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Unraveling spatial agglomeration patterns in agri-environmental schemes: Evidence from the improvement of steppe habitats in the Natura 2000 network in Catalonia (Spain)

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ABSTRACT

The European payment for ecosystem services in the agricultural sector, or agri-environmental schemes (AES), have shown limited success in stopping biodiversity loss due to the mismatches between the scale at which they are adopted and the scale of ecological processes. This study analyzes the spatial distribution of farmer participation in the "Improvement of the steppe habitats of the Natura 2000 Network" AES in Catalonia (Spain) to test and explain potential agglomeration patterns. Our findings evidence spatial agglomeration of AES enrollment both within the farm (with farmers enrolling their adjacent or nearby plots in the scheme) and among farms (with farmers that adopt AES being near each other). Plots under the Natura2000-AES are located within a maximum distance of 2.4 km from their nearest enrolled plots, which would provide sufficient habitat continuum to allow for birds' mobility across landscapes. Our results also indicate that participation concentrates on larger, non-irrigated and/or fallow plots, farms that are managed by professionals, young farmers, and/or members of a farmer organization, and municipalities with lower socioeconomic indexes. These results contradict the assumption that there are no agglomeration patterns in the AES context and reveal the interest of further studying the socio-ecological factors that underlie spatial agglomeration patterns of AES and designing landscape-management strategies accordingly.

1. Introduction

The survival of farmland biodiversity is at serious risk, with declining plant and animal populations at alarming rates (EEA, 2019). Such biodiversity loss is closely tied to the intensification of agricultural practices across Europe (Rigal et al., 2023). The European Common Agricultural Policy (CAP), which has been criticized for accelerating agricultural intensification and reducing its multifunctionality (Ferrer and Kaditi, 2007; Hodge et al., 2015), has undergone a series of reforms to mitigate the negative impacts on biodiversity and maintain socio-ecological values in farmland (Pe'er et al. 2017).

The Agenda 2000 review restructured CAP in two pillars: pillar 1, which comprises direct payments to farmers and market-related expenditures, and pillar 2, which provides payments for Rural Development. Although pillar 1 payments condition 30% of the aid to the implementation of greening measures, the requirements are not very demanding and therefore unlikely to benefit biodiversity (Dicks et al., 2014; Pe'er et al., 2014). A more ambitious strategy to conserve biodiversity lies in agri-environmental schemes (AES) implemented under Rural Development Plans (pillar 2) at national and regional scales. AES are contracts signed with farmers who voluntarily implement environmentally friendly management practices in exchange for payments that may compensate for the additional farming costs and forgone revenue. The design of AES at the regional scale enables the tailoring of measures to the heterogeneity of agroecosystems, addressing local problems, and guaranteeing the provision of ecosystem services where they are most needed (Arata and Sckokai, 2016; Beckmann et al., 2009; Hodge et al., 2015).

However, studies have shown moderate success in the environmental outcomes of AES (Berendse et al., 2004; Kleijn et al., 2006). For example, a review concluded that about half of the agri-environmental measures had no benefits for biodiversity (Kleijn and Sutherland, 2003), and a more recent review showed no sign of improvement in AES effectiveness over time (Batáry et al., 2015). Some factors that could explain the

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effectiveness deficits are the insufficient farmer participation and coordination to reach environmental thresholds and to ensure the connectivity of AES (Kuhfuss et al., 2015), and the lack of geographical targeting of AES in areas where they can be more effective (Arnott et al., 2019; Früh-Müller et al., 2019; Zabala et al., 2017).

Despite the abundance of articles advocating for spatial coordination of AES adoption (Leventon et al., 2017; Rotchés-Ribalta and Ó hUallacháin 2018; Wossink et al. 1999) and studies analyzing potential coordinated and collaborative strategies to achieve landscape-level management (Kuhfuss et al., 2015; Westerink et al., 2017), few studies examine AES spatial patterns on the ground. Some of these studies show the scattering of AES participation over large areas (Arnott et al., 2019), while others provide evidence of agglomeration patterns linked to the influence that neighboring farmers exert on each other when enrolling in AES programs (Raggi et al., 2015; Schmidtner et al., 2012).

This study investigates the spatial distribution of the AES "Improvement of the steppe habitats of the Natura 2000 Network", hereafter referred to as Natura2000-AES, which aims to maintain and improve the conditions for birds of the steppe habitats designated as Specially Protected Areas (SPAs) in Catalonia (Spain). Additionally, it explores associations with biophysical and socioeconomic factors that could explain the adoption of the AES. The research questions of the study are: How does farmer participation in the Natura2000-AES distribute spatially? Are there any agglomeration patterns in the adoption of this scheme? Which socioeconomic and biophysical factors may explain participation, and therefore affect AES adoption patterns?

Our working hypothesis is that AES adoption displays agglomeration patterns due to the spatial concentration of biophysical and/or social conditions that favor AES participation, scale economies and diffusion dynamics. As we argue, testing the existence of such spontaneous patterns is a necessary step before designing policies that promote spatial coordination.

The rest of the article is structured as follows. Section two reviews the literature concerning the spatial distribution of AES and the factors that drive participation in AES. The next section presents the research methods. Sections four and five present the results and discussion, respectively. Finally, conclusions are given in section six.

2. Understanding spatial patterns and farmer participation in AES

Designing an optimal spatial configuration for schemes aimed at biodiversity conservation is a difficult task, as different species have different mobility ranges and therefore interact with the environment at different spatial scales (Concepción et al. 2008). In general, farmland birds require a landscape composed of a mosaic of habitats (rainfed cereals alternated with fallows and low-growing vegetation), for food, shelter, and nesting on the ground (PDR, 2014–2020). If the distance that birds have to cover in order to fulfill their needs is excessively long, the energetic costs of traveling and the increased predation risk could detract from any positive effects on survival derived from AES management (Siriwardena, 2010). Consequently, AES management at a landscape level should reduce the fragmentation of conservation efforts, by improving the ecological connectivity among enrolled farms.

This idea has motivated different mechanisms to achieve spatial agglomeration of agri-environmental contracts. These strategies range from coordinated approaches (where land managers work towards the same objective but in isolation) to collaborative approaches (where land managers meet and work together) (Boulton and Lockett, 2013). Coordinated approaches include innovative financial incentives, such as agglomeration bonuses or threshold payments which aim to prevent the fragmentation of AES adoption and guarantee enough participation to reach environmental thresholds (Bamière et al., 2013; Nguyen et al., 2022). Collaborative strategies include collective schemes for farmers who jointly manage common land and collective contracts for groups of neighboring farmers who manage individual plots under the same scheme and submit a joint application (Emery and Franks, 2012; Westerink et al., 2017).

