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Disentangling the drivers of marginalisation in Mediterranean inlands: A case study in the Sardinian mountains

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ABSTRACT

Farmland abandonment is a growing issue in many mountainous regions worldwide, particularly in the Mediterranean basin. The central region of Gennargentu-Mandrolisai in Sardinia (Italy) is particularly susceptible to this trend due to its distinctive topography, its remote localisation and the distance from the primary urban centres of the region. In fact, this region was traditionally suited for agro-silvopastoral systems, but it was included in the national strategy for inland areas mainly because of the demographic decline and land abandonment. This paper aims to identify the main drivers of rural marginalisation, abandonment and de-anthropisation by combining qualitative and quantitative spatial data. Qualitative data were collected from 30 farmers' interviews targeting young, dynamic, innovative farmers in order to identify possible triggers for maintaining agricultural activities. A diachronic analysis of land use from Corine Land Cover maps at five different dates over thirty years (1990, 2000, 2006, 2012 and 2018) was used to understand the main land use changes. The analysis of the surveyed farmland (1602 ha) showed that 21 % of the area was abandoned in the last three decades, and 15 % of abandoned land was recovered as farmland. The drivers of marginalisation identified by the farmers were analysed by a logistic regression model, which revealed that field management was influenced by 'crop type', 'slope' and 'road distance from the farm buildings'. The interactions that arose between the natural characteristics and the traditional organisational system contributed to non-competitiveness and abandonment of farms in Gennargentu-Mandrolisai. The present data allow us to propose hypotheses on how agricultural activities could be shaped and how some drivers of marginality could be overcome thanks to the presence and the active work of many young farmers who are willing to further improve agriculture.

1. Introduction

Farmland abandonment is an increasing issue in many inland regions, where characteristics like slope and land fragmentation constrain agricultural intensification. Logistical difficulties are increased, and farms depend on the local workforce that is often scarce because local people tend to emigrate from these areas (MacDonald et al., 2000). Inland areas can often be defined as marginal due to geo-morphological and environmental characteristics such as altitude, a short crop growing season, steep slopes and low soil productivity, which constrain land uses (Bertaglia et al., 2007; Pinto-Correia and Breman, 2008). Depending on the specific local contexts, abandonment of agricultural lands can result in diverging outcomes on the ecosystems. On the one hand, the restoration of natural ecosystems and the new habitats for biodiversity during the transition to woodlands can contribute to pedogenesis and soil protection from erosion, to carbon sequestration, and influence both the water balance and the nutrient cycle (Benayas et al., 2007; Quintas-Soriano et al., 2022). On the other hand, abandonment, in addition to having a negative impact on the local economy, can increase the risk of wildfires and result in a loss of cultural landscape value (Quintas-Soriano et al., 2023; Pinto-Correia, 2000; Terres et al., 2015). Moreover, if abandonment is not managed, it can compromise rural livelihood and substantially reduce incomes (Pinto-Correia et al., 2014; Pawlewicz and Pawlewicz, 2023).

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Like many other marginal European areas, Italian inlands – especially mountainous areas – are being affected by a sharp trend of agricultural abandonment (Renwick et al., 2013). This phenomenon was particularly fast after the Second World War and the subsequent industrialisation process. Farmland and forestry abandonment lead to a sharp reduction of arable land and grassland surfaces and consequent renaturalisation of the landscape leading to the expansion of unmanaged forests (Agnoletti, 2014). In Italy, 24 % of municipalities are located in peripheral or outermost areas, mainly concentrated in the Alps, along the Apennines and in the inland and mountainous areas of Sicily and Sardinia. These areas suffered an average population decline of 9.1 % between 2001 and 2020 (ISTAT). Population ageing and the migratory flows towards the main urban centres are the main causes of this phenomenon which, added to social disaggregation, has caused the deterioration of cultural heritage and landscapes (MIUR, 2013). After the economic crisis of 2008, the Italian government introduced a targeted strategy known as the National Strategy for Inland Areas (SNAI). This strategy was designed to alleviate the adverse impacts on socio-economic contingencies and foster the growth of inland regions. It entailed the improvement of local development initiatives, with a focus on promoting economic activities, particularly in the agricultural sector (Arzeni and Storti, 2021). Through the activities carried out by the Italian Department for a cohesion policy, marginalised areas were identified based on several parameters, among which the decrease of total used agricultural area (Italian government, 2014). In Sardinia – the second largest island in the Mediterranean region –, Gennargentu-Mandrolisai (GMA hereafter) was identified as a marginal area. The inland areas of Sardinia indeed experienced rapid de-anthropisation during the last decades of the 20th century. Together with severe depopulation and an increase of the average age of the local population, this resulted in the erosion of the traditional local silvo-pastoral and rural economy (Battino and Lampreu, 2017). During the 1991–2022 period, a 28 % decrease of the population was observed in GMA, with negative consequences on agricultural activities and a 68 % drop in the number of active farms (ISTAT, 2010). At the same time, geographical isolation and the relationships historically established between humans and lands during the long anthropisation process made these areas rich in resources and often unexpressed potentialities, as in other similar marginal mountain areas (Battino and Lampreu, 2017).

Our hypothesis was that it is essential to have a thorough knowledge of the main drivers of marginalisation and how they interact with farmers' activities in each specific context to exploit the agricultural potential of marginal areas and revitalise local farms. Most of the existing literature focuses on the ecological aspects related to abandonment, but there is a research gap about understanding the socio-cultural aspects and local perspectives related to the abandonment and recovery of marginal Mediterranean areas. These aspects are crucial for elaborating plans about land management options (Quintas-Soriano et al., 2023). This study explores a new perspective for analysing marginalisation: it integrates a biophysical analysis of the study area and the collection of ideas and data from a group of young, active local farmers. In this sense, it is not limited to identifying the drivers of abandonment linked to ecological parameters. It is rather aimed at highlighting farmers' views and perceptions, which are the real drivers of their choices, to identify possible solutions. The specific objectives were to 1) understand and collect farmers' perceptions about the agricultural dynamics related to marginalisation, and 2) understand the underlying drivers of marginalisation in the specific context of GMA, as a first step to identify possible management and agronomic alternatives. This approach allowed us to collect data on the constraints and problems and also the insights, ambitions of local farmers whose activity is strictly interconnected with ongoing ecological processes and deals with social, cultural and economic aspects. In this sense, the area of Mandrolisai is peculiar: people usually abandon rural lands to move towards city centres, but in this case marginalisation is strictly related to the depopulation that is affecting the whole island.

