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Farmland Abandonment and Afforestation—Socioeconomic and Biophysical Patterns of Land Use Change at the Municipal Level in Galicia, Northwest Spain

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Abstract: Over the last few years, new land use planning instruments to reduce the negative consequences of recent land use/cover changes (farmland abandonment, wildfires) have been proposed in Galicia (northwest Spain). Understanding the complex relationship between biophysical constraints, socioeconomic drivers and land use/cover changes is paramount for their successful implementation. In this work, we present an analysis of recent (2005–2017) land use/cover changes in the region, along with a classification of municipalities in homogeneous groups with different patterns of land use and land use change. We then characterize those groups regarding the demographic and employment structure, the economic performance, the characteristics of the primary sector, the land ownership structure and the relative importance of recent wildfire events and the biophysical suitability for the main productions of the primary sector in the region. The results allowed us to identify four different groups of municipalities which are clearly separated by specific patterns of land use (an area where most of the population lives, an area devoted to forest production, another for farming production and a final one dominated by semi-natural covers). These four areas followed a gradient of decreasing levels of population density and economic activity. While land use patterns in different areas could be explained largely by biophysical suitability, the fragmentation of land ownership emerged as a relevant factor, which can explain the greater presence of farmland abandonment—and, therefore, higher wildfire risk—in certain areas. These results offer relevant guidelines for the successful implementation of the new land use planning instruments in the region.

Keywords: Galicia; Spain; farmland abandonment; land fragmentation; wildfire risk; cluster analysis

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1. Introduction

Since the mid-twentieth century, large transformations of the land use system have taken place in Spain as a result of extensive social and economic changes. A dramatic economic improvement that started in the decade of the 1960s, sustained on the growth of the industrial and services sectors [1], strongly intensified the depopulation of rural areas [2] and the marginalization of the farming sector within the national economy [3]. These resulted in the expansion of urban and forest areas, often at the expense of land formerly used for farming [4,5]. The effect of natural constraints, nevertheless, resulted in diverging trajectories at the regional and local scale, with some areas undergoing urbanization and population growth, or agricultural intensification, and others, usually those in mountainous or remote locations, enduring land abandonment and depopulation [6,7].

While the main trends were maintained until today, for the most part, subsequent economic, political and institutional changes had effects on the pace and location of observed land use changes. The accession to the European Economic Community in 1986, for example, increased the rate at which farmland abandonment and forest expansion took place in certain areas [8]. More recently, the financial crisis that started in 2008 greatly reduced, and even reversed, urban growth in some areas of the country [9]. The successive reforms of the EU Common Agricultural Policy (CAP) may also have introduced slight variations in the previous trends. Oñate et al. [10], for example, suggest that the decoupling of payments from production, applied since the 2003 Mid-term Review of the CAP, might reduce profit margins in low-income agricultural systems and, therefore, increase farmland abandonment in areas in which these systems are more prevalent.

The large changes in the landscape during the second half of the twentieth century in Spain were coupled with significant changes in fire regimes [11,12]. Farmland abandonment increased wildfire risk as it led to increased volumes and spatial continuity of biomass in most of Southern Europe [13]. Vegetation encroachment, often coupled with (sub)urban expansion, means that wildfires pose a great risk to properties and human lives in the wildland–urban interface [14].

Within this overall context, recent wildfire events in 2017 in Galicia, northwest Spain [15], raised awareness among regional policymakers about the strong connections between land planning, landscape changes and wildfire risk. This triggered the passing, in May 2021, of the Law for the recovery of agricultural land of Galicia, which set up a combination of zoning regulations, information systems about land markets, the creation of administrative departments specialized in facilitating agreements concerning property rights, and legal instruments to promote the productive recovery of abandoned farmland [16]. These instruments are aimed at curbing or even reversing farmland abandonment in the region, promoting more adequate land use and thus reducing wildfire risk. These include instruments that were already operating in the region, such as a land bank operating as a mediator between farmers and landowners, as well as completely new ones, thus forming a "toolbox" of instruments at the disposal of the public and the Administration: an attempt to introduce zoning regulations to demarcate the area of forest expansion; "model settlements" to promote farming at the fringes of inhabited areas and thus reduce the amount of biomass in the wildland–urban interface; "agroforestry polygons" intended to promote the joint use of the land in areas of high property fragmentation; and a "farm bank" intended to facilitate the transfer of farm installations from retiring farmers to young ones. However, the implementation of this new legal framework and policy instruments may be hindered by the limited existing knowledge about recent landscape changes, the different patterns of change at the local level and the conditioning factors.

In order to achieve this, first, we use the latest land use/cover map series available in Spain (Spanish Land Use Information System, SIOSE) to identify the main patterns of land use/cover change at the municipal level in the region during the period 2005–2017. Second, we use a selection of biophysical and socioeconomic variables to analyze their relationship with the observed land use/cover change patterns. With this analysis, we intend to test the role played by constraints related to physical suitability for the main agricultural and forest productions, or fragmentation of land ownership, as well as to clarify the interaction of land use/cover change with other socioeconomic factors. We based the selection of variables on a review of previous studies for different countries and regions, under the theoretical assumption that these socioeconomic and biophysical variables interact with land use, in the line of Hietel et al. [17,18]. The direction of these interactions is something we try to clarify in the interpretation of the results.

Although referring to the case study of the Spanish region of Galicia, our research aims to be of more general interest, especially for other European regions facing similar problems (farmland abandonment, expansion of forest area and increasing wildfire risk in a climate change scenario). The recent approval by the regional Parliament and Government of a new legal framework and policy instruments to address these problems gives greater interest to this case study. This paper aims to contribute to the general literature on land use/cover change in three directions. First, we offer an analysis of land use/cover changes and resulting land use/cover patterns at the local level by producing a typology of municipalities. Second, we test the hypothesis that these land use/cover patterns are largely determined by biophysical constraints, but are also strongly related to socioeconomic variables. Third, we pay special attention to the role played by land ownership structure and the impact of land use/cover patterns on wildfire risk.

2. Materials and Methods

2.1. Study Area

In this paper, we focus on the Spanish region (NUTS 2) of Galicia, located in the northwest of Spain (Figure 1). Covering an altitude range from sea level to slightly above 2000 m, the region offers a range of different suitability levels for agricultural and forest production. Small-scale holdings dominate the farming and forest sectors; the average farm-utilized agricultural area was 7.9 ha according to agricultural census data in 2020, with about a third of the Spanish average [19] as a consequence of a very fragmented land property system (average land plot is currently 0.26 ha and the average area per owner is 1.63 ha [20]). A general trend of farmland abandonment has occurred simultaneously with the sharp decline in agricultural employment and the depopulation of rural areas since the 1960s, but greatly accelerated after the accession of Spain to the European Economic Community in 1986 [8]. As a consequence of land use/cover changes over the last half century, the territory has undergone intense spatial specialization, with wood production dominating the western third, dairy production dominating the central third, and spontaneous vegetation encroachment being dominant in the eastern mountainous areas. The combination of high natural biomass productivity, forest expansion in the west, and spontaneous vegetation growth in the east, with short periods of drought during the summer, has resulted in a very high risk of wildfires. This is of greater concern in the wildland–urban interface between populated and semi-natural and forest areas [21], and it caused a steady increase in the yearly public spending in fire suppression equipment and infrastructures, reaching EUR 160 million in 2023 [22].