However, some farm-scale designs of AES can create landscape-scale impacts, reducing the need for coordination or collaboration (Westerink et al., 2017). For example, reducing the scattering of AES adoption over large areas can be steered by targeting a certain area where the scheme can be most effective (Arnott et al., 2019). Furthermore, our hypothesis is that agglomeration patterns in AES adoption may appear spontaneously. In fact, agglomeration effects have been frequently observed in economic activities. For example, companies tend to establish near each other to benefit from gains in efficiency and cost reductions that result from their proximity (Lavrinenko et al., 2019). This can also apply to AES adoption, as neighboring farmers may be more likely to participate because they benefit from scale economies external to the farm, such as reduced transactions cost of learning about the schemes. Yet, few studies examine the agglomeration patterns that AES display on the ground, with notable exceptions such as Schmidtner et al., (2012); Raggi et al., (2015) and Yang et al., (2014), who study this at the county, municipality, and parish scale, respectively. This study goes a step further, investigating agglomeration patterns at the plot scale.

Beyond scale economies, our hypothesis builds on the first law of geography which states that "everything is related to everything else, but near things are more related than distant things" (Tobler, 1970). Because some of the factors explaining AES adoption are likely to be spatially correlated, we expect AES to be agglomerated as well. To better understand which factors might influence AES spatial patterns, we draw upon research that explains farmer participation. According to the literature, the main aspects that affect farmers' enrollment in AES are scheme design, personal motivations, and farm or farmer characteristics. Here we review the latter, for being more prone to spatial relationships.

With some exceptions for specific schemes in certain regions (see Vanslembrouck et al., 2002), there is consensus that AES uptake increases with farm size (Bartolini and Vergamini, 2019; Unay-Gailhard and Bojnec, 2016; Wilson, 1997). For small farms, transaction costs represent a barrier to participate, whereas larger farms have economies of scale that allow them to take more profit since payments are established per hectare (Avendaño-Cantor et al., 2015).

Biophysical characteristics, such as altitude and slope, which affect land productivity can also influence participation in agri-environmental contracts. In this respect, marginal farms confronted with natural restrictions are more likely to adopt AES (Arnott et al., 2019; Capitanio et al., 2011; Früh-Müller et al., 2019), which is frequently explained by farmers' need of additional sources of income to make up for the low productivity of land and because they generally maintain low-intensity management practices that fit well with those required by the contracts.

Land tenure has also been found to be a determinant of AES participation. Having property rights over land appears to positively affect farmers' willingness to participate (Defrancesco et al., 2008; Unay-Gailhard and Bojnec, 2016; Wilson, 1997). When landlord-tenant relations are complicated, AES can be a source of conflict (Wittstock et al., 2022). Unclear or ambiguous ownership can also be a barrier to AES participation (Pe'er et al. 2017).

Social capital also plays a crucial role in AES uptake (Alló et al., 2015). Belonging to a farming organization or trade union has been found to have a significant impact on participation, although the effect is not consistent among studies (Capitanio et al., 2011; Polman and Slangen, 2008). Polman and Slangen (2008) observed that participation in organizations focused on productivity had a negative impact on the uptake of schemes that promote extensification and landscape maintenance. This contrasts with Capitanio's et al. (2011) findings which suggest that farmers who are members of an agricultural cooperative are more likely to participate in AES.

Several studies assess how farmers' age and education determine AES participation, but no clear trend has been found in the literature. While Peerlings and Polman (2009) found that young and educated farmers were more likely to adopt sustainable farming practices, Defrancesco et al. (2008) found older non-educated farmers were more likely to apply for AES, and Barreiro-Hurlé et al. (2010) observed that older farmers participated more because they were already following traditional farm management that fitted AES requirements.

3. Material and methods

3.1. Studied scheme: Natura2000-AES

The Natura2000-AES aims to provide favorable conditions for avifauna in the steppe habitats designated as Specially Protected Areas (SPAs) in the agricultural plain of Lleida province, Catalunya. This scheme was selected for study for several reasons. First, Mediterranean AES remain understudied, compared to the better-understood context of Northern Europe (Batáry et al., 2015; Kleijn and Sutherland, 2003; Sutcliffe et al., 2015). Second, Spain is one of the European countries with the highest proportions of high natural value farmland and lower budgets allocated to agri-environmental contracts (Farmer et al., 2008), and Catalonia has one of the lowest percentages of Utilized Agricultural Area (UAA) potentially covered by AES of the Spanish State (Zabala et al., 2017); here, the low AES coverage in high natural value areas stresses the need to increase AES effectiveness. Third, the success of the Natura2000-AES, as any other measure aimed at enhancing habitat conditions to promote biodiversity, depends on its spatial configuration (Stallman, 2011), which makes this scheme especially relevant to answer our research questions.

The SPA area of the agricultural plain of Lleida targeted by the studied AES, constitutes our study area (Fig. 1). This Natura 2000 area comprises 8 SPAs, regulated by the European Bird Directive. All of them, except for Anglesola-Vilagrassa, are also Special Areas of Conservation (SACs), regulated under the Habitats Directive. These dryland habitats are reservoirs of flora, fauna, and cultural heritage with unique characteristics in the European context (PDR 2014–2020). Among its biological values, the ornithic community of farmland birds stands out, with several red-listed species living in the area (PDR 2014–2020). The region is characterized by an arid climate with an average rainfall of around 400 mm and diverse soil types ranging from poor to good quality for agriculture (Cantero-Martínez and Moncunill Geniz 2011); and displays a structure and function resembling herbaceous steppe ecosystems (Generalitat de Catalunya 2010; Sainz-Ollero and van Staalduinen, 2012). Winter cereals, olive, and almond trees are the main uses of land in these areas and are cultivated mostly in a rainfed regime (Cantero-Martínez and Moncunill Geniz 2011). The area comprises 50 municipalities and 8 SPAs, covering 473 km^2. Most of the municipalities within this area have a population density below 75 inhabitants/km^2 and are predominantly rural (Generalitat de Catalunya 2010).

The Special Plan for the Protection of the Natural Environment and Landscape of this Natura 2000 area establishes some management rules. These include the prohibition of fences other than drystone walls or vegetative fences with native species, the prohibition of major earthworks, the limitation of irrigation (which is forbidden except in areas already irrigated with water concessions duly legalized at the time of the declaration of the space as Natura 2000) and the regulation of land-use change (limiting woody crop expansion) and land consolidation (ensuring the conservation of the landscape). These rules collectively contribute to the sustainable management of this Natura 2000 site and constitute the minimum management requirements for farmers within the area.

Due to the insufficient budget allocation within the Natura 2000 network, this area relies on CAP funding and the voluntary cooperation of farmers through the Natura2000-AES for further environmental-friendly management practices. In this scheme only owners and land managers of agricultural holdings with herbaceous crops within the 8 targeted SPAs are eligible. This conservation measure offers two possible actions: management of cereals and unsown areas (which requires a minimum area of 2 ha devoted to this measure per farm) or management of fallow (with a minimum area of 0.5 ha per farm). The prescribed management practices include the postponement of harvesting date, the maintenance of stubble and fallow, the reduction of pesticide application, the preservation of landscape elements with interest for fauna such as water points, stone margins, and traditional constructions, and the establishment of bands where no agricultural work can be carried out for a certain period of time. These actions should in theory favor the presence of endangered bird species.