Understanding the fundamental drivers of the marginalisation process in this specific case study could serve as a template applicable to similar situations elsewhere, while paying special attention to the experience of the rural community plays a crucial role in clarifying their understanding of the ongoing dynamics and their vision of the future. We applied an integrated qualitative-quantitative methodology by merging 1) interviews of local farmers to understand the factors they perceived as most relevant for increasing or limiting agricultural activities with 2) a quantitative space–time analysis to understand the influence of farmers' choices on landscape changes.

2. Materials and methods

2.1. Study area

The study was carried out in the mountainous inland region of GMA (Fig. 1). The study area included six municipalities in the province of Nuoro and Oristano: Desulo, Tonara, Sorgono, Ortueri, Atzara, and Samugheo, covering around 33,860 ha with an average population density of 30.6 inhabitants km^{-2} and an average inhabitant age of 50.6 years. Demography in GMA is critical: a negative population trend has been ongoing since 1961 and the average age has been increasing from 38.6 years in 1990 to 50.6 in 2022. Desulo and Tonara are in a mountainous sub-area called "Alto Mandrolisai", closest to the Gennargentu mountain; Sorgono, Atzara, Ortueri and Samugheo are located in the area called "Basso Mandrolisai", which is mostly hilly. The highest peak in GMA is Bruncu Spina (1,828 m a.s.l.) – the second highest in Sardinia. Average annual precipitation ranges from 700-800 mm in the hills to 1000–1200 mm around the mountain peaks (ARPAS, 1922–2011). The sharp slopes of Alto Mandrolisai impose important constraints on agricultural and forestry mechanisation, whereas a more favourable topography in the Basso Mandrolisai results in more arable cropland. The most important and traditional crops in this area are grasslands, represented mainly by wooded grassland, hay crops and vineyards. Basso Madrolisai is one of the most important wine-growing districts in Sardinia (Mercenaro et al., 2019). Despite the relatively favourable conditions for agriculture, 85 % of the non-urbanised area of Basso Mandrolisai is occupied by permanent grasslands, woods and Mediterranean shrub, while only 15 % of the total area is cropland.

2.2. Data collection

A dataset containing quantitative and qualitative variables characterising farm management in GMA was collected following a 2-step data collection strategy. The first step was a questionnaire submitted to local farmers, and the second step was a spatial analysis of the lands belonging to the interviewees. The spatial analysis was strictly connected with the interviews, as the agricultural area of each farm was identified by the farmers themselves on a map specifically prepared for the interview and then digitised. The interviewees had responded to a call for interview launched *via* farmers' associations that were active in GMA and provided a list of farms that proved to be particularly dynamic and active in the area. We used the data saturation approach (Saunders et al., 2018) to choose the number of farmers to be interviewed, i.e., starting to hear the same comments repeatedly indicated that data saturation had been reached.

2.2.1. Farmers' interviews

The questionnaire submitted to the local farmers was organised in three parts. The first part included general information about the farmer and the farm structure management. The second part consisted of 12 questions to identify and localise fields abandoned or recovered by the farmers. The current crop type and the management type (stable use of fields, recovery or abandonment) in the last thirty years was identified for each field. The questionnaire was designed so as to understand the farmer's vision of the future, in particular their intention to recover a