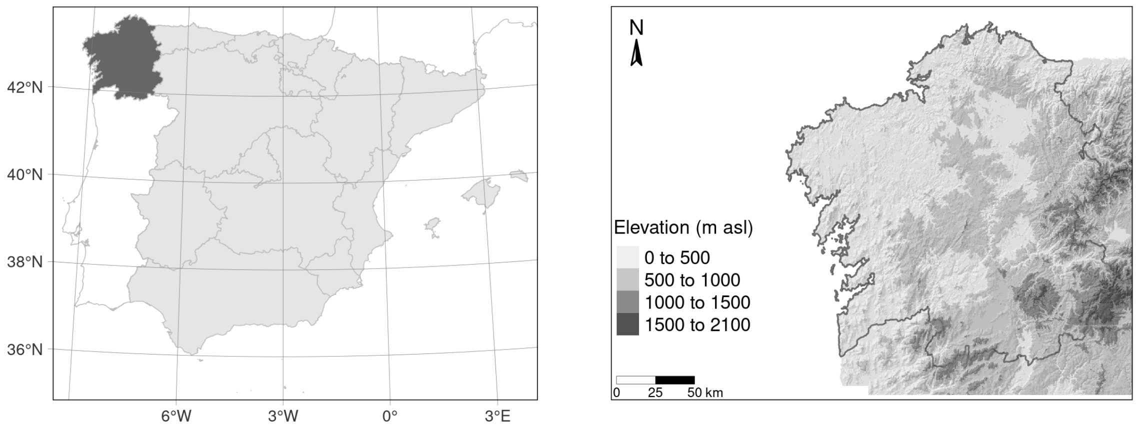

Figure 1. Location of Galicia in Spain and elevation above sea level.

Over the last six decades, the area devoted to crops and pastures was constrained to a small portion of the territory (just over 20%), while the agro-livestock use of hill land, which was very important until the mid-twentieth century, disappeared. This has led to the paradoxical case of a region in which the land has historically been, and remains today, a scarce production factor in the farming sector, characterized at the same time by a significant presence of farmland abandonment [23]. On the other hand, the forest sector has experienced a significant expansion in the last half century, predominantly based on the plantation of fast-growing species and has positioned the region as the main producer of timber at the national level, accounting for more than half of the total production [24].

2.2. Data Sources

The trends of land use/cover change in this study are based on the Spanish Land Use Information System (SIOSE), which is currently the most detailed land use/cover map in Spain. SIOSE is available for the years 2005, 2009, 2011 and 2014 at a 1:25,000 scale (minimum mapping unit of 1–2 hectares depending on the dominant land use/cover) and for the year 2017 at a 1:5000 scale. SIOSE uses a data model that records the proportion of area occupied by different land use/cover categories for each polygon in the map, which sets it apart from more conventional maps that record just one land use/cover category for each patch or polygon. In principle, this new data model makes it possible to produce more precise estimates of the area occupied by each land use/cover category. While we used some of the intermediate editions of SIOSE for the assessment of overall trends in the region, we relied on the first and last available editions (2005 and 2017) for the evaluation of trends at the local (municipal) scale.

There are 38 land use/cover classes in SIOSE, which we reclassified to a reduced set of six broad classes: built-up areas, farmland, shrubland, forest plantations, native forests and other areas (Table 1). These simplified classes provide a broad characterization of the pattern of land use in each municipality. For each of the 313 municipalities in the region, we calculated the share (proportion) of municipal area that was occupied by each of the six broad classes in 2005 and 2017. The resulting set of twelve variables was then used as input in a hierarchical cluster analysis, carried out using euclidean distance among observations and the Ward (minimum variance) clustering method. Variables were standardized before the analysis because, although they were naturally constrained to the [0, 1] interval, they presented considerably different ranges and dispersion values. We decided on the appropriate number of clusters by reflecting on the results of twenty different numeric indexes provided in the NbClust package (v. 3.0.1) for R [25]. The resulting clusters were interpreted using the average proportion of land occupied by the six broad land use/cover classes in each year considered. All spatial and statistical analyses were carried out using GRASS GIS [26] and R programming language [27].

Table 1. Land use/cover classes in the study and original SIOSE classes.

Original SIOSE Class	Assigned Class
Urban and industrial areas, roads, other infrastructures	Built-up areas
Annual and permanent crops, pastures	Farmland
Shrublands and rangelands	Shrubland
Deciduous hardwood forest	Native forest
Softwood (conifer) forest, perennial hardwood forest	Plantation forest
Rivers, lakes, rocky areas, burnt areas, beaches	Other areas

In order to enable the characterization and interpretation of the groups of municipalities formed by the cluster analysis, we compiled an auxiliary set of variables at the municipal scale. These variables were used to describe the differences in biophysical, demographic and socioeconomic characteristics of each group. Variables that work at a finer scale (e.g., that of individual land plots) are often used in land use/cover change analysis [28], but here, we focused only on variables available at the municipal level, as the clustering exercise was intended to produce groups of municipalities. Furthermore, many socioeconomic and demographic variables that potentially interact with the land use system are only available from public statistical records at the municipal level.

When choosing the appropriate reference year or period for these auxiliary (context) variables, we considered two possible options. Choosing a point in time previous to the time frame of the cluster analysis (2005–2017) would be preferable if the auxiliary variables were used to explain why different municipalities underwent different land use trajectories. On the contrary, choosing a point in time after the dates of the cluster analysis would simply allow us to describe the characteristics of municipalities showing a specific land use pattern or land use change trajectory. For this choice, we considered that the period of time for the cluster analysis was not particularly long (12 years), and, because of that and the fact that we base the analysis on the percentage of each use (not its rate of change) at the beginning and end of the time period, the results showed that the cluster analysis captured different patterns of land use at the municipal level rather than radically different trajectories of land use change. For this reason, we opted to use current (the most recent) values of the context variables. As such, we do not see socioeconomic variables in this study as drivers of land use/cover change, but rather as variables that interact with land use, in the line with the work of Hietel et al. [17,18]. Instead, we conceptualize explanatory variables as "suites of interacting factors [that] work in conjunction with one another" [29] and that have co-evolved with land use/cover patterns as a result of two-way feedback effects between the land use system and the socioeconomic context along time.

As described in the previous section, the primary sector in the study area has undergone a marked process of specialization in dairy farming and wood production. For this reason, we used a suitability map for maize (*Zea mays* L.) production [30] and for white eucalyptus (*Eucalyptus globulus* Labill) production [31] as a way to capture the biophysical suitability for these activities, as maize is one of the main forage crops used by dairy farms in the region, and E. globulus is the single tree species responsible for up to one-half of wood production in the region. We computed the suitable area for each as a share of total municipal area.

As for socioeconomic variables, based on a review of previous studies for different countries and regions [17,18,28,32–35], we selected 21 indicators classified into five groups: demographic, employment structure, general economic, agricultural and forestry sectors, and land ownership (Table 2). The literature offers examples of the kind of "suites of interacting factors" associated to different land use/cover change processes. For example, Hietel et al. [18], in their study of a region in Central Germany between 1945 and 1999, found that the high density of farms, high levels of employment in agriculture and high livestock density were associated with areas maintaining a large proportion of agricultural area, while high population density and a high presence of industrial employment were associated with areas that underwent significant urbanization. On the contrary, they found that small average farm size and low levels of non-agricultural employment were associated with areas where farming activity declined. Another example which combines the analysis of biophysical and socioeconomic variables is that of De Freitas et al.'s study [32] in their analysis of an area in southern Brazil, where agricultural intensification appeared to be related to a combination of biophysical (interfluvial areas, smooth relief, high landscape fragmentation) and socioeconomic characteristics (large average farm size, low population density), while extensification took place in areas with similar biophysical conditions but lower economic development. Punzo et al. [35], in a study of urban expansion in Italy, found a positive relationship between a combination of increasing population density and economic development (GDP per capita, employment rates) and increasing levels of land consumption for urban development. In line with these findings, in our study area, we expect to find a positive relationship between population density, population growth and employment in non-agricultural sectors with the expansion of urban areas; a positive relationship between agricultural employment, farm density, average farm size and other indicators of a dynamic agricultural sector, with higher percentages of agricultural land; a positive relationship between land ownership fragmentation and farmland abandonment; and a relationship of very low population and agricultural employment densities with land abandonment or more extensive land use.