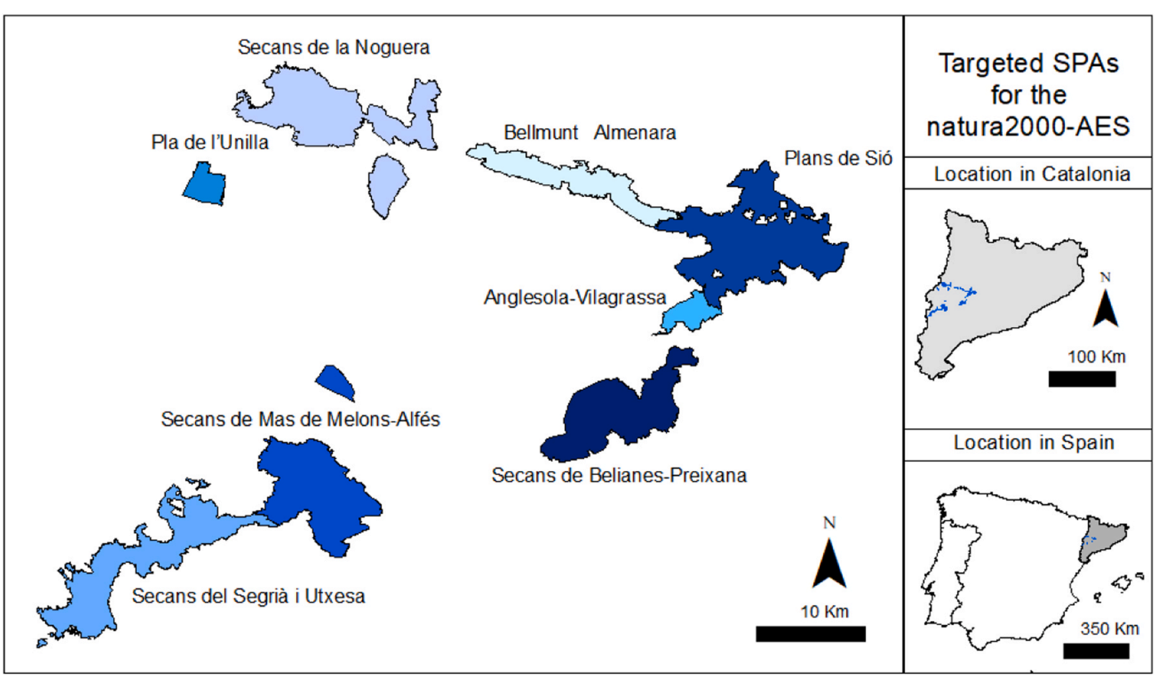

Fig. 1. Study area map showing the SPAs targeted in the "Improvement of the steppe habitats of the Natura 2000 Network" agri-environmental scheme in different gradients of blue. The maps on the right show their location in Catalunya and Spain.

3.2. Data preparation

This section provides a summary of the process of data preparation, which was carried out utilizing Microsoft Excel 365 and ArcGIS 10.8.

For this study, a georeferenced dataset with the limits of the agricultural plots and the information on their enrollment or not in each agri-environmental scheme in Catalonia in 2019 was provided by the Department of Climatic Action, Food and Rural Agenda of the Catalan Government upon request (Table 1). Plots that could potentially apply for the studied AES according to the eligibility criteria (those located within the targeted SPAs and whose declared use was an herbaceous crop) were selected for the analysis. As one condition was to devote a minimum area of 0.5 ha per farm to fallow management or 2 ha to cereal management, we selected all the plots that belonged to a farm that had at least 0.5 ha of herbaceous crops.

In order to understand if the spatial agglomeration of participation was due to neighboring farmers participating in the scheme or to the enrollment of contiguous plots by the same farmer, we prepared two datasets. The first one, hereafter referred to as the “original dataset”, contains the official division of plots. In the second one, which we named “combined adjacent plot dataset”, contiguous plots with the same ID of exploitation (and therefore managed by the same farmer) were combined. As farmers may enroll only some of their plots in AES, we combined enrolled adjacent plots and, independently, those that were not enrolled.

To investigate the role of drivers in AES participation, biophysical and socioeconomic data were obtained from open data platforms of the regional and national public administrations (Table 1, Tables 2 and 3). Data for biophysical factors was studied at the plot scale (Table 1). To that end, we calculated plot size using the geometry calculator tool, and calculated the average altitude and slope (which we obtained from a 2 m Digital Elevation Model) for each plot using ArcGIS.

Socioeconomic factors were analyzed at the farm level when the data was available at this scale (Table 2). However, for some other socioeconomic factors, the study had to resort to the municipal level due to the unavailability of farm-level data. Although not ideal, analysis at this scale can help unveil territorial dynamics of AES adoption otherwise ignored at the plot level (Bartolini and Vergamini, 2019).

Socio-demographic indicators at the municipal level were acquired from the Catalan Statistics Institute of Catalonia (Table 3). Farm and farmer characteristics were obtained from the 2020 agrarian census which contains anonymized data at the farm level. This dataset is not georeferenced; however, it contains a code of the municipality in which the farm is located. Thus, data for these variables were aggregated and analyzed at the municipal level.

3.3. Data analysis

To understand if the Natura2000-AES uptake follows a specific spatial pattern, the first step was to create a map to observe the distribution of enrolled plots. Then, we conducted Global Moran’s I test, which provides evidence of the existence of spatial autocorrelation (-1=fully dispersed; 0=random distribution; 1=fully clustered distribution) and its statistical significance (Getis, 2010). Spatial autocorrelation describes the relationship between some variable and a measure of geographical proximity, which can be distance or contiguity. In this case, the Moran’s I test was conducted for both proximity measures, applying two different conceptualizations of spatial relationships.

First, we tested if enrolled plots clustered with each other on the basis of distances between plot centroids, using inverse distance to conceptualize spatial relationships. With this specification, closer neighbors exert a stronger influence than more distant neighbors. Beyond a certain distance, it is assumed that a spatial effect does no longer affect participation in AES, and therefore a threshold distance must be specified. Inspired by Lapple and Kelley (2015), who use a threshold distance of 30 km to study the spatial dependence of organic farming in Ireland, in this study we chose a 10 km cut-off, which is the approximate distance between the two farthest plots within a municipality. Second, we tested if farms are interrelated by sharing a part of their boundaries, conceptualizing spatial relationships of the Global Moran I test by “contiguity-edges-corners”. The minimum, average, and maximum one-neighbor distance between the boundaries of plots enrolled in the Natura2000-AES, were also calculated.