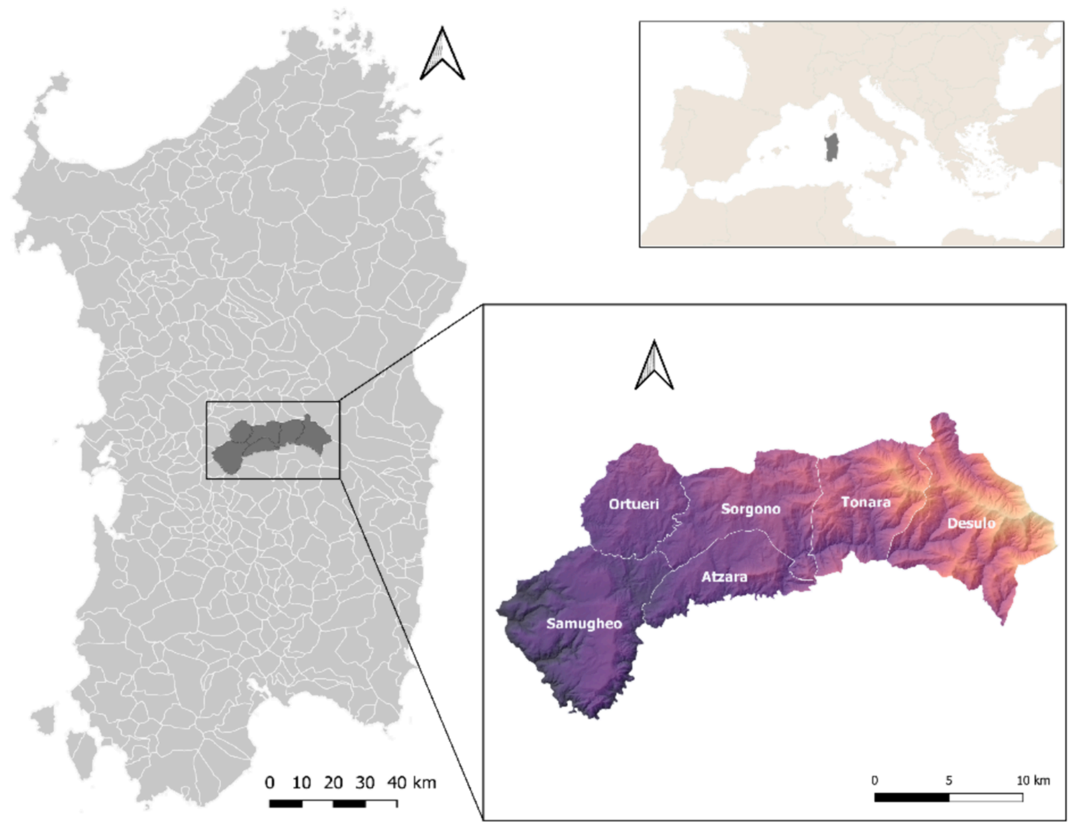

Fig. 1. Localisation of the study area.

portion of their farm in the next years, and the possible localisation of the fields to be abandoned/recovered; the aim was to try to understand if specific crops, animal species or general conditions could push the farmer to undertake recovery. The interview was supported by a map where the farmer was asked to describe and indicate the position of each field of his/her domain. The third part of the interview was focused on the management practices at the farm level, i.e., water supply sources, livestock, farm roads, agronomic practices (e.g., irrigation, fertilisation), and the degree of technological innovation of the farm. Thirty farmers were interviewed in the six municipalities of GMA between May and September 2021.

2.2.2. Data analysis

The collected data were merged to spatial data over the 1990–2018 timespan. Spatial data about farm surfaces and localisation were digitised using Qgis software (version 3.16.3). Land use changes were identified for the 1990–2000, 2006–2012 and 2012–2018 periods across the whole case study area (GMA) and within the farm fields using Corine Land Cover (CLC) which provides an expanded table at level IV for Sardinia, particularly detailed for wooded, silvo-pastoral and semi-natural areas. The interconnection between the spatial analysis and the interviews was particularly relevant because it contributed to further understand the processes underlying the territorial dynamics in the study area, and how the presence of still active and proactive farms can benefit the local dynamics. The changes detected on the farms through CLC data analysis were partially corrected for 2021, using the data collected from the farmers' interviews and the existing historical orthophotographs. In this way, we avoided considering mis-classifications as effective changes. 'Crop type', 'utilised area' and 'management system' were identified for each field, and the different farm areas were classified as 'recovered', 'abandoned' and/or 'stable'. The degree of fragmentation of each farm, considered as the average distance between the farm buildings and each field, was assessed, and a field distance matrix was built. The distance to each field was also measured considering the road paths from the farm buildings to get information about the actual distances travelled by the farmers during their activity. To explore the drivers of the farmers' field abandonment or recovery choices, a statistical analysis was performed using a logistic regression model. Two models identified as model A (abandonment) and model R (recovery) were built. The logistic regression model describes systems where it is possible to identify dichotomous or binary dependent variables when the number of predictors is $z > 1$. In our models, the dependent variable assumed a value of 0 for stable fields, and 1 if the field had been abandoned (in model A) or recovered (in model R). The advantage of multiple logistic regression over simple multiple regression is that an appropriate linking function is added to the usual linear regression model, so that variables can be continuous or categorical or a combination of both. The dependent variable represents the possibility for the investigated phenomenon to occur or not to occur. The logistic regression model is described by the following formula: (Wang et al., 2020)

$$P(Y_i = 1|X) = \exp(Xb)/1 + \exp(Xb)$$

$$Xb = \alpha + X_{fi} \cdot \beta_{fi} + \mu_i$$

where Yi represents the dependent variable indicating if in the i_{th} field the investigated phenomenon occurs or not. When in the i_{th} field the phenomenon occurs, $Yi = 1$; otherwise, it is 0. Exp(Xb) is the exponential of the scalar product between the vector of covariates X and the vector of coefficients of the model *b*, this is the term that models the odds ratio, which can be defined as the ratio of the probability of success to the probability of failure. The denominator $1 + exp(Xb)$ normalizes the value of the exponential, bringing it into the range [0, 1]. $Xb = \alpha + X_{ft} \cdot \beta_{ft} + \mu i$ represents the scalar product between the covariate vector X_{ft} and the model coefficients vector β_{ft}. The terms α and μi represent an intercept term and an error term, respectively. X_{fi} are the factors influencing field management and leading fields to be abandoned or recovered. β_{fi} is the parameter to be estimated. The predictors were chosen based on the main causes of recovery and abandonment cited by the farmers during the interviews. The marginalisation factors for the two models were 1) the crop cultivated in the field and water availability, which are discrete variables; the first consists of seven numerical levels each associated with a particular crop, the second is a binary variable; 2) the ratio of the area of each field to its perimeter (as an indicator of the field shape); 3) the slope and the road distance between the farm buildings and other fields, considered as continuous independent variables. Table 1 summarises the characteristics of the variables.

A pairwise analysis was run to identify the distributions of the statistically significant variables assessed through the models on the three types of fields (stable, abandoned and recovered). A Wilcoxon-Mann-Whitney test was used to perform pairwise analyses and to test significant differences between the distributions of two continuous variables. In this way, the differences between abandoned/recovered fields, abandoned/stable fields and stable/recovered fields were analysed.

3. Results

3.1. Characteristics of the farmers and farm structures

Among the 30 interviewed farmers, 67 % were men and 33 % were women. Four farm subgroups were identified according to the main farm specialisation: 1) livestock farms with mainly breed beef cattle, dairy sheep or dairy goats and pigs; 2) farms relying on arable fields, with chestnut or olive groves, vineyards and horticultural crops; 3) mixed livestock-arable farms with livestock, chestnut or olive groves and horticultural crops; 4) forest farms for firewood production (Tables 2 and 3). The 30 farmers represented around 4 % of the total number of farms in the area, although most of all 750 farms were not active in a professional way. The interviewed farmers represented a sample of the most active and dynamic ones in the region, and they managed around 8 % of the total agricultural surface.