Finally, considering the fact that wildfires have affected a large portion of the total area in the region over the last several decades, we included several variables related to the number of wildfires and burnt area, taken from the statistics of the Spanish Ministry of the Environment.

Table 2. List of variables used to describe biophysical and socioeconomic characteristics of the municipalities within the study area.

Variable (Units, Year)	Source
Demographic	
Population density (inhab/km, 2022)	Galician Statistics Institute (IGE), demographic data
Population change (%, 2000–2022)	
Ageing index (%, 2022) [1]	
Population over 65 years (%, 2022)	
Employment by economic sectors	
Agriculture and forestry (%, 2022)	Galician Statistics Institute (IGE), affiliations to social security
Industry (%, 2022)	
Construction (%, 2022)	
Services (%, 2022)	
Economic	
Gross domestic product per area (EUR/km², 2020)	Galician Statistics Institute (IGE), gross domestic product by municipalities
Gross disposable income per inhabitant (EUR/inhab, 2020)	Galician Statistics Institute (IGE), household income by municipalities
Agriculture and forestry	
Density of farm labor (workers/km^2, 2022)	Galician Statistics Institute (IGE), affiliations to social security
Farm density (farms/km^2, 2020)	Spanish Statistics Institute (INE), agricultural census
Average farm size (ha, 2020)	Spanish Statistics Institute (INE), agricultural census
Stocking density (livestock equivalent units/km^2, 2020)	Spanish Statistics Institute (INE), agricultural census
Bovine stocking density (animals/km^2, 2022)	Galician Statistics Institute (IGE), cattle registration
Wood extraction (m^3/km^2-year, 2019–2021)	Galician Statistics Institute (IGE) and Regional Ministry for Rural Affairs
Land ownership	
Landowner/inhabitant ratio (2022)	Cadastral Statistics, Spanish Ministry of Economics and IGE (demographic data)
Average property size (ha/owner, 2022)	Cadastral Statistics, Spanish Ministry of Finances
Average plot size (ha, 2022)	Cadastral Statistics, Spanish Ministry of Finances
Average number of plots per owner (num., 2022)	
Proportion of municipal area occupied by common land (%, 2022)	Galician Statistics Institute (IGE) and Regional Ministry for Rural Affairs
Wildfires	
Wildfires smaller than 1 ha (events/km^2, 2006–2015)	Wildfire Statistics, Spanish Ministry for Ecologic Transition and Demographic Challenge
Wildfires larger than 1 ha (events/km^2, 2006–2015)	
Wildfires, total (events/km^2, 2006–2015)	
Burnt area—forest, as percentage of municipal area (%, 2006–2015)	
Burnt area—shrubland, as percentage of municipal area (%, 2006–2015)	
Burnt area—total, as percentage of municipal area (%, 2006–2015)	
Biophysical suitability	
Areas suitable for maize production (percentage of municipal area)	Díaz-Fierros and Gil, 1984 [30]
Areas suitable for Eucaliptus globulus (percentage of municipal area)	Calvo de Anta, 1992 [31]

[1] Ageing index defined as the ratio between population over 65 years old and population of 20 years or less.

As most of the variables evaluated in this study present a skewed distribution, we used a Kruskal–Wallis Rank Sum Test to evaluate the existence of stochastic dominance among the resulting clusters of municipalities for each of the analyzed variables. The test indicates whether it is likely that an observation in one cluster presents greater values for a given variable than an observation in any other group. The results of the test, indicating whether there are significant differences among clusters for a given variable, were complemented by median and median absolute deviation values, along with boxplot and whiskers graphics in order to interpret these differences.

3. Results

3.1. Observed Trends of Land Use/Cover Change

The estimated figures produced using SIOSE editions from 2005 to 2017 indicate a net expansion of built-up areas (1.69%) and especially of plantation forests (37.87%), while the remaining classes showed a shrinking trend all along the period: a slight reduction in the case of shrubland (−1.13%) and much more relevant for farmland (−8.40%), native forests (−13.02%) and other areas (−40.49%) (Table 3). The sharp reduction in the "other areas" is probably largely explained by methodological changes in the 2017 edition of SIOSE (its most detailed scale), in addition to fluctuations in the area affected by forest fires. Excluding this, the main trends can be summarized by a decrease in farmland and native forest, and an expansion of plantation forests and built-up areas.

Table 3. Area covered by different land use/cover classes in Galicia (values in square kilometers). Authors' elaboration from SIOSE 2005, 2009, 2014 and 2017.

Land Use/Cover Class	Year				Variation 2005–2017
	2005	**2009**	**2014**	**2017**	
Built-up areas	1896.49	1916.19	1984.41	1928.73	+1.69%
Farmland	6933.70	6900.55	6718.50	6351.03	−8.40%
Shrubland	9216.91	9546.39	8736.65	9112.73	−1.13%
Plantation forests	5248.73	5063.77	5674.31	7236.78	+37.87%
Native forests	4404.62	4424.97	4791.65	3830.99	−13.02%
Other areas	1876.30	1724.87	1671.22	1116.49	−40.49%

3.2. Results of the Cluster Analysis

The results of the cluster analysis divided the 313 municipalities into four clusters (Figure 2, Table 4). Cluster 1, the smallest of them all (32 municipalities and 4.58% of regional area), comprises the main urban areas in the region and some of their surroundings. Accordingly, it presents the highest share of built-up areas (23% in 2005, 25% in 2017), but also a high share of plantation forests (25% in 2005, 26% in 2017), both of which are clearly above the regional average values.

Cluster 2 (116 municipalities, 31.25% of regional area) is clearly the domain of plantation forests (31% of area in 2005, 40% in 2017), albeit with a significant presence of built-up areas, also higher than the regional average. For the most part, this cluster is limited to the coastal areas of the region, although it includes municipalities in higher-elevation areas along the main valleys.

Cluster 3 (54 municipalities, 25.34% of regional area) occupies areas of medium elevation, mostly in the northern half of the region (with the notable exception of areas in the Limia valley in the southern half). It is the domain mainly of farmland (39% in 2005, 36% in 2017) and, to a much lesser extent, of native forests (17% in 2005, 14% in 2017), both of them above the regional average. Furthermore, while this was no longer the case in 2017, built-up areas were around the regional average in 2005.

Cluster 4 (111 municipalities, 38.81% of regional area) is clearly the domain of shrublands (41% in 2005, 44% in 2017) and native forests (19% in 2005, 18% in 2017). These municipalities are located in the highest elevations in the region, less suitable for farming and plantation forests.

In general, most of the regional trends in the period 2005–2017 mentioned above are observable in all or almost all the clusters. For example, the contraction of farmland area and the expansion of forest plantations are present in all clusters, although at different rates.