All the above tests were conducted both with the “original dataset” and the “combined adjacent plot dataset”, in order to understand if the spatial agglomeration of participation was due to the willingness of farmers to enroll adjacent plots within their farms or to neighboring farmers participating in the scheme. The “combined adjacent plot dataset” eliminates the effect of contiguity within the farm, however, it cannot mitigate the distance-based spatial autocorrelation that arises from the enrollment of nearby plots within a farm. Therefore, to ensure that there was farm-level agglomeration, we also calculated Global Moran’s I index for the ratio of the number of farms that participate per municipality/total number of farms with eligible plots of the municipality. To add robustness to the results, we calculated Moran indexes for the “original dataset” in each individual SPA (Table A.1, supplementary material). All the spatial statistical tests were conducted in ArcGIS 10.8.

Then we explored relationships between AES uptake and social and biophysical characteristics. Numerical variables at the plot and farm level (plot size, altitude, slope, age) followed non-normal distributions, so we ran Mann-Whitney tests. For categorical variables at the plot and farm level (land-use, irrigation, legal personality, professionality, gender, and belonging to a farmer’s organization) we conducted chi-square tests and calculated odds ratios to assess the strength of the association. To explore associations between the municipal level data and the ratio of enrolled plots/total of eligible plots per municipality, we calculated Spearman’s correlation coefficients. All statistical tests were conducted using XLSTAT 2023.

Table 1
Factors that could explain farmer participation in AES studied at the plot level.

Variable		Description	Data source	Year	Format
Dependent variable	AES enrollment	Plots enrolled in the Natura2000-AES	Dataset provided by Dept. of Climatic Action, Food and Rural Agenda of the Catalan Government	2019	Vectorial (shapefile)
Biophysical characteristics	Plot size	Plot size (square meters)	Calculated with the spatial dataset provided by the Dept. of Climatic Action, Food and Rural Agenda of the Catalan Government	2019	Vectorial (shapefile)
	Altitude	Average altitude of the plot (meters above the sea)	Digital Elevation Model (DEM) 2×2m from the Cartographic and Geological Institute of Catalonia	2016	Raster (TIFF)
	Slope	Average slope of the plot (meters above the sea)	Calculated with DEM 2×2 m from the Cartographic and Geological Institute of Catalonia	2016	Raster (TIFF)
	Land use	Land use (cereal or fallow) according to the Agricultural Declaration (DUN)	Catalonian map of crops according to DUN from the open data platform of the Government of Catalonia	2019	Vectorial (shapefile)
	Irrigation	Irrigated vs rainfed according to the Agricultural Declaration (DUN)	Catalonian map of crops according to DUN from the open data platform of the Government of Catalonia	2019	Vectorial (shapefile)

Table 2
Socioeconomic factors that could explain farmer participation in AES studied at the farm level.

Variable		Description	Data source	Year	Format
Dependent variable	AES enrollment	Farms enrolled in the Natura2000-AES	Dataset provided by Dept. of Climatic Action, Food and Rural Agenda of the Catalan Government	2019	Vectorial (shapefile)
Socioeconomic characteristics	Legal personality	Legal entity (company) or natural person	DUN (agricultural declaration (DUN) from the open data platform of the Government of Catalonia	2019	Vectorial (shapefile)
	Professionality	Professionals (individuals with more than 50% of their income coming from the farm) or non-professionals (otherwise). For natural persons only	Dataset provided by Dept. of Climatic Action, Food and Rural Agenda of the Catalan Government	2019	Vectorial (shapefile)
	Gender	Gender of the farm manager. For natural persons only	DUN (agricultural declaration (DUN) from the open data platform of the Government of Catalonia	2019	Vectorial (shapefile)
	Belonging to a farmer's organization	Whether or not the farm manager belongs to a farmer organization	DUN (agricultural declaration (DUN) from the open data platform of the Government of Catalonia	2019	Vectorial (shapefile)
	Age	Age of the farm manager. For natural persons only	DUN (agricultural declaration (DUN) from the open data platform of the Government of Catalonia	2019	Vectorial (shapefile)

Table 3
Factors that could explain farmer participation in AES studied at the municipal level. *INE is the Spanish National Statistics Institute and Idescat is the Statistics Institute of Catalonia.

Variable		Description	Data source	Year
Dependent variable	AES_ratio	Number of farms enrolled in the Natura2000-AES per municipality/total number of farms with eligible plots per municipality	Data provided by Dept. of Climatic Action, Food and Rural Agenda of the Catalan Government	2019
Municipality characteristics	Pop_dens	Population density (people per km^2)	Idescat	2019
	Socioeco_index	Territorial socioeconomic index composed of the following six indicators: employment rate, average net income per capita, percentage of the population with low-qualified jobs (registered with Social Security that is listed in group 10, laborer), percentage of the population over 20 years with low studies (primary school at most), percentage of the population aged 20–34 with the first stage of secondary education at most, and percentage of people with nationality of a low and middle-income country according to the 2019 World Bank ranking. The index ranges from 1 to 10, with lower values indicating a higher vulnerability of the municipality.	Idescat	2019
Farm characteristics	%UAA_owned	% UAA (Utilized Agricultural Area) in property	Agrarian Census from the INE	2020
	%UAA_rent	% UAA (Utilized Agricultural Area) under rent	Agrarian Census from the INE	2020
Farmer's characteristics	%women_farmer	% farm managers that are women	Agrarian Census from the INE	2020
	Av_age	Average age of farm manager	Agrarian Census from the INE	2020
	Av_number_years	Average number of years in which the farm manager has worked at the farm	Agrarian Census from the INE	2020
	%work_time>50%	% farm managers that work on the farm more than 50% of their working time	Agrarian Census from the INE	2020
	%agrarian_experience	% farm managers with agrarian experience exclusively	Agrarian Census from the INE	2020
	%agrarian_courses	% farm managers with agrarian training courses	Agrarian Census from the INE	2020
	% agrarian_prof_training	% farm managers with agrarian professional training	Agrarian Census from the INE	2020
	% agrarian_univ_studies	% farm managers with agrarian university and/or superior studies	Agrarian Census from the INE	2020

4. Results

4.1. Natura2000-AES uptake and distribution

In 2019, 149 farmers participated in the Natura2000-AES, which corresponds to a 5.8% participation rate among the farmers with eligible plots for the scheme. These farmers enrolled 3242 plots, covering a total area of 4326 ha. Participation is scattered throughout 29 of the 50 municipalities with plots eligible for the Natura2000-AES. In those municipalities, a few farmers participate in the measure (average of 6 farms enrolled per municipality), enrolling several plots. Most farmers that participated decided to manage only a part of their land under this scheme, enrolling an average of 71% of their eligible plots in this measure.

The studied AES uptake appears to be more concentrated in some of the targeted SPAs, especially those in the South and East, while in one of the SPAs in the Northwest (Pla de l'Unilla) no farmer participated (Fig. 2).

Moran's I test for the "original dataset" evidences a positive and significant spatial autocorrelation for both distance and contiguity (Table 4). In particular, Moran's index for contiguity-edges-corners is two times higher than Moran's index for inverse distance. The average distance from the enrolled plots to their nearest enrolled neighbor is 7 m, with many plots sharing borders and others being at a maximum distance of 2.4 km from other enrolled plots (Table 4). Moran's I indices within each individual SPAs are all positive and significant, although lower than for all the targeted area (see Table A.1 in the supplementary material).