3.2. Abandonment or recovery

The data analysis showed that the dynamics of abandonment and recovery occurred in different combinations. The most common condition was the one in which both abandonment and recovery coexisted: 18/30 farmers decided to permanently abandon some fields and to recover others that had been abandoned before 1990. Agricultural fields were recovered and no abandonment occurred in 10/30 farms, and the farmers also recovered fields abandoned before the examined period, or in many cases these areas became part of the farms through purchases or rentals. Two farms presented different dynamics from the above-cited ones: one in which the managed fields remained the same throughout the 30 years of observation, and one where some surfaces had been abandoned without undertaking any kind of recovery measure over the years. Table 4 shows the causes of abandonment and recovery cited by the farmers (grey boxes), and the grouping of farmers according to the abandonment/recovery dynamics listed above.

The most frequent recovery factor was reclaiming land for grassland to reduce haymaking or feed costs. Winegrowers converted abandoned land exclusively into vineyards.

Table 1
Description of the variables used in models A and R.

Description of the variables	Type of variable	Unit
Management of fields	Discrete/	–
Level 0 = stable in the last 30 years	Dependent	
Level 1 = abandoned (model A) or recovered (model R) in the last 30 years		
Type of crop cultivated in the field Levels	Discrete/	–
1 = Arable crop	Independent	
2 = Grassland		
3 = Vineyard		
4 = Wood		
5 = Olive grove		
6 = Horticulture		
7 = Chestnut grove		
Availability of water for irrigation	Discrete/	–
Level 1 = available	Independent	
Level 2 = not available		
Field	Continuous/	–
area/perimeter	Independent	
Field slope	Continuous/ Independent	Grade
Road distance between farm buildings and fields	Continuous/ Independent	Meters

Table 2
Characteristics of the interviewed farmers.

Characteristics of the interviewed farmers	Number	Percentage
Gender		
Men	20	67 %
Women	10	33 %
Educational level		
Lower secondary school (ISCED 2)*	6	20 %
Upper secondary school (ISCED 3)*	16	53 %
Higher education (ISCED 7)*	8	27 %
Age	Years	
Average age	38	
Minimum age	26	
Maximum age	56	

*International Standard Classification of Education.

Table 3
Characteristics of the farms.

Characteristics of the farms	Number	Percentage
Farming system		
Livestock	12	40 %
Livestock-Arable	10	33 %
Arable	7	23 %
Forestry	1	3 %
Irrigation		
Rainfed	20	67 %
Irrigated	10	33 %

3.3. Spatial data analysis

The total agricultural area (TAA) managed by the interviewed farmers was 1,602 ha with an average farm size of 53 ha. The average size of the livestock farms was 83 ha, the average mixed livestock-arable farm size was 45 ha, while that of arable farms was 12 ha. Grasslands are exclusively wooded in GMA. They represented 70 % of the total investigated area followed by woods (11 %), arable land (9 %), chestnut groves (6 %) and vineyards (3 %). Olive groves and horticultural fields (0.8 %) were scarce. Woods are mainly exploited by farmers to produce timber or for cork extraction, while chestnut groves are mainly used for timber and fruit production. Vineyards and olive groves are cultivated with local varieties exclusively dedicated to wine and oil production, respectively; arable lands are mainly used for fodder production, and only occasionally to grow grain cereals for food production.

The data showed how the level of field abandonment or recovery changed according to the agricultural use. Abandoned, recovered, or stable fields were identified for the following land uses: grassland, chestnut groves, vineyards, and arable land. The forest was abandoned or stable, whereas the horticultural fields were the least stable: all of them were abandoned or recovered during the period. Table 5 shows the stable, abandoned and recovered surfaces *per* agricultural use.

The CLC data analysis for the 1990–2000, 2006–2012, and 2012–2018 periods across the entire GMA territory, encompassing large

Table 4
Causes of abandonment/recovery mentioned by the farmers in the questionnaires. Each farmer's name was anonymised to abide by the GDPR; each letter identifies the municipality where the farm was located, and each number the temporal ranking of the interview in the list of that specific municipality.

		Causes of abandonment				Causes of recovery					
	Farmer code	Profitability	Field fragmentation	Road distance	Protection laws	Grasslands	Chestnut/ olives groves	Forage crops	Horticulture	Viticulture	Cereals
Abandoned/Recoverd Farms	D1	■	■	■		■	■	■	■		
	D3	■	■	■		■	■	■			
	D6	■	■	■				■	■		
	D2	■	■	■				■			
	D5	■	■	■					■		
	Sa3	■	■	■		■					
	Sa6	■		■			■				■
	A4	■	■					■			
	D7	■	■	■				■	■		
	O1	■	■							■	
	S2				■	■	■				
	Sa5	■		■		■					
	T3				■	■	■				
	T4	■						■	■		
	S3		■								■
	S4		■							■	
	T1	■					■				
	T2	■				■					
Recovered farms	D4							■	■		
	Sa2					■	■				
	T5					■			■		
	A1						■				
	A2									■	
	A3									■	
	O2									■	
	O3					■					
	S1									■	
	Sa1					■					
	*D8	■									
	**Sa4										
	Total citations	15	11	9	2	11	8	8	7	6	2

* Farmer who claimed to have exclusively abandoned agricultural fields.
** Farmer who claimed not to have recovered/abandoned any agricultural fields.

Table 5
Stable, abandoned and recovered areas of agricultural land according to land use during the last thirty years.