Something similar is observed for the increase in built-up areas (only with the exception of Cluster 3) and the reduction in native forest (the only nuance is its stability in Cluster 1). The main divergence is found in the trend of shrubland area, which declines in Clusters 1 and 2, while it expands in Cluster 3 and especially in Cluster 4 (where it reinforces its dominance).

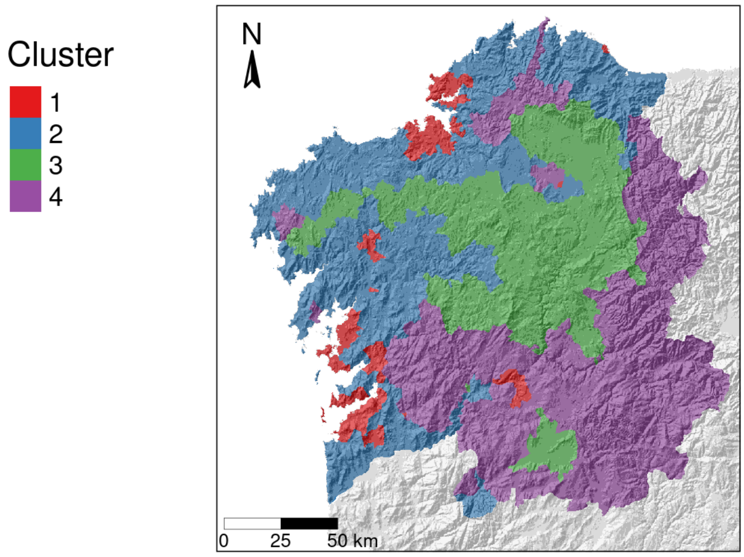

Figure 2. Results of the clustering of municipaliies into homogeneous groups of land use/cover in 2005 and 2017.

Table 4. Distribution of total area, number of municipalities, average elevation and percentage of area covered by different land uses/covers for each cluster of municipalities. Values of land use/cover higher than regional average are highlighted in bold.

Variable	Cluster 1	Cluster 2	Cluster 3	Cluster 4	Galicia (Total)
Number of municipalities	32	116	54	111	313
Area (km^2)	1353	9244	7496	11,480	29,572
Area (%)	4.58	31.25	25.34	38.81	100
Average elevation (m asl)	125	232	532	646	502
Plantation forest 2005 (%)	**24.83**	**30.79**	11.09	10.75	17.75
Plantation forest 2017 (%)	**26.39**	**39.74**	16.77	16.97	24.47
Native forest 2005 (%)	7.22	8.78	**17.10**	**19.27**	14.90
Native forest 2017 (%)	7.20	6.71	**14.03**	**17.95**	12.96
Farmland 2005 (%)	21.58	21.56	**38.54**	15.32	23.45
Farmland 2017 (%)	19.79	20.06	**36.24**	13.17	21.48
Shrublands 2005 (%)	19.22	26.05	24.10	**41.29**	31.17
Shrublands 2017 (%)	16.85	21.63	24.51	**43.96**	30.82
Built-up areas 2005 (%)	**22.81**	**7.17**	**6.57**	3.75	6.41
Built-up areas 2017 (%)	**24.51**	**7.43**	5.74	4.17	6.52
Other areas 2005 (%)	4.32	5.63	2.57	**9.59**	6.35
Other areas 2017 (%)	**5.25**	**4.41**	2.70	3.76	3.78

3.3. Biophysical and Socioeconomic Characterization of Clusters

A summary of median values of all the biophysical and socioeconomic variables for the four clusters of municipalities formed by land use trends is presented in Table 5. A graphical representation can also be found in Appendix A (Figures A1–A3). All variables showed significant differences among clusters ($\alpha < 5\%$) in the Kruskal–Wallis test, with the exception of the percentage of employment working in services.

Demographic variables show a clear gradient from Cluster 1 to Cluster 4: along this gradient, population density decreases (from 530 inhab/km^2 in Cluster 1 to 20 inhab/km^2 in Cluster 4) and population ageing increases (median ageing index of 135% in Cluster 1, 537% in Cluster 4). Of all groups, only Cluster 1 showed a positive change in population in the last two decades, while all the other clusters showed increasing rates (from Cluster 2 to Cluster 4) of population decline.

If we analyze the relationship between these demographic variables and land use (Tables 4 and 5), some expected facts can be seen for the two extreme groups, such as very high demographic densities and population growth in Cluster 1 (the one with the largest expansion of built-up areas); an opposite demographic structure and dynamics (very low densities, strong population decline and marked aging) in Cluster 4, where land use is characterized by the predominance of shrublands and native forests; and the percentage (albeit very small) of both built-up areas and farmland. However, other findings are less predictable—even striking. We highlight two: (i) the area occupied by plantation forest reaches the highest values in Clusters 1 and 2, i.e., those with higher population densities; and (ii) Clusters 3 and 4 have similar demographic structure and dynamics (only somewhat worse in 4), while the land use patterns are very different (high proportion of farmland in Cluster 3) in contrast to the dominance of shrublands in Cluster 4.

Gross disposable income per inhabitant, a global indicator of the level of economic development, shows a consistent picture with demographic dynamics, decreasing as we move from Cluster 1 to Cluster 4 (from 15,417 to 11,525 EUR/inhab). The same happens for gross domestic product (GDP) per area (density or pressure of economic activities on the territory). It shows a negative gradient from Cluster 1 to Cluster 4, with greater differences (from 9632 to 283 EUR/km^2).

Based on these data, the sectoral structure of employment in the first three clusters fits that which was expected: the lower the level of economic development, the greater the percentage of agricultural employment and lower the percentage of employment in the industry, construction and services, although employment in the services sector seem in this case remarkably stable across the four groups of municipalities. This relationship is broken, however, in Cluster 4: this includes the municipalities with the lowest economic development and the most regressive demographics, but the percentage of agricultural employment is clearly lower than in Cluster 3. Therefore, we can characterize Cluster 4 by a marked deagrarianization given its level of economic development. This employment structure must be put in relation to the low percentage of farmland in Cluster 4, the lowest of the four clusters.

As it could be expected, most indicators of farming activity (density of farm labour, average farm size, stocking density) reach the highest value in Cluster 3, usually followed by Cluster 2. Overall, these indicators show a clear positive relationship with the area occupied by farmland. The only exception is farm density, indicating that for the total area of farmland, farm size is more relevant than their density (the number of farms). Stocking density values, particularly those of cattle, underline the specialization of the farming sector in Cluster 3.

Wood extraction shows the highest values in Cluster 2, followed by Clusters 1 and 3, and very low levels in Cluster 4. As expected, this variable has a clear positive relationship with some nuances, with the weight of plantation forest as the conditioning factor and a result of afforestation.

Variables related to land ownership follow a clear gradient in the first three clusters. Both the average size of plot and the average area per landowner record the lowest values in Cluster 1, increasing in Cluster 2 and especially in Cluster 3 (in short, less land fragmentation as population density decreases). However, this relationship is broken in Cluster 4, the one with the lowest demographic densities. Compared to Cluster 3, municipalities of Cluster 4 are characterized by two notes: the high proportion of municipal area occupied by common land (units with an average size above 200 ha); and the much higher fragmentation of individual private property land, reflected in a smaller area per owner, a smaller average plot size and a higher number of plots per owner. Those differences in land ownership have a clear relationship with land use.