When Moran's I test is run for the "combined adjacent plot dataset" in which the enrolled adjacent plots which belong to an individual farmer are combined, the spatial agglomeration based on distance is lower, and contiguity although positive and significant, is close to zero (Table 4). For this dataset, the average minimum distance between enrolled plots is 38 m.

At the municipality scale, there is significant spatial autocorrelation for the ratio "number of farms that participate per municipality/total

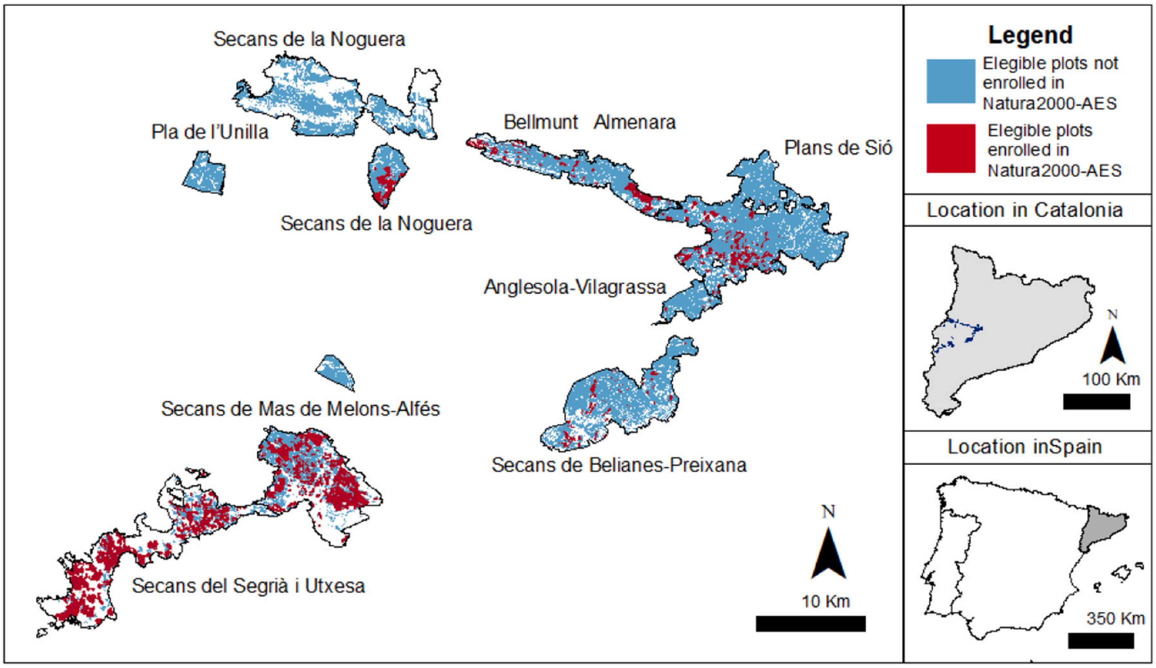

Fig. 2. Study area map showing the distribution of enrolled and not enrolled farms in the "Improvement of the steppe habitats of the Natura 2000 Network" agri-environmental scheme across the 8 targeted SPAs in 2019. The maps on the right show the location of the targeted SPAs in Catalunya and Spain.

Table 4
Results of the spatial autocorrelation tests: Moran's I for inverse distance and contiguity edges-corners, and distance from the nearest neighbor. The "original plots" correspond to the initial dataset, and the "adjacent plots of the same farmer combined" correspond to the modified dataset in which contiguous plots of the same farm have become a larger single plot.

		Original dataset	Combined adjacent plot dataset
Inverse distance	Moran's I	0.2171	0.1326
	Statistic (z-score)	1987.39	190.32
	p-value	**<0.0001**	**<0.0001**
Contiguity edges-corners	Moran's I	0.4711	0.0646
	Statistic (z-score)	106.08	8.40
	p-value	**<0.0001**	**<0.0001**
Distance from the nearest enrolled plot	Minimum distance from nearest neighbor	0 m	0 m
	Maximum distance from nearest neighbor	2445 m	2445 m
	Average distance from nearest neighbor	7 m	38 m
	Standard deviation	63 m	132 m

number of farms with eligible plots of the municipality" (contiguity-edges corners Moran's Index: 0.485458; z-score: 4.984756; p-value <0.0001).

4.2. Factors affecting farmer participation in the Natura2000-AES

Mann-Whitney tests show that all numerical variables studied at the plot level (plot size, altitude, and slope) significantly affect participation in the studied AES (Table 5). Enrolled plots are more likely to be bigger and located on lower lands and present a lower slope than non-enrolled plots. However, it should be noticed that our study area is quite homogeneous in terms of biophysical characteristics, varying a few degrees in slope and a few meters in altitude (see maps and boxplots in Fig. 3). Therefore, we suggest that these factors may not be influencing the decision to participate but are spatially correlated with other factors that drive participation (See Table B.1 in the supplementary material).

Table 5
Mann-Whitney tests' results for numerical variables studied at the plot and farm level.

	Variable	Mean (not enrolled)	Mean (enrolled)	Mann-Whitney U	p-value
Plot level	Plot_size	9868 m^2	13343 m^2	**39020050**	**<0.0001**
	Altitude	345 m.s.l.	255 m.s.l.	**9321844**	**<0.0001**
	Slope	4.8 degrees	3.5 degrees	**6311577**	**<0.0001**
Farm level	Age	63 years	52 years	**196718**	**<0.0001**

Chi-square tests show that categorical variables studied at the plot level (land use and irrigation) also significantly influence the adoption of Natura2000-AES (Table 6). According to calculated odds ratios, enrolled plots are 4.5 times more likely to have fallow and 3.8 times more likely to be rainfed than plots not registered in the scheme.

According to the Mann-Whitney test, farmers that participate in the Natura2000-AES are significantly more likely to be younger than farmers that do not participate (Table 5). Chi-square tests show that of the categorical variables studied at the farm level, only professionality, and belonging to a farmers' organization significantly influence participation (Table 6). According to calculated odds ratios, enrolled farms are 4.3 times more likely to be managed by a professional farmer and 2.5 times more likely to belong to a farmer's organization than farms that do not participate in the scheme. A further look at the data of this last variable revealed that either all or none of the farmers belonging to a cooperative were enrolled in the scheme.

A visual examination of the spatial distribution of the factors (see Fig. 3) suggests that large plots, plots in high elevation, as well as fallow land, irrigated land, and farmers enrolled in cooperatives tend to concentrate spatially, and their clusters partly overlap the clusters of AES participation (see Fig. 2). Conversely, farmers' age and professionality display more dispersed patterns.