Land use	Stable (ha)	%	Abandoned (ha)	%	Recovered (ha)	%	Total (ha)	%
Grassland	702	43.8 %	250	15.6 %	162	10.1 %	1,114	69.5 %
Wood	146	9.1 %	37	2.3 %			183	11.4 %
Arable land	131	8.2 %	2	0.1 %	17	1.1 %	150	9.4 %
Chestnut grove	32	2.0 %	35	2.2 %	26	1.6 %	93	5.8 %
Vineyard	19	1.2 %	3	0.2 %	27	1.7 %	49	3.1 %
Horticulture			3	0.2 %	8	0.5 %	11	0.7 %
Olive grove	2	0.1 %			1	0.1 %	2	0.1 %
Total	**1,032**	**64.4 %**	**329**	**20.5 %**	**241**	**15.0 %**	**1,602**	**100.0 %**

abandoned agricultural regions, revealed that the predominant trends involved the transformation of abandoned agricultural land into semi-natural or wooded areas. The most substantial changes occurred between 1990 and 2000 on 2,010 ha mostly located in the hills of Basso Mandrolisai. The changes can be grouped in two time steps of re-naturalisation:

- Step 1: from agricultural areas to semi-natural bush areas.
- Step 2: from semi-natural bush areas to forests.

The re-naturalisation processes identified by the CLC analysis were mainly located in areas characterised by steep slopes where the soil morphology limits mechanisation. Most of the abandoned areas were outside the areas of interest for the surveyed farmers. The average slope of the areas that underwent re-naturalisation in GMA was 30°, higher than the average slope of the abandoned fields (23°). The dynamic of change of the fields managed by the farmers differed from that of GMA as a whole. Overlapping the areas identified by the CLC analysis with the fields of the 30 selected farms showed that re-naturalisation predominantly occurred in distinct areas that did not coincide with the farmers' fields. In some cases, these transformations only affected a fraction of the fields, as illustrated in Fig. 2, which provides an in-depth overview of specific areas on the map. For a complete representation of these results, Table 6 outlines the character of these changes and the extent of their impact on the farms.

3.4. Drivers of farmland abandonment

Statistically significant predictors were identified by the two logistic regression models (A and R) built to identify the drivers of field abandonment and recovery. The correlation coefficients of the variables were all lower than 0.23 in both models, confirming the absence of collinearity issues among the variables. This low level of collinearity was further confirmed by the analysis of the variance inflation factor (VIF): models R and A exhibited maximum values of 1.81 and 1.39, respectively, well below the critical threshold of 10, indicating the absence of collinearity among variables. Furthermore, the area under the curve (AUC) was calculated to assess the model fitness. The AUC values were 0.812 for model R and 0.875 for model A, indicating a strong fit for both models. The significance levels of models A and R are reported in Table 7.

The slope and the road distance to the farm buildings were frequently highlighted by the farmers as pivotal factors of filed abandonment and recovery, and emerged as strong predictors in the logistic regression

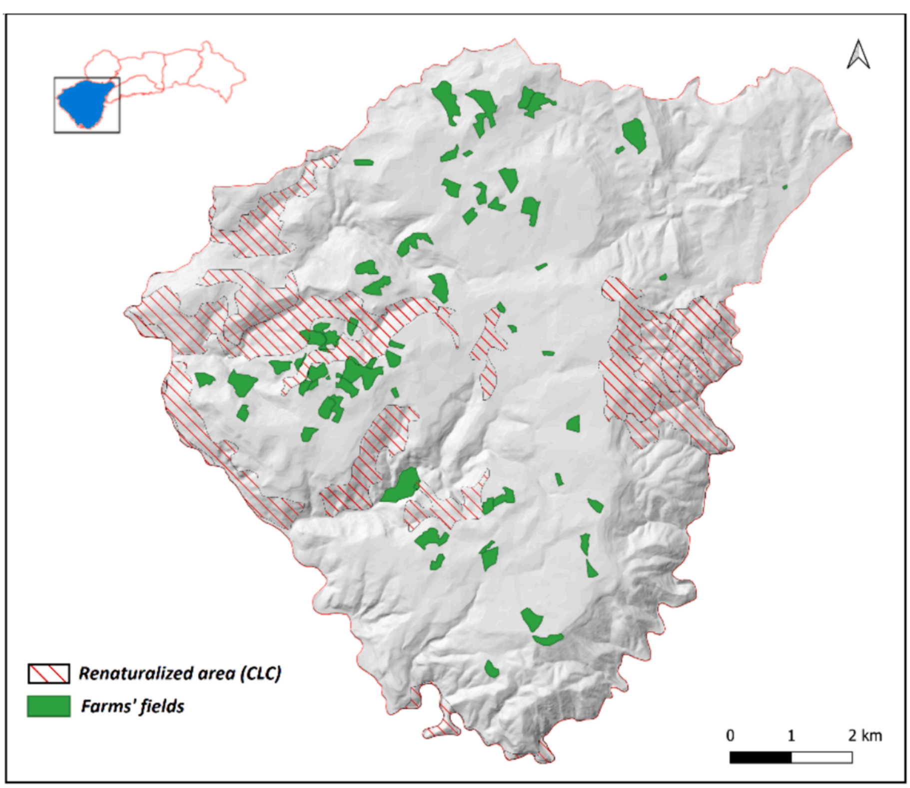

Fig. 2. Spatial distribution of the re-naturalised areas identified by the CLC analysis (1990–2018) and of the cultivated fields managed by the farmers identified in the survey. Inset, localization of the municipality of Samugheo in the Basso Mandrolisai area.

Table 6
Changes identified by CLC for the 1990–2018 period. The data were split in the following periods: 1990–2000, 2000–2006, 2006–2012 and 2012–2018. The areas of the fields belonging to the 30 selected farms and undergoing those changes are reported.