The density of wildfire events showed different gradients for small (less than 1 ha) and large (more than 1 ha) events. While large wildfire events showed an increase from Cluster 1 to Cluster 4 (from 0.18 to 0.38 events/km^2 in 2006–2015), small events decreased from Cluster 1 to Cluster 3 (from 1.66 to 0.62 events/km^2) but increased again in Cluster 4 (1.02 events/km^2). As the number of small fires is substantially higher than that of large fires, total density of wildfires showed the same pattern as the density of small fires. The relative importance of burnt area as a proportion of municipal area also differed depending on the kind of vegetation affected: burnt forest area was significantly higher in Cluster 2 and lower in Cluster 3, while shrubland burnt area was higher in Cluster 4 and lower in Cluster 1. Accordingly, total burnt area was higher in Cluster 4 (6.20% of total area in 2006–2015)—owing to the higher presence of fires affecting shrubland areas—and Cluster 2 (3.14%)—because of the higher importance of fires affecting forest areas.

Finally, the biophysical suitability for maize (*Zea mays* L.) indicates a higher suitability of municipalities in Clusters 1 and 3, in contrast especially to Cluster 4, while suitability for eucalyptus (*Eucalyptus globulus* Labill.) appears to be higher in Clusters 1 and 2, decreasing in Cluster 3 and especially in Cluster 4.

Table 5. Medianvalues of biophysical and socioeconomic variables for the 4 clusters of municipalities (with median absolute deviation [1] in parentheses).

Variable	Cluster 1	Cluster 2	Cluster 3	Cluster 4	Kruskal–Wallis Significance
Demographic					
Population density 2022 (inhab/km^2)	530.3 (238.1)	76.0 (68.8)	21.9 (10.4)	20.6 (15.9)	0.000
Population change, 2000–2022 (%)	9.93 (16.70)	−10.15 (20.51)	−26.97 (12.04)	−31.55 (12.24)	0.000
Ageing index, 2022 (%)	134.9 (26.9)	219.4 (109.4)	412.4 (170.3)	537.2 (236.8)	0.000
Population over 65 years, 2022 (%)	23.05 (2.83)	30.21 (6.98)	37.20 (5.08)	42.14 (5.54)	0.000
Employment					
Agriculture and forestry (%), 2022	3.20 (3.63)	5.85 (7.12)	11.60 (12.00)	9.60 (7.41)	0.000
Industry (%), 2022	16.70 (7.78)	14.75 (4.15)	11.50 (3.78)	13.50 (4.44)	0.000
Construction (%), 2022	10.40 (3.04)	8.50 (1.93)	8.25 (2.30)	9.10 (2.22)	0.029
Services (%), 2022	62.95 (6.96)	63.60 (9.64)	62.85 (8.30)	64.60 (8.75)	0.771
Economic					
Gross domestic product per area (EUR/km^2), 2020	9632 (3306)	11,348 (984)	445 (236)	283 (198)	0.000
Gross disposable income per inhabitant (EUR/inhab), 2020	15,417 (2297)	13,781 (1326)	12,635 (1492)	11,525 (1713)	0.000
Agricultural and forest sectors					
Density of farm labor (workers/km^2), 2022	1.70 (0.97)	1.27 (0.68)	2.15 (0.89)	0.49 (0.32)	0.000
Farm density (farms/km^2), 2020	3.24 (1.59)	2.16 (1.31)	2.71 (1.51)	1.81 (1.21)	0.002
Average farm size (ha), 2020	2.01 (1.83)	6.87 (6.20)	9.87 (7.15)	6.54 (6.35)	0.000
Stocking density (livestock equivalent units/km^2), 2020	4.68 (5.94)	19.67 (19.27)	91.90 (47.06)	12.27 (14.95)	0.000
Bovine stocking density (animals/km^2), 2022	2.41 (2.88)	12.68 (16.29)	71.58 (35.27)	8.25 (8.51)	0.000
Wood extraction (m^3/km^2-year), 2019–2021	299.18 (265.59)	364.88 (351.94)	243.41 (214.22)	24.95 (27.02)	0.000
Land ownership					
Landowner/inhabitant ratio, 2022	0.41 (0.23)	1.28 (0.79)	1.67 (0.69)	2.91 (1.29)	0.000
Average property size (ha/owner), 2022	0.39 (0.12)	1.00 (0.69)	2.36 (1.03)	1.78 (1.17)	0.000
Average plot size (ha/plot), 2022	0.14 (0.05)	0.22 (0.11)	0.44 (0.17)	0.20 (0.14)	0.000
Average number of plots per owner, 2022	2.37 (0.81)	4.68 (1.53)	5.85 (1.80)	8.83 (3.28)	0.000
Proportion of municipal area occupied by common land (%), 2022	1.17 (1.73)	6.01 (8.91)	8.83 (11.03)	35.44 (27.99)	0.000

Table 5. *Cont.*

Variable	Cluster 1	Cluster 2	Cluster 3	Cluster 4	Kruskal–Wallis Significance
Wildfire events					
Wildfires smaller than 1 ha (events/km^2), 2006–2015	1.66 (0.92)	0.77 (0.69)	0.62 (0.36)	1.02 (0.84)	0.000
Wildfires larger than 1 ha (events/km^2), 2006–2015	0.18 (0.08)	0.24 (0.19)	0.28 (0.22)	0.38 (0.32)	0.000
Wildfires, total (events/km^2), 2006–2015	1.86 (0.96)	1.11 (0.97)	0.88 (0.53)	1.38 (1.10)	0.000
Burnt area—forest, as percentage of municipal area (%), 2006–2015	1.06 (1.24)	1.78 (2.41)	0.51 (0.48)	1.55 (1.70)	0.000
Burnt area—shrubland, as percentage of municipal area (%), 2006–2015	0.42 (0.51)	0.90 (1.21)	1.25 (1.31)	3.64 (4.19)	0.000
Burnt area—total, as percentage of municipal area (%), 2006–2015	1.59 (1.82)	3.14 (4.18)	1.74 (1.69)	6.20 (6.18)	0.000
Biophysical suitability					
Area suitable for maize production, as percentage of municipal area (%)	59.64 (25.17)	39.13 (15.63)	58.65 (20.42)	24.27 (19.22)	0.000
Area suitable for eucalyptus, as percentage of municipal area (%)	100.00 (0.00)	91.68 (12.32)	59.95 (59.37)	25.36 (37.03)	0.000

[1] Median absolute deviation was calculated using a scale constant of 1.4826 to ensure compatibility with the standard deviation.

4. Discussion

The analysis of the main land use/cover changes in Galicia for the period 2005–2017 indicates that the only expanding categories were built-up areas and plantation forests, at the expense of farmland, native forests and shrubland areas, in similar fashion to other regions in Spain [36]. The expansion of urban areas has been one of the characteristic land use/cover changes in Spain [4] and in other European countries, where population density has been identified as one of the major relevant variables [35,37], although it has been suggested that a rapid deceleration of the urban sprawl process took place after the economic meltdown of 2008, particularly in the less-densely populated areas [9]. Forest expansion, on the other hand, is also common to other areas in Spain [36,38]. Forest expansion in Spain started in the late nineteenth century and accelerated during the second-half of the twentieth century as a result of Spanish public policy in the decades of the 1950s–1970s [5,39] and as a result of European policy later on [40].

Our cluster analysis was intended to capture differences in these trajectories among groups of municipalities. The results, nevertheless, did not find many differences in the direction of change among groups. The expansion of plantation forests and the decline in total farmland area appear to be common to the four resulting groups. The same happens, with small nuances, for the expansion of built-up areas (only not observed in Cluster 3), and the decline in native forests (common to all groups with the exception of stability in Cluster 1, where it already occupied a very small area). We only found significant differences for the shrublands, which decreased in Clusters 1 and 2, remained stable in Cluster 3 and expanded in Cluster 4, thus increasing the geographical contrasts in the distribution of this use (Table 4).