Some socioeconomic factors studied at the municipal level show significant correlations with the uptake of Natura2000-AES (Table 7). Municipalities with lower values of the socioeconomic index (which can be interpreted in general terms as more vulnerable municipalities), a

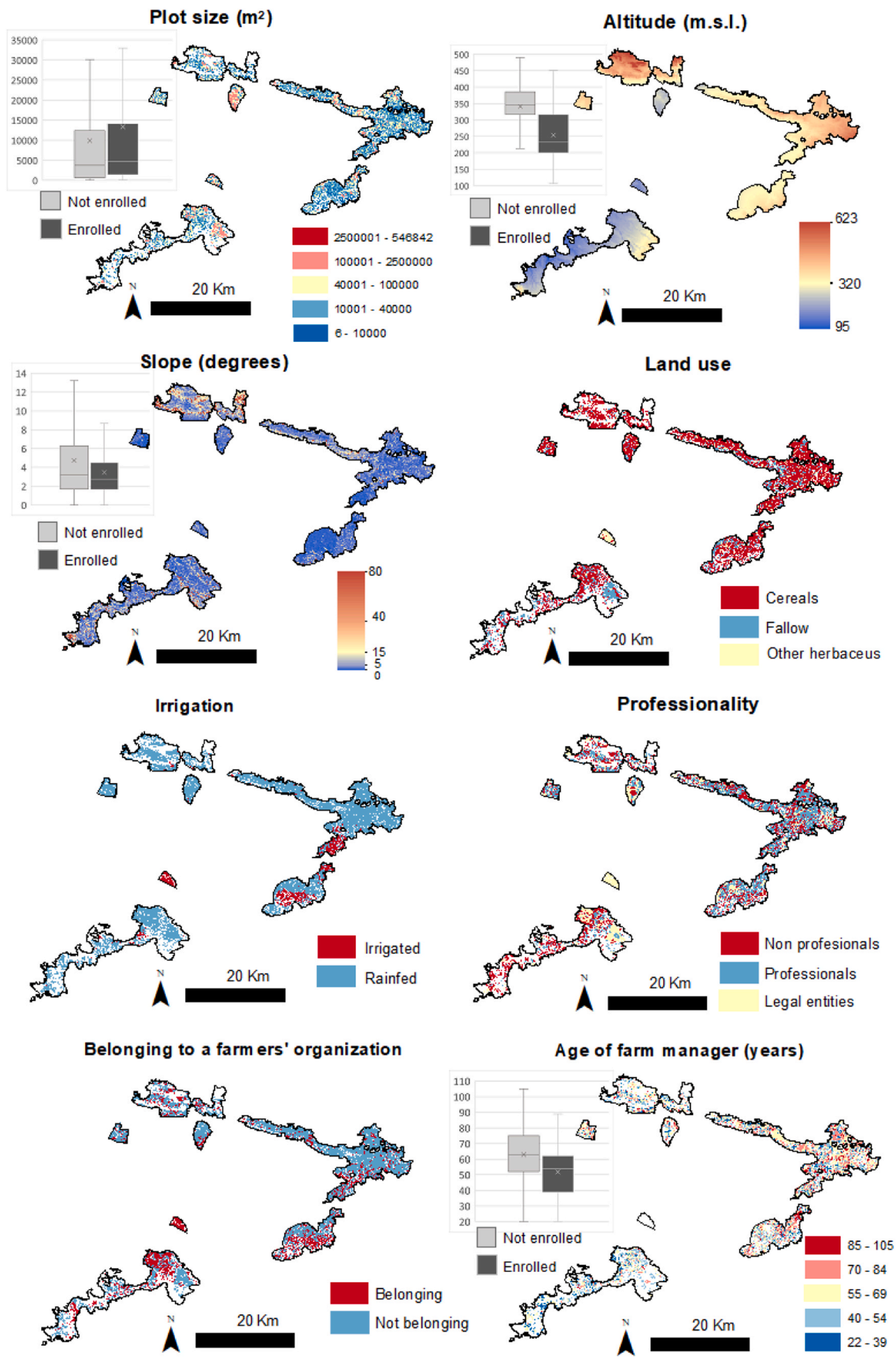

Fig. 3. Spatial distribution of the plot and farm-level factors that could influence farmer participation in AES. For numerical variables, boxplots are shown for both enrolled and not enrolled plots.

Table 6
Chi-square (Chi^2) tests' results for categorical variables studied at the plot and farm level.

Variable			% of non-enrolled plots/farms	% of enrolled plots/farms	Chi^2	p-value	Odds ratio
Plot level	Land_use	Fallow	25%	60%	**1718. 128**	**<0.0001**	**4.54**
		Cereals	75%	40%			
	Irrigation	Rainfed	88%	97%	**213.915**	**<0.0001**	**3.82**
		Irrigated	12%	3%			
Farm level	Legal personality	Natural person	90%	88%	0.724	0.3948	1.24
		Legal entity	10%	12%			
	Professionality	Professional	28%	63%	**69.687**	**<0.0001**	**4.27**
		Non-professional	72%	37%			
	Gender	Woman	28%	22%	2.357	0.1247	1.39
		Man	72%	78%			
	Belonging to a farmers' organization	Belonging	24%	44%	**29.921**	**<0.0001**	**2.49**
		Not belonging	76%	56%			

Table 7
Spearman correlation coefficients (with the ratio of farms participating/total number of farms with eligible plots of the municipality) for socioeconomic variables studied at the municipal level.

Variables	Spearman	p-value
Pop_dens	0.051	0.725
Socioeco_index	**-0.294**	**0.039**
%UAA_owned	-0.155	0.281
%UAA_rent	0.222	0.121
%women_farmer	-0.130	0.367
Av_age	**-0.376**	**0.007**
Av_number_years	-0.239	0.095
%work_time>50%	**0.369**	**0.009**
%agrarian_experience	**-0.300**	**0.035**
%agrarian_courses	**0.328**	**0.021**
%agrarian_prof_training	-0.002	0.989
%agrarian_univ_studies	0.229	0.109

higher percentage of full-time farmers, younger farmers, and/or farmers with agrarian courses as their maximum education level register significantly more participation. Conversely, municipalities with higher proportions of farmers with no agrarian training or education, present significantly lower levels of participation. It is remarkable that the three variables that we analyzed both at the farm and municipality levels -age, gender, and professionality (using income or working time as proxies)- show similar results at both levels, which might indicate some robustness of the results.

5. Discussion

5.1. Natura2000-AES uptake and distribution

As noted earlier, 5.8% of farmers with eligible plots participated in the Natura2000-AES in 2019. This participation rate may seem low, as it indicates that only a small share of farmers is interested in applying agronomic practices that favor biodiversity. That said, the area covered by these contracts (4326 ha) was as high as it could have been. In fact, prioritization criteria had to be applied and 9 farmers that applied for the scheme in 2019 were not final beneficiaries. Zabala et al. (2017) criticized the low budget assigned to this conservation measure, arguing that the area that can benefit from it is very small in relation to the importance and extension of these habitats, which are considered High Natural Value Areas.