Period	Land use	Management	Dynamic	Description	Area (ha)
1990–2000	Grassland	Abandoned	Re-naturalisation	Non-irrigated arable land –> Land mainly occupied by agriculture, with significant areas of natural vegetation	0.9
		Continuous	Re-naturalisation	Land mainly occupied by agriculture with significant areas of natural vegetation –> Sclerophyllous vegetation	5.1
		Continuous	Re-naturalisation	Natural grassland –> Sclerophyllous vegetation	1.6
	Arable land	Continuous	Re-naturalisation	Land mainly occupied by agriculture, with significant areas of natural vegetation –> Transitional woodland/shrub	0.6
	Chestnut grove	Abandoned	Re-naturalisation	Natural grassland –> Transitional woodland/shrub	0.5
		Abandoned	Re-naturalisation	Natural grassland –> Transitional woodland/shrub	1.7
		Continuous	Re-naturalisation	Natural grassland –> Transitional woodland/shrub	1.0
				Total	**11.3**
2006–2012	Grassland	Recovered	Deforestation	Broad-leaved forest –> Transitional woodland/shrub	1.05
	Arable land	Continuous	Deforestation	Broad-leaved forest –> Non-irrigated arable land	1.82
				Total	**2.9**
2012–2018	Grassland	Continuous	Forest evolution	Transitional woodland/shrub –> Broad-leaved forest	1.05
	Arable land	Continuous	Forest evolution	Transitional woodland/shrub –> Broad-leaved forest	1.5
	Chestnut grove	Abandoned	Deforestation	Broad-leaved forest –> Transitional woodland/shrub	1.3
	Woods	Continuous	Forest evolution	Transitional woodland/shrub –> Broad-leaved forest	13.1
				Total	**17.0**

Note: No changes were identified in GMA during the 2000–2006 period.

Table 7
Significant predictors of the two A (abandonment) and R (recovery) models.

Variable	Model A (abandonment)	Model R (recovery)
Crops		
Grassland	0.008853**	0.002473**
Vineyard	NS	NS
Wood	NS	NS
Olive grove	NS	NS
Horticulture	NS	NS
Chestnut grove	0.008658 **	NS
Area/Perimeter	0.015449 *	0.022511 *
Slope	2.95e-05 ***	0.000335 ***
Road distance	0.002386 **	0.000383 ***
Water availability	NS	NS
AUC	0.812	0.875

*, ** and ***, significant at $P < 0.05$, $P < 0.01$ and $P < 0.001$, respectively; NS, not significant.

models as supported by statistical significance. The abandoned fields exhibited higher average slopes and greater road distances from the farm buildings than stable or recovered fields, which displayed similar average values (Fig. 3). A more detailed analysis of these field characteristics, employing the Wilcoxon-Mann-Whitney test, unveiled statistically significant differences in 'slope' and 'road distance' between the abandoned and stable fields and between the abandoned and recovered fields, while no noteworthy distinctions were detected between the stable and recovered fields (Table 8).

Table 7 highlights the significance of the area/perimeter ratio used to describe field shape. Terraced fields, which are crucial for cultivation in marginal areas, exhibited low area/perimeter values because their shape had to be adapted to the contour lines. Furthermore, the availability of water for field irrigation emerged as a critical factor for the statistical validity of the logit model. Poor access to water for irrigation was a common issue, with only 0.5 % of the total area relying on irrigation.

3.5. How farmers perceive the agricultural system and anticipate future challenges

At the end of the questionnaire, the respondents were invited to share their thoughts about the current state of the farming sector in GMA, as well as their expectations for the coming decades. The analysis of their responses provided valuable insights into the farmers' perceptions of the present agricultural landscape in GMA, highlighting several recurring themes:

Different exposure levels of the farming sector to the risk of decline: the farmers were convinced that not all farming sectors were experiencing the same level of decline. They specifically identified livestock farming – particularly traditional and extensive methods – as most vulnerable to abandonment.

A potential for growth in specific directions: the respondents felt that certain activities, e.g., horticulture, chestnut cultivation, olive farming, and cereal production had a potential for significant development in the region if properly supported.

A need for economic support in reclaiming abandoned areas: the farmers emphasized the importance of funding to revitalise abandoned areas in order to promote the recovery of agricultural activities.

A positive look on viticulture: the farmers believed that viticulture was the only sector experiencing growth and could become a driving force of the local farming industry. This perception was supported by data indicating substantial recovery in vineyard cultivation (Table 5). Although vineyards represented a relatively small portion of the sample, 55 % had been restored or replanted within the past 10–20 years. Looking ahead to the next two decades, the farmers anticipated further abandonment of agricultural activities. This projection was primarily attributed to the prevalence of older and older farm operators. The most concerning factor identified was the labour shortage resulting from demographic decline that could affect different activities in the area. Drastic effects could be expected during periods of intense activity like spring milk production, fodder harvesting or fruit harvesting.