The changes described above for the period between 2005 and 2017 are very similar to those reported in the literature for the decades of the 1980s and 1990s [40,41], with the remarkable exception of the contraction of the area occupied by native forests, which, according to previous sources, had been expanding until recently. Actually, this seems to be the case of the SIOSE data used in this study up to 2014. From 2014 to 2017, nevertheless, the data show a sharp decline in native forests (ca. 1000 km^2, −20%) in just three years (Table 3), which raises concerns about the comparability of both figures. We suspect that changes in the level of detail of the last SIOSE edition (2017) in comparison to that of previous years (SIOSE 2017 was published at a 1:5000 scale, while previous editions were published at a 1:25,000) may account for part of the inconsistencies in the series. For example, according to SIOSE data, built-up areas actually decreased between 2014 and 2017 by 55 km^2 (2.8% of the figure in 2014). The higher level of detail of the 2017 edition allows us to better delineate urban and built-up areas (as these usually occupy small patches of land), which were probably overestimated in 2014, and this may have been also the case with native forests. It should be noted that the change in the 2017 edition was not only in scale but also in the production method, as this was produced by the aggregation of already existing spatial databases, thus limiting photointerpretation (which had been the main production method up to 2014) for special cases that could not be solved by automatic methods. Other apparent inconsistencies in the SIOSE series, like the reduction in the area occupied by plantation forests between 2005 and 2009, may be attributed, at least in part, to the effect of the successive wildfire waves, for example, that of 2006, which affected 555 km^2 of forest area in total in the region [42]. Nevertheless, the trend followed by plantations is clearly positive and seems to have accelerated in the last period (2014–2017).

Therefore, the clusters of municipalities resulting from this work seem to be more based on the current distribution of land use/cover inside each municipality, rather than on the observed changes in the period 2005–2017, as the latter are similar across the region. Nevertheless, even though most of the general trends of land use/cover change seem applicable to all clusters, several distinctions can be made. For example, the expansion of built-up areas seems to have concentrated, for the most part, in Cluster 1. The expansion of plantation forests was more relevant in Cluster 2. And the area occupied by shrublands actually increased greatly in Cluster 4. We believe that this indicates the progressive deepening of a process of spatial specialization that had started decades before, which means that the distinction between areas where most of the population live (Cluster 1), areas where timber production takes place (Cluster 2), farming areas (Cluster 3) and semi-natural areas (Cluster 4) is likely to deepen in the mid-term.

To what extent that spatial specialization is a consequence of actual biophysical conditions remains an open question. Results indicate that plantation forests are actually concentrated in the best areas for the main tree species used in plantations (Eucalyptus globulus Labill.), while farming has largely concentrated in the best areas for maize production. Thus, the pattern of spatial specialization at the municipal scale that this work presents would be largely the consequence of the action, in the context of biophysical conditions, of the main trends of productive specialization of the Galician primary sector in dairy farming and pulpwood, neither of which could be adopted in the highlands to the east of the region (Cluster 4).

However, once the central role of biophysical conditions is confirmed, the results of our analysis also show the relationship with the land use of several socioeconomic variables, either as autonomous drivers or as an effect of the interaction with biophysical conditions. In this sense, we must highlight a fact observed when comparing Tables 4 and 5: while farmland area in the four clusters presents a clear correlation with the area suitable for cultivation (maize is one of the main crops in the region and is being used here as a proxy for other intensive crops), the current farmland area in all groups is clearly lower than the potential area—about one-third in Cluster 1 (20% out of 59%), about one-half in Clusters 2 and 4, and about two-thirds in Cluster 3. The difference between the area that would be suitable for intensive crops and the area actually used by farming activities corresponds to land suitable for cultivation that is devoted to plantation forests, built-up areas or abandoned land [23,43].

With respect to socioeconomic variables, the results are in line with others in showing a higher increase in urban area in municipalities with a higher population density and higher economic development, where urban area occupied a larger share of the land at the beginning of the studied time period. The correlation between a strong presence of urban area and its eventual expansion has also been highlighted for the general case of Spain [44].

The results also show that there is a clear gradient of worsening values of demographic and economic variables as we move from the most developed areas in the western half of the region towards the higher grounds in the East and Southeast, where accessibility issues and more demanding living conditions prevail. As might be expected, this is accompanied by a lower percentage of built-up areas and a higher presence of semi-natural areas (shrublands and native forests). In this context, there are two facts to highlight, determined by the interaction between biophysical and socioeconomic factors. The first is the high area of plantation forests in Clusters 1 and 2, i.e., those with the highest population density and economic development. The other is the lack of agricultural sector activity and the small farmland area in Cluster 4, in contrast to Cluster 3, despite both having similar population densities. Differences between Clusters 3 and 4 may be attributed in part to the structure of land ownership: the larger share of common lands and the higher fragmentation of private land ownership in the municipalities of Cluster 4 compared to Cluster 3 (smaller size of plots, smaller area per owner and higher number of plots per owner). The origin of these differences, which already existed in the middle of the 20th century, must be sought in historical and institutional factors, mainly related to inheritance patterns [45]. These factors, coupled with the more stringent biophysical conditions, can largely explain the current land use in Cluster 4 and why a large share of the population of these municipalities looked for opportunities somewhere else. In addition, efforts to expand their ownership by farmers in Cluster 3, where the land market is more active [46], have also contributed to these differences in recent decades. Nevertheless, other indicators of land ownership result from the interaction with decades of migration outflow; particularly, the ratio between landowners and inhabitants (almost three times more landowners than inhabitants is the median for municipalities in Cluster 4) indicate that many former inhabitants of those municipalities are currently living elsewhere even though they still retain their property rights.

The increasing presence of forest area in the region is expected to continue increasing the risk of wildfires, in a context in which they already represent one of the main sources of risk in the Spanish landscapes [47,48]. This seems to be confirmed because the presence of large areas of forest (Clusters 1 and 2) is associated to high values of fire event density and burnt area as a proportion of total area. This is likely associated with the increased spatial continuity and quantity of biomass present over the terrain but also due to some of the characteristics of the plantation forests created (mono-specific, regular in age, covering large patches of land with only firebreaks of relatively small size) [49]. In addition, the fact that the two groups of municipalities with the largest share of plantation forest (Clusters 1 and 2) are those with the highest demographic densities also increases the risk posed to human lives and properties. Nevertheless, the highest values of fire event density and burnt area take place in municipalities of Cluster 4, where shrubland areas dominate the local landscape. The homogenization of the landscape as the result of very large fires [50] may actually be one of the drivers behind the expansion of shrubland areas in Cluster 4, a vicious cycle with poor prospects for the future.

When exposed to images of large fires, the reaction of a mainly urban population is often to increase the effort of fire suppression and the protection of the forested landscape [36]. Nevertheless, it is the promotion of a patchwork of different land uses/covers at the landscape level that has the potential to greatly reduce the risk and the effects of wildfires. The recovery of abandoned farmlands for agricultural and extensive animal husbandry may offer a reduction in the volume and continuity of biomass, and thus, a more effective way of dealing with wildfire risk. Measures to promote farming in formerly abandoned lands, most of them a recent novelty included in the Law for the recovery of agricultural land of Galicia, may offer an important contribution to local economies as well [43]. Only three years have elapsed since the passing of this law in 2021, which makes it difficult to evaluate its results. The experience of the last two decades indicates that the combination of factors leading to a large wildfire wave (i.e., above or around 50,000 ha, about twice the average value of 25,000 ha/year in the period 2005–2024) takes place with a frequency of 5–6 years. For example, total burnt area in the region was 79,583 ha in 2005, 95,946 ha in 2006, 42,392 ha in 2011, 61,901 ha in 2017 and 51,496 ha in 2022 [51]. The potential effects of the application of the law will only become apparent after a longer period. Nevertheless, the preliminary results obtained so far seem rather modest—a slight improvement in the performance of the regional land bank, a small number of model villages and agroforestry polygons in execution, zoning regulations for forest/farm areas still unpublished—which suggests that a more determined application is probably needed [16].