There is evidence that the amount of land under conservation contracts plays a role in promoting avifauna (Zingg et al., 2019). Zingg et al. (2019) show that the amount and quality of habitats under AES can contribute more to bird species richness than their spatial configuration; as the proportion of land cover enrolled in AES reaches a certain threshold, a certain level of ecological connectivity naturally emerges. However, increasing the area of potential AES uptake often means increasing the budget allocated to agri-environmental measures. This would align with some scientists' and social movements' recommendations to redirect funds from the direct payments of CAP's first pillar towards the greener agronomic practices of the second CAP pillar (Bartz et al., 2019; Pe'er et al., 2014). Still, increases in AES budget should not undermine efforts to maximize cost-efficiency, via e.g., spatial coordination of participation (Nguyen et al., 2022; Wossink et al. 1999).

Our results evidence a spatial agglomeration of AES uptake, with autocorrelation both for distance and contiguity proximity measures, which implies that plots under these contracts are more likely to be near and next to other enrolled plots than not. We found that spatial autocorrelation based on contiguity for the "combined adjacent plot dataset" is seven times lower than for the "original dataset". This indicates that farmers tend to enroll contiguous plots within their farms, which might be a strategy to achieve internal economies of scale. However, there is still a significant spatial autocorrelation for the "combined adjacent plot dataset", which suggests that farmers that participate in AES tend to be close to other participating farmers. Furthermore, we found a significant spatial autocorrelation for the percentage of farms enrolled per municipality, which demonstrates that the spatial clustering of AES participation is not solely a result of the enrollment of contiguous or nearby plots within farms but also comes from the spatial agglomeration of farms that participate in the program.

From the ecological point of view, the spatial agglomeration of this scheme can enhance the connectivity of high-quality habitats. Our results show that the average distance from combined-adjacent-plots enrolled in the Natura2000-AES to their nearest neighbor is 38 m, and the maximum distance is roughly 2.4 km. These findings align with Siriwardena's (2010) recommendations, who, based on the observed average distances that farmland birds moved, advised that habitat patches managed under AES should be spaced 1–2 km from one another. Therefore, our findings suggest that plots under the Natura2000-AES are close enough to enhance ecological connectivity, providing sufficient habitat continuum to allow for birds' mobility across landscapes (Zingg et al., 2019). That said, the specific location of enrolled plots is also important. Through a voluntary implementation by farmers without any spatial coordination strategy, enrolled plots may be close to roads or other landscape features that make birds' living conditions more difficult (Sanz-Pérez et al. 2021). Therefore, although connectivity might be ensured by high participation rates or agglomeration patterns, coordination and collaboration among farmers might still be needed to deliver an optimal location of AES.

From the social point of view, spatial agglomeration can also be beneficial. If interested farmers are relatively close together, social learning is likely to occur, reducing transaction costs of inquiring about the scheme, sharing good practices, and building a community spirit of conservation (Kuhfuss et al., 2015). This could pave the way for further attempts to transition from individual farm-scale operations to landscape-level management through cooperation among farmers. As suggested by Schmidtner et al. (2012), who found spatial agglomeration in organic farming in Germany, proximity among enrolled farmers could lead to scale economies external to the farm. In fact, recent research demonstrated that spatial agglomeration of sustainable agricultural practices can lead to better economic outcomes. For instance, Chang et al. (2023) reveal that the clustering of organic rice farming had a notable positive impact on the economic performance of rice farms in Taiwan, in terms of cost reduction and profit growth. Similarly, Marasteanu and Jaenicke (2019) demonstrated that being part of an organic hotspot in the United States was associated with decreases in poverty rates and increases in median household income at the county level. There is a notable research gap concerning the economic advantages of AES agglomeration in Europe. Further research shall address that gap.

5.2. Factors affecting farmer participation in the Natura2000-AES

Larger plots were more likely to be enrolled in the Natura2000-AES, which echoes findings from previous studies across Europe (Morris and Potter, 1995; Unay-Gailhard and Bojnec, 2016; Wittstock et al., 2022). This might be attributed to the fact that farmers with larger plots can profit disproportionally more from AES since payments are disbursed on a per hectare basis (Wilson, 1997). These scale economies might be especially important in the area targeted by the scheme, where plots are relatively small (Carricondo et al., 2012).

The higher willingness of professional farmers to participate in the AES has two possible explanations. First, these farmers have the resources to hire advisors to deal with the bureaucratic burden of schemes, which has been found to be an important obstacle to AES participation (Wittstock et al., 2022). Second, full-time, professional farmers may prefer diversifying their sources of income (including AES payments) than engaging in an agricultural intensification strategy, given the increased volatility of input and output prices and weather uncertainty (Ridier, 2012). This could explain why enrolled farms tend to concentrate in dryland and fallow land; farmers would be applying a kind of land sparing strategy, where less productive land is devoted to conservation measures and more productive land to intensification. This would also align with the tendency of farmers to prefer conservation measures that require little effort and can be easily implemented (Arnott et al., 2019).

We observed significantly higher participation among the farmers who belong to a farmer's organization. This can be explained by the fact that being part of such organizations helps reduce transaction costs, as they typically handle the bureaucratic burden of applying to the AES and/or provide advice to farmers (Wittstock et al., 2022). Furthermore, in a study conducted in Catalonia, farmers who were members of cooperatives mentioned that they delegate the decision to participate in AES to the cooperatives (Wittstock et al., 2022). This is consistent with the observation that either all or none of the farmers belonging to a certain cooperative participated in the Natura2000-AES. This pattern could be attributed to varying organizational values, with some being profit-driven while others prioritize environmental values (Polman and Slangen, 2008).

Our findings show significantly higher participation in the municipalities with lower socioeconomic indexes. This suggests that the AES is an important source of income in vulnerable territories and households, given their incapacity to invest in intensive agriculture. Further research should assess at the household level if the measure is indeed providing opportunities for the disenfranchised and contributing to reducing inequalities.

The spatial distribution of the above-discussed drivers of AES participation might explain the spatial patterns of AES uptake. For example, higher participation in AES contracts might be concentrated in zones where there are larger, non-irrigated, or fallowed plots, or where young, educated, or professional farmers concentrate. Although we did not model the impact of the spatial distribution of AES drivers on the AES agglomeration patterns, we can visually explore spatial associations between the clusters of biophysical and sociodemographic variables and the clusters of AES uptake. Comparing the maps of these variables in Fig. 3 with the maps of AES adoption in Fig. 2, we can appreciate that some AES drivers (such as age or professionality) are quite dispersed and therefore unlikely to explain AES agglomeration patterns, while others (such as land use and irrigation) are highly clustered and partly overlap the clusters of AES adoption.