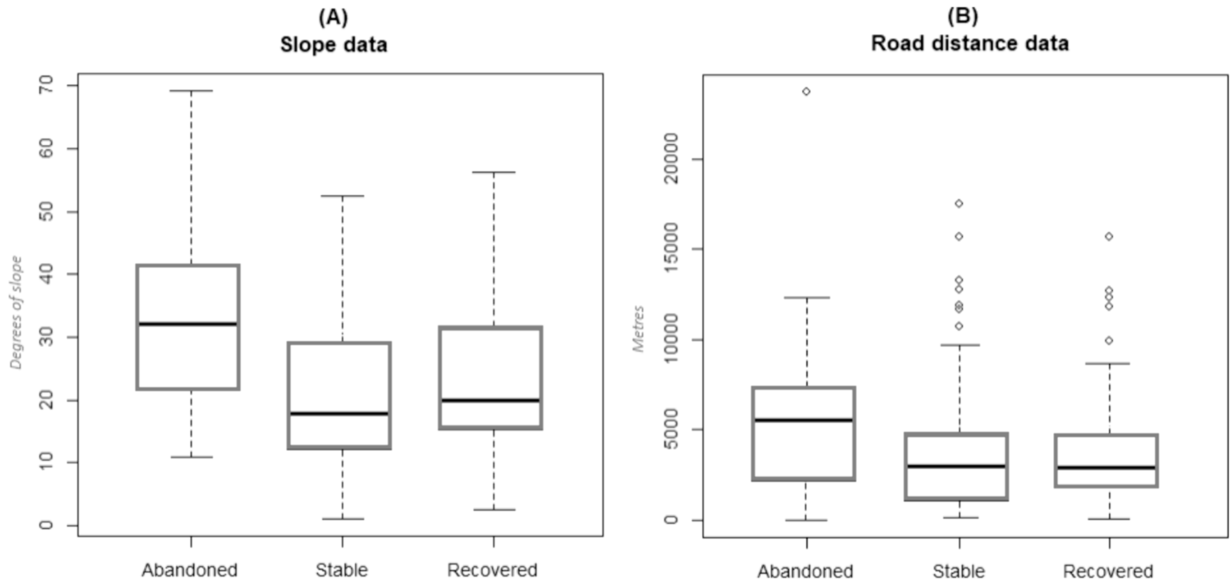

Fig. 3. (A) Differences in the slope data (degrees) of the abandoned, stable and recovered fields. (B) Differences in the distance road data (m) of the abandoned, stable and recovered fields.

Table 8
Statistical differences between the types of fields for 'slope' and 'road distance from the farm buildings'.

Field type	*P*-value
Slope	
Abandoned/Stable	3.277e-11***
Abandoned/Recovered	6.021e-06***
Stable/Recovered	NS
Road distance	
Abandoned/Stable	0.0003***
Abandoned/Recovered	0.0136*
Stable/Recovered	NS

*, ** and ***, significant at $P < 0.05$, $P < 0.01$ and $P < 0.001$, respectively; NS, not significant.

4. Discussion

The results of the CLC spatio-temporal analysis of the whole GMA showed that the main changes between 1990 and 2018 were extensive reforestation of former grassland and semi-natural areas in areas characterised by steeper average slope gradients than in the abandoned areas within the surveyed farms. Similar dynamics have been observed elsewhere in Sardinia where wooded grasslands and silvo-pastoral activities are commonly found: wooded grasslands decreased by 60 % in Sardinia over the same period because of abandonment (Bagella et al., 2020), as in many other silvo-pastoral Mediterranean areas (Delattre et al., 2020; Esgalhado et al., 2021; Rabelo et al., 2023). The maintenance of such landscapes requires grazing and mowing to prevent shrub encroachment and the consequent vegetation dynamics toward woodlands, to preserve the landscape and provide important ecosystem services such as reducing the risk of wildfire (Rossetti and Bagella, 2014; Roggero et al., 2021). Such maintenance could be ensured thanks to the presence of active farmers on the territory. In the surveyed farms, 21 % of the surface area was declared abandoned even though the farms were active and managed by young farmers. These data underline the difficulty for farmers to keep on with conventional farming practices, and the need to support them to avoid them having to shut down their farms. From this point of view, the analysis of land use changes in marginal areas was not sufficient to understand the dynamics of abandonment. The abandonment process needs 20–30 years to generate substantial changes, and about 60 years to transform cultivated fields into Mediterranean forests (Romero-Díaz et al., 2017), and this implies that agricultural activities have already ceased for a long time when abandonment is detected. In this sense, integrating farmers' perceptions with spatial analysis is particularly relevant. Moreover, one of the specificities of the results was that the most abandoned areas were not located on the most mountainous and marginal region, but on the hilly part, where vineyards and cereal crops are generally more scattered. This seems to be in agreement with the "mountain effect" described by Hinojosa et al. (2016): the probability of abandonment is sometimes greater in medium-mountain areas than in high-mountain regions. This is related to a sense of belonging and attachment – socio-cultural aspects often neglected in the assessment of land use changes. In this context, EU policies based on compensatory measures to maintain economic activity in mountainous regions tend to be ineffective, as intra-regional differences in agricultural land abandonment patterns should be taken into account when designing land use and rural policies (Hinojosa et al., 2016, 2019). For this reason, it is crucial to gain a deeper understanding of the context, trends, and potential evolution of mountain communities, territories, and businesses in order to design effective policies that protect mountain areas from the threats of climate change and capitalise on emerging opportunities.

The vulnerability of the farms in GMA was further demonstrated by the decline of the number of active farms since 1991. An average 68 % decrease of the number of farms was observed, with a peak at 90 % in the mountainous municipalities of Desulo and Tonara. This decline influenced the demographic trend, with a consequent strong ageing of the population and a consistent drop of birth rates in the area (Mazza et al., 2018). Similar de-population has been observed in other Mediterranean inland and mountainous areas (Viñas, 2019; Bruno et al., 2021; Kobayashi et al., 2020; Živanović et al., 2022). In GMA, it is associated with a general population decrease across the whole region.

The results of the statistical analysis showed that the recovered fields had similar characteristics to those of the stable fields, i.e., a gentler slope and a reduced distance from the farm buildings, hence easier recovery thanks to mechanisation. In other areas of the world similar to GMA, poor mechanisation has been reported to prevent the full potential of the fields being exploited by limiting production to a single harvest *per* year even in those areas where crop succession would guarantee more than one harvest. On the contrary, policies supporting micro-mechanisation of small farms can both satisfy the absence of workforce and guarantee greater agricultural and productive biodiversity

(Devkota et al., 2020). Furthermore, the promotion of scale-appropriate mechanisation has proven to be an excellent way of reducing abandonment and promoting small-farm activities, as well as ensuring better allocation of labour (Liao et al., 2022). The road distance from the farm buildings to other fields belonging to the same farm represents a key element likely to cause field abandonment and limit recovery. This poses the problem of the extreme fragmentation of agricultural land often mentioned by farmers during the interviews. In the case of grasslands far from the farm buildings, the problem was further increased by possible stress to livestock. In those cases of highly fragmented fields, livestock cannot be sheltered at night or when the weather is bad, and farmers cannot use the milking rooms usually located in the farm buildings and requiring electrical power. All these factors would affect the general quality of farm management by increasing manual work for the farmer (e.g., milking) and because of the continuous movements suffered by livestock at crucial moments such as gestation and lactation, hence decreased production, particularly for dairy cattle (Collier et al., 1982). In addition, high fragmentation has been recognised as the main source of high management costs and greater effort in managing activities such as sowing, weeding, harvesting, because of slopes and unpaved roads. The statistical significance of the area/perimeter ratio in the logistic regression models highlighted the susceptibility to abandonment of fields with unique shapes, which arose from the need to adapt to steep terrain. The fields with a low area/perimeter ratio were predominantly composed of slender, elongated terraces designed for cultivating tree and shrub crops. In line with studies conducted in the Mediterranean region, terraced fields are difficult to mechanise due to their characteristics, and are susceptible to abandonment (Gennai-Schott et al., 2020).