5. Conclusions

In this work, we have presented an analysis of land use/cover patterns of change along a relatively short period of time in the recent past in a Spanish region (Galicia). The analysis did not find large differences of land use/cover change across groups of municipalities but rather produced groups of municipalities that shared a particular pattern of land use/cover that indicate a clear pattern of spatial specialization: an area where most of the population lives, an area devoted to forest production, another for farming production and a final one dominated by semi-natural covers. While not too different from one area to another, the observed recent land use/cover changes, nevertheless, tend to deepen this spatial specialization.

Results showed the close interaction between biophysical and socioeconomic variables, and in particular, the relatively important role of property fragmentation (along with biophysical suitability) in explaining the lack of farming activity in the most remote and mountainous areas. The results are also relevant for the prevention of wildfires, which present a very relevant risk in the region, as they indicate that tackling property fragmentation may be crucial to introducing heterogeneity (in the form of patches of farmland) in the areas most affected by wildfires (Cluster 4), but also the relevance of introducing heterogeneity in the area dominated by productive forestry (Cluster 1 and Cluster 2), as it is here where high wildfire prevalence couples with higher population densities.

Our analysis leads to two important guidelines for the successful implementation of the instruments of the recently approved Law for the recovery of agricultural land of Galicia. First, this implementation must consider the diversity of situations existing within the region, by applying different instruments and focusing on different objectives in the four groups of municipalities that we have defined. More specifically, the analysis highlights that the strongest need of instruments aimed at breaking the continuity of biomass by introducing heterogeneity in the landscape concentrates in Clusters 2 and 4. It would be in these areas where instruments like agroforestry polygons and model settlements are likely to provide better results. In contrast, instruments aimed at promoting the viability of already existing farms (land bank, farm bank) should probably concentrate in Cluster 3, where most of the farming sector is currently present. Second, although the law is specifically focused on the mobilization of private (individual) property, it is apparent that measures specifically tailored for common land (private but collective property) may be of higher relevance in municipalities of Cluster 4, where this kind of property is more prevalent.

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Data Availability Statement: The data presented in this study are available in github at https://github.com/ecorbelle/Climaplan1 (accessed on 27 August 2024). These data were derived from the following resources available in the public domain: https://www.siose.es/presentacion, https://www.ine.es/, https://www.ige.gal (accessed on 27 August 2024).

Conflicts of Interest: The authors declare no conflicts of interest.

Appendix A. Supplementary Plots

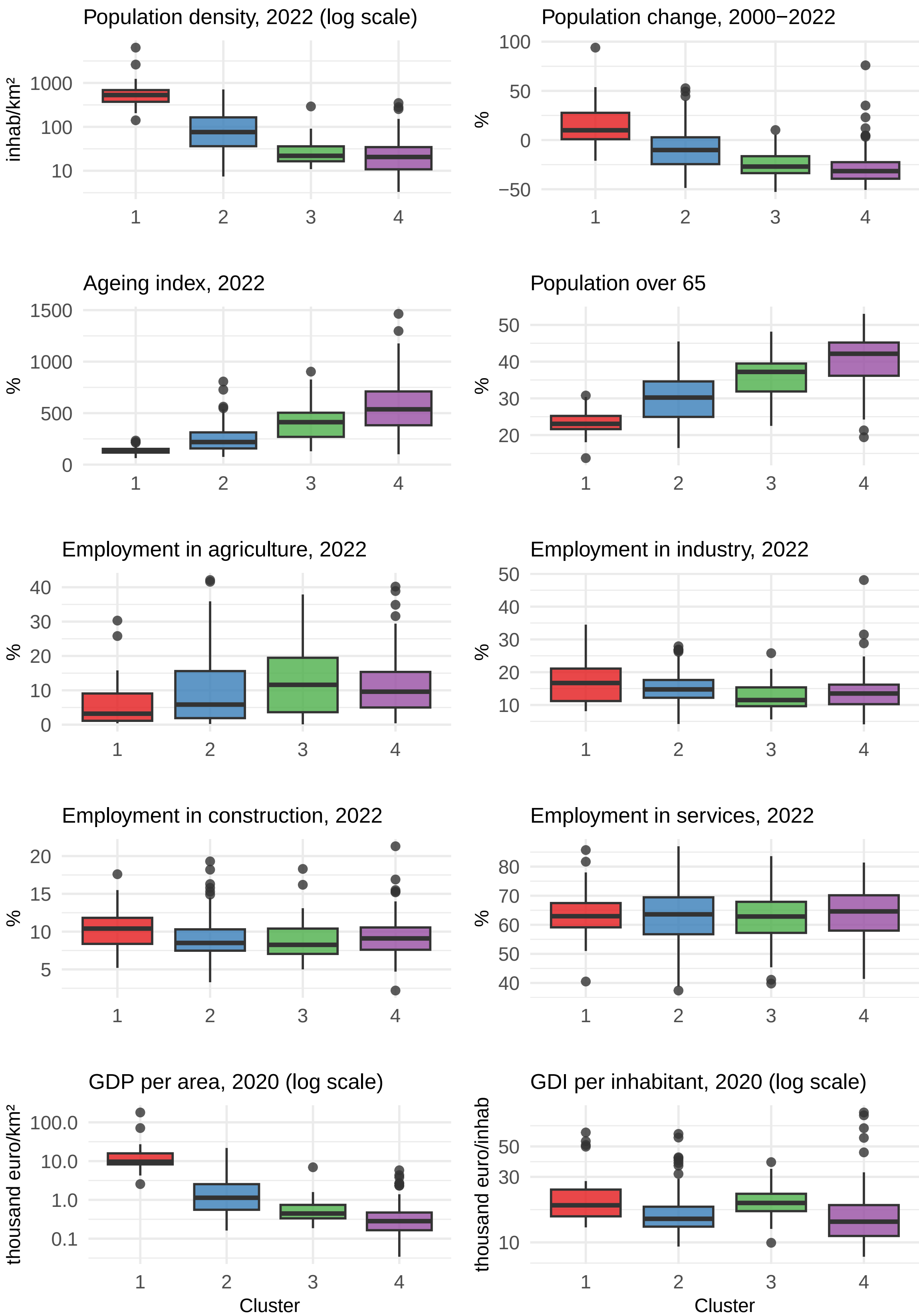

Figure A1. Boxplots showing values of socioeconomic and biophysical variables at the municipal level for the 4 clusters of municipalities (1 of 3).