A complementary explanation to the spatial influence of the above factors is that of diffusion dynamics in AES uptake. This is known as the bandwagon effect, i.e., individuals adopt a particular behavior because others adopted it around them; (Rosenkopf and Abrahamson, 1999). These imitation dynamics could arise from the need for social approval (van Dijk et al., 2015). For instance, Lapple and Kelley (2015) demonstrated that in the adoption of organic drystock farming in Ireland, attitudes and social norms had spatial spillover effects (a positive environmental attitude by one farmer correlated positively with the adoption of organic management by nearby farmers). Economic motivations may also influence scheme adoption; farmers may be more willing to participate if their neighbors do too, in order to benefit from external scale economies. Likewise, the spatial agglomeration of AES adoption may be attributed to the dissemination of AES knowledge by neighboring farmers. Studies in Catalonia and the neighboring region of Aragon have revealed that peer-to-peer influence can play a large role in the early years of AES, because 'pioneers' share their experience and help to spread knowledge about the schemes (Wittstock et al., 2022) and because farmers rely more on the recommendations of other farmers' and farmer organizations than of those of scientists or the government (Villamayor-Tomas et al., 2019). This aligns with our findings about the positive association between the membership of farmers in farmer organizations and AES adoption. Consequently, we recommend administrations to intensify the promotion of AES in collaboration with those organizations.

As we tested spatial autocorrelation within the SPA area targeted by the scheme, the results indicate spontaneous (or non-steered) agglomeration effects. However, it is important to reflect that spatial agglomeration in the Natura2000-AES is partly a consequence the 'narrow-and-deep' scheme design of the measure (Baker et al., 2012), specifically designed for farmland birds and targeted where it could be most effective (the steppe habitats SPAs of the agricultural plain of Lleida). If there were no spatial targeting and participation were open to farmers from all parts of Catalonia, AES adoption might not exhibit the agglomeration patterns observed here. Hence, this targeting can help overcome the failure of fragmented uptake of AES and some incoherencies shown in other European regions where participation in schemes designed to promote a bird species recovery occurred in areas where no populations of the species were observed (Arnott et al., 2019). The combination of targeted funding in a High Natural Value Area and voluntary willingness to join a scheme has been pointed by some scholars as an optimal way to deliver public goods in agricultural landscapes (Arnott et al., 2019; Baker et al., 2012). That said, targeting specific areas favors the spatial segregation of conservation and agricultural intensification, which has been criticized for its lack of effectiveness to protect the environment precisely in the areas where it is most threatened (Früh-Müller et al., 2019). From a social perspective, it may also entail that low-productive farms located outside the targeted area cannot benefit from the economic gains of these rural development measures.

This study's implications extend beyond local boundaries, resonating at a broader European level, where both the Natura 2000 network and agri-environmental schemes are central biodiversity conservation measures. However, while European countries share a common regulatory framework on agriculture and conservation, regions have adapted it differently to their own contexts, with varying outcomes (Tucker, 2023). As the Natura2000 applies to cereal cultivation, the significance of our findings is emphasized by the fact that cereal crops occupy nearly a third of the European Union's agricultural area (EU, 2019). That said, Europe also exhibits a remarkable diversity in both agroecosystems and farming practices. Thus, while insights from this study can offer valuable lessons, we recommend caution when extrapolating them to other regions or different agri-environmental measures.

5.3. Limitations and areas to explore in future research

Some uncertainty is introduced into our study because some socioeconomic variables were studied at the municipal level. Addressing this limitation would require the accessibility of farm-level socioeconomic data, which could compromise the anonymity of personal information. Nevertheless, the consistency of results across scales in the analysis of the three variables for which data were available at both the farm and municipal levels supports the robustness of our findings. Additionally, our methods, which are entirely based on secondary data, could be enriched by primary data collection. This would allow the inclusion of other important variables that have been indicated to display spatial spillover effects (e.g., attitudes and values towards conservation or the influence of extension services)(Lapple and Kelley, 2015). This presents an interesting area for further investigation.

6. Conclusions

The level of participation in the agri-environmental scheme for the "Improvement of the steppe habitats of the Natura 2000 Network" is relatively low, considering that only 5.8% of farmers with eligible plots enrolled in the program. However, this represents the maximum potential achievable, considering the available budget for the measure. Plots enrolled in this scheme are spatially agglomerated; located within a maximum distance of 2.4 km from their nearest enrolled plots. This clustering of participation seems to be occurring both at the plot level -agglomeration within the farm, with farmers choosing to enroll their adjacent or nearby plots in the scheme- and at the farm level -with farmers that adopt AES being near other participating farmers. This could be a result of a strategic approach aimed at achieving internal and external economies of scale, as the spatial agglomeration of enrollment might lead to reduced transaction costs and better economic outcomes.

The observed agglomeration might also be attributed to the existence of clusters of AES drivers (we can expect more participation in areas where drivers of AES participation concentrate). Our results show that participation concentrates on fallowed and non-irrigated land, as well as in larger plots. We also observed that professional farmers, young farmers and/or farmers that belong to a cooperative are more likely to participate in the Natura2000-AES, by contrast, farmers with no agrarian education are less likely to adopt this AES. In addition, municipalities with lower socioeconomic indexes (indicating a higher unemployment rate, lower income per capita, higher percentage of the population with low-qualified jobs and low education, and/or higher proportion of immigrants from a low and middle-income country) have significantly higher participation rates. A visual examination of maps displaying the distribution of the above drivers leads us to conclude that the agglomeration of AES adoption might partly come from the spatial distribution of these biophysical and sociodemographic factors, as some of them are spatially agglomerated and their clusters partly overlap AES clusters. However, some other drivers are more homogeneously distributed and therefore unable to explain the nearness of enrolled farms.

Hence, we could assume that agglomeration might also come from the influence that neighbors have on a farmer's decision to adopt AES. For example, studies have shown that environmental attitudes affect neighboring farmers, generating a bandwagon effect that spreads the adoption of conservation practices. Additionally, neighboring farmers can be a source of information on AES, sharing their experiences and helping to spread knowledge about the schemes.

From the ecological point of view, the spatial agglomeration of this scheme might have positive implications for habitat connectivity. In fact, the observed distance between enrolled plots aligns with the recommendation given in studies that analyze farmland birds' movements in similar settings. However, agglomeration patterns cannot guarantee an ecologically optimal location of enrolled plots, for which landscape contextual factors must be considered. Therefore, coordination strategies might still be needed to deliver effective landscape planning. In this respect, the spatial agglomeration of participation offers a promising opportunity for future attempts to transition from individual farm-scale operations to landscape-level management through cooperation among farmers.

Although these findings are representative of the studied context, the understandings gained with this study resonate beyond the local, as similar measures within the AES program extend throughout the European Union. Future research could investigate this issue in different settings and broaden our analytical scope to assess the environmental and social effectiveness of spatial agglomeration in the AES context. Policymakers and practitioners within this field could benefit from these lessons and give a necessary consideration to the spatial patterns of conservation schemes within agricultural landscapes.

Declaration of Competing Interest

The authors declare no conflict of interest.

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Declaration of Generative AI and AI-assisted technologies in the writing process

During the revision of this work, the authors used ChatGPT 3.5 in order to assist in rephrasing certain sentences to improve their readability. After using this tool, the authors reviewed and edited the content as needed and take full responsibility for the content of the publication.

Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.landusepol.2024.107145.

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