Water management was another important point of discussion. Poor rationalisation of water sources for agricultural use in GMA made it difficult to understand how much land can be irrigated. Moreover, the water supply of the farms is managed by the farmers themselves, who often use natural springs or wells close to the farms that do not guarantee sufficient flow rates for irrigation but mainly meet livestock needs. The impossibility for farmers to rely on constant water availability limits the possibility of strengthening activities such as horticulture or chestnut cropping. Most of the winegrowers complained about yield losses and plant die-off because of heat waves in summer. Among all the different drivers highlighted by the present study, some were of natural origin such as the slope, which cannot be removed but can be overcome by reorganising the local agricultural system. Including marginal areas such as GMA in projects of agroecological map construction or using agro-ecological zoning could be a valid tool to identify the areas most at risk of abandonment and promote projects for the sustainable development of the territory, to increase the productivity of the local agricultural system (Patel, 2007). Detailed knowledge of the steep areas in GMA, often occupied by wooded grassland, would make it possible to identify areas suitable for the recovery and replanting of chestnut groves. In addition to ensuring additional income compared to grassland, chestnut groves could efficaciously reduce erosion in early autumn (Barrena-González et al., 2020).

Given the framework of the main drivers of marginalisation following the interviews and given the positive attitude of the respondents, setting up a consortium of farmers would be feasible to overcome most of the technical problems. In other mountainous regions, cooperation among farmers has represented a strategy for revitalising agricultural activities and enhancing natural resources (Marandola, 2012). Moreover, considering that the challenges reported by GMA farmers are shared by many others working in other European marginal areas (Corbelle-Rico et al., 2012), the creation and the exploitation of networks for exchanging information, at least at the European level, could lead to the revitalisation of these areas that retain a high natural and human value.

4.1. Strengths and limitations of the study

The subject related to marginal land abandonment in mountainous or island regions has been extensively addressed in the literature over the past decades, at various spatial scales and under varied conceptualisations of drivers and diverse methods for analysing land use changes (e.g., Petanidou et al., 2008; Kizos et al., 2009; Weissteiner et al., 2011; Lasanta et al., 2017). However, our research work highlights how the causes of abandonment have specific site characteristics that deserve attention. A point of interest is the focus on the perceptions that emerged from the interviews of farmers chosen among the most active and dynamic ones in the study area. Farmers' views and perceptions can be considered as the real driver of choices, and this also strengthens the identification of possible solutions (e.g., a demand for specialisation, also as regards technical means and network development). Moreover, the trends of abandonment are also associated with a lack of innovation at different levels, not only in management tools but also in the governance and collective management of large areas that are now fragmented. Specific points highlighted in the study area were the importance of stable surfaces, and the drivers of recovery: as underlined by Burgi et al. (2004), persistence and landscape changes represent a relevant knowledge gap to be addressed.

In this study, we adopted a post-interpretative approach to capture the perceptions of local farmers and land users regarding the drivers of land abandonment and recovery in the past decades. While this approach provides valuable insights into the human dimension of the landscape dynamics, it only represents one aspect of a complex multifactorial process. In terms of conceptual models applied for linking drivers, stakeholders and landscape dynamics, the applied scheme of driving forces/stakeholders / land changes are usually considered to analyse the interactions between stakeholders and drivers and to identify possible policy interventions (Hesperger et al., 2010; Kizos et al., 2018). A future development of this study will integrate multiple approaches, including quantitative analyses and citizen-science methods, to complement the present post-interpretative perspective.

5. Conclusions

The present study was driven by the hypothesis that disentangling the drivers of marginalisation and understanding how these drivers interact with farmers' activities is crucial to exploit the agricultural potential of marginal areas and revitalise local farms.

Although from a merely geographical point of view the areas at greatest risk of abandonment were those located in the mountains, a multilayered approach of driver analysis and farmers' perceptions evidenced that the presence of young and lively farmers profitably counteracted natural disadvantages, and this motivated them to maintain production in those areas. Conversely, farmland abandonment was consistent in hilly areas. This means that socio-cultural factors can play a crucial role in the management of inland marginal regions, and need to be considered by decision-makers when implementing related policies.

Our study also pointed out that the farmers operate within a highly individualistic system, and this erodes the potential competitiveness of their farms. Encouraging improved coordination among farmers, e.g., through farmer consortia, could help mitigate the impacts of field fragmentation and optimise cost allocation for specialised mechanisation in mountain agriculture.

CRediT authorship contribution statement

Pietro Todde: Writing – review & editing, Writing – original draft, Investigation, Formal analysis, Data curation, Conceptualization. **Marta Debolini:** Writing – review & editing, Writing – original draft, Software, Methodology, Investigation, Conceptualization. **Pier Paolo Roggero:** Writing – review & editing, Supervision, Resources, Project administration. **Vittoria Giannini:** Writing – review & editing, Writing –

original draft, Supervision, Project administration, Methodology, Conceptualization.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: [Vittoria Giannini and Pietro Todde reports financial support was provided by Autonomous Region of Sardinia.].

Data availability

Data will be made available on request.

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