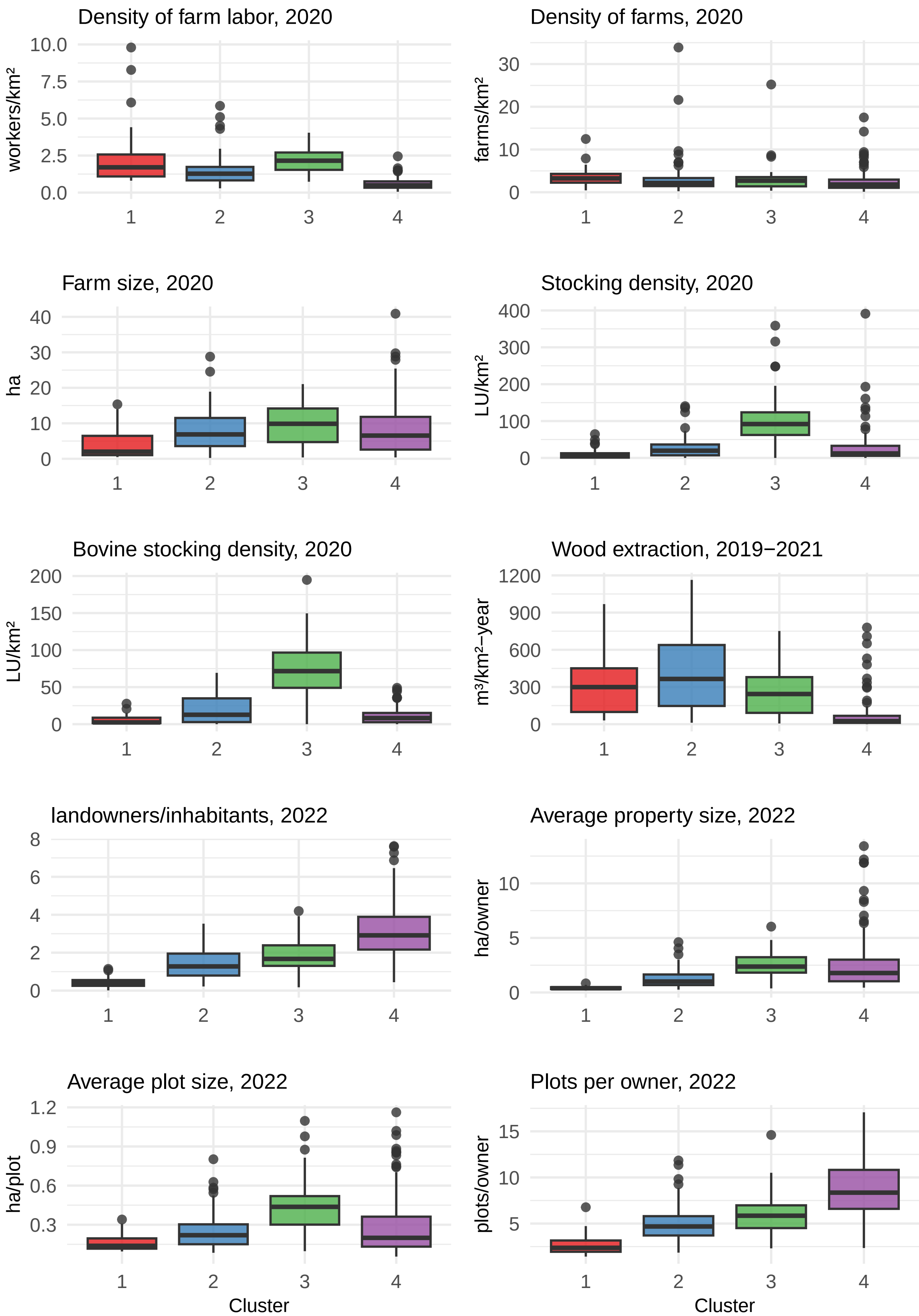

Figure A2. Boxplots showing values of socioeconomic and biophysical variables at the municipal level for the 4 clusters of municipalities (2 of 3).

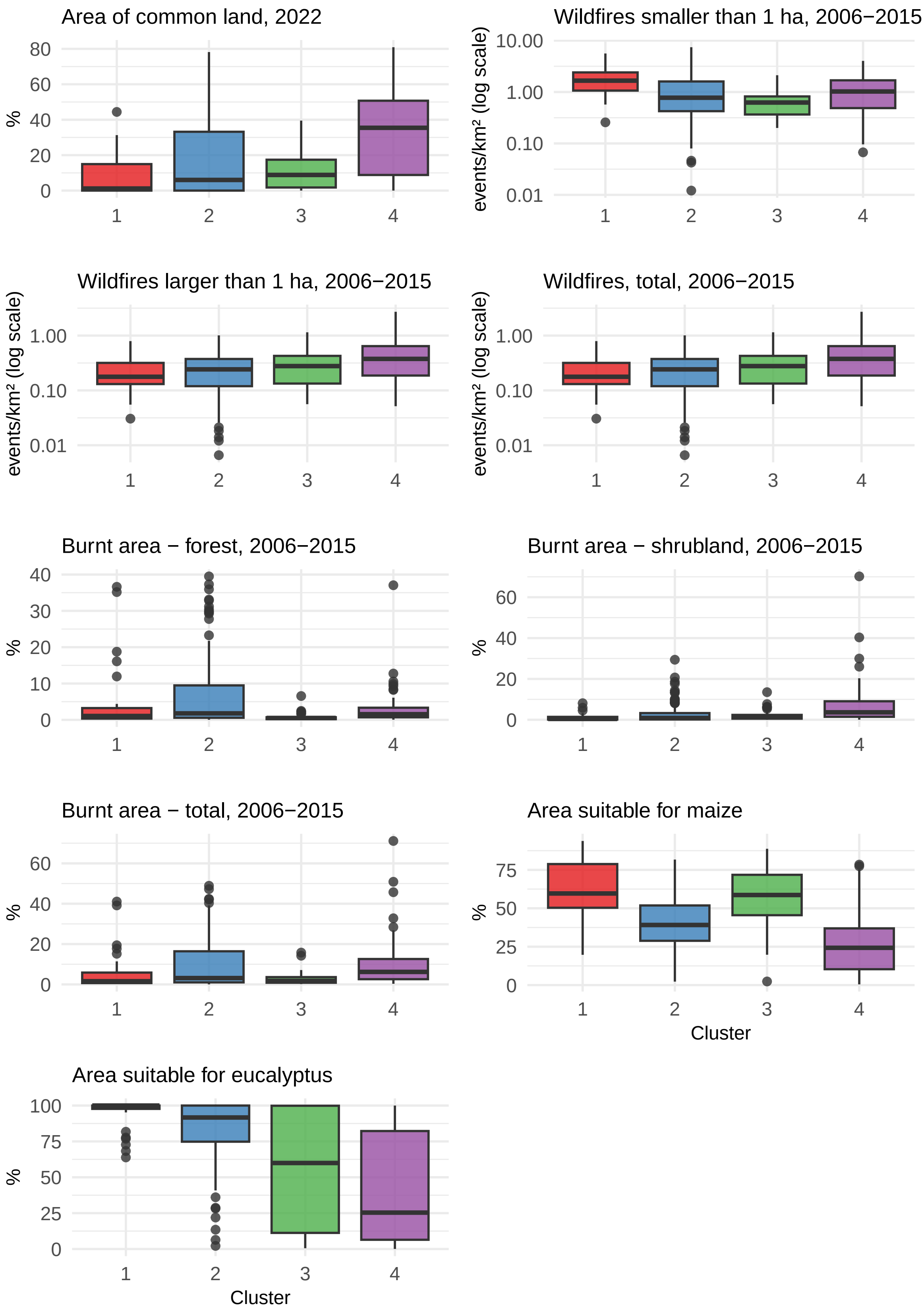

Figure A3. Boxplots showing values of socioeconomic and biophysical variables at the municipal level for the 4 clusters of municipalities (3 of 3).

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