands in the coast, towards mountain areas along a west-east gradient of decreasing agricultural intensity. Such results diverge from previous research by Olivero et al. (2011) and González-García et al. (González García et al., 2008), in which High Nature Value farmlands were associated with farming areas under higher agricultural management intensity (matching landscapes dominated by intensive cattle-based and annual crops farms, LTs 1 and 4, respectively). Such contrasting results seem related to the different approaches used, including the taxonomic groups considered, criteria used to select species and analytical approaches implemented. While an extended list of plants, reptiles, amphibians, birds and mammals of conservation interest showing a relation to agricultural landscapes were considered in this study, Olivero et al. (2011) included only species (plants, reptiles, amphibians, birds, mammals, invertebrates and fishes) protected by Spanish legislation and species associated to agricultural landscapes, regardless of their conservation interest. Selection of indicator species in this study followed consolidated guidelines in the field of High Nature Value farmlands assessment (e.g. see Campedelli et al., 2018; Lomba et al., 2014), providing, in our view, a more accurate description of HNVf systems. Altogether, such differences, including the temporal mismatch of data reflecting farm-level management used, may explain the contrasting results, and highlight the importance of the selection of indicators and the definition of common approaches to assure comparability of assessments and monitoring in space and time. Still, our results are consistent with previous research obtained for the targeted region performed at the EU level e.g. see Paracchini et al. (2008).

While our results are promising, there is room for improvement and further research. The mismatch between the spatial and temporal resolutions of farm-level management (IACS data) and species and habitats data hindered a fine-scale assessment of the impact of agricultural management on biodiversity patterns. In fact, the best available biodiversity data, a 10 × 10km presence-only dataset, do not include information on the abundance of species, which would be relevant to further scrutinize patterns of biodiversity across farming systems. The use of habitats and species protected under the different legal regulations at the European, Spanish and Galician level, is an asset for the work, since they allow an evaluation of the impact of agricultural management on the most vulnerable elements of biodiversity. In contrast, while being the best information available for the study area, biodiversity datasets target mainly species under any legal protection (required for monitoring and reporting purposes), are unbalanced for some taxonomic groups, often dominated by mobile species, thus providing a limited overview of the species richness across the taxonomic groups considered, and likely to impact the observed patterns. As an example, while expected, no significant relationship was found between plant richness and the distribution of different farming systems (except for the case of low-intensity cattle-based FS; LT3), fact that may reflect the lower number of plants in the dataset as being linked to the occurrence of agricultural landscapes. Similar constraints should be considered regarding available data on natural and semi-natural habitats. Further, while not within the scope of this research, habitat richness patterns could be scrutinized by focusing only on those known to be fully or partly dependent on agricultural practices, and by comparing patterns inside and outside Natura 2000 sites. While based on farm-level data (IACS) and state-of-the-art approaches, results from our modelling should consider the dominance of specific farming systems across the study area. In fact, cattle-based farming systems (FS 1 to 3, intensive, intermediate and extensive cattle farming) and the resulting landscape types (LTs 1 to 3) include most of the farms and thus prevail in the study area, potentially masking any significant link between other farming systems and biodiversity. Moreover, IACS dataset does not include other relevant information, such as N input, or the share of irrigated area that could be useful to characterize the identified FS from a management intensity perspective. Also, IACS/LPIS are provided after a process of anonymization, assuring that farmers' identity and the geographical location of each agricultural plot are not disclosed, which limited our ability to account for spatial complexity (eg through assessment of plot size or shape) in our assessment. Finally, while IACS dataset includes all farm holdings under CAP payments, it does not integrate information from other farmers and respective farm holdings, namely family farms, and part-time or retired farmers', which may be reflected by the patterns observed at the landscape level.

5. Conclusions

To our knowledge, our study is among the few explicitly addressing the relationship between farming systems and habitat and species richness at the landscape level. Our results highlighted potential links (positive or negative) between specific landscape types (defined by the dominant farming systems) and protected habitats and/or species richness across targeted taxonomic groups. While not within the scope of this manuscript, such link is expected to be reflected as the set of ecosystem services occurring at the landscape level e.g. Santos et al. (2020). Still, understanding the relationship between farming systems under different management practices, and resulting patterns of biodiversity and ecosystem services is key to achieve social-ecological viability in agricultural landscapes. Such understanding provide relevant knowledge to support decision-making towards tailored management programs, allowing to design and implement actions to foster biodiversity and/or ecosystem services according to the characteristics of targeted landscapes and dominant farming systems. Pursuing such knowledge entails, though, access to high-resolution data (such as IACS) and investing efforts in making suitable data on biodiversity and ecosystem services available at compatible temporal and spatial resolutions. Nevertheless, further research on how biodiversity is related to farming systems, is particularly important in the case of High Nature Value farmlands, which are associated to high levels of biodiversity (and provision of multiple ecosystem services), but are also severely threatened by ongoing processes of land abandonment and intensification (Lomba et al., 2020b). Among other reasons, scrutinizing such relation will allow a detailed analysis of the agricultural practices that are promoting specific levels of biodiversity and ecosystem services, and support the identification of farm-level indicators that can be translated into the design and monitoring of biodiversity or agriculture-related policies at several scales of decision.

Credit author statement

AL: Conceptualization, Methodology, Writing – original draft preparation; Writing – review & editing, Funding acquisition, Project administration, JFC: Data curation, Writing – review & editing. PRR: Data curation, Writing – review & editing. ECR: Conceptualization, Methodology, Formal analysis, Writing – original draft preparation; Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

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