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Beyond Cadaster: Landowners and Land Fragmentation—Insights from a Case Study

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Abstract

Land management is a relevant problem in rural areas all over the world, conditioning the planning decisions and the applicability of planning instruments. This study evaluates the limitations of cadastral data in representing land fragmentation and management patterns in wild-fire-prone landscapes, using Alferce (Portugal) as a case study with broader international relevance. Similar challenges—fragmented ownership, incomplete land registries, and increasing wildfire risk—affect many regions worldwide, particularly across the Mediterranean basin and other fire-prone rural landscapes. A mixed-methods approach combines cadastral data with field data from 23 landowners producing two datasets: cadaster-only and ownership-enhanced. Fragmentation is assessed using Simmons and Januszewki indices, supported by spatial analysis (Kernel Density and Moran's I). Results show that cadastral data alone significantly overestimates fragmentation. While parcel-based analysis suggests a highly fragmented landscape, incorporating ownership information reveals more aggregated management structures. The 23 landowners manage 1247 ha (≈13% of the area), forming a "keystone" group with strong potential for coordinated land management and fire prevention. Higher fragmentation is associated with population centers. These findings demonstrate that cadastral units do not reflect functional management units and considerations about property fragmentation are biased by the lack of information about the owners, a key theoretical contribution with implications beyond Portugal. For policymakers, integrating ownership data and targeting key land managers can improve land use planning and wildfire mitigation and, overall, the sustainability of the territory. Despite limitations (small sample), the approach is transferable to other regions facing similar structural constraints.

Keywords: land registry; territorial management instruments; sustainable management; rural areas

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1. Introduction

Forest ecosystems harbor extensive biodiversity, ensuring ecological equilibrium and preserving natural capital while enhancing societal well-being. Mediterranean forests constitute a distinctive mosaic of terrestrial, aquatic, and marine systems—precipitated by

specific regional climates and dynamic topography—thereby sustaining significant biological diversity [1]. Since the early 1990s, forests have been key topics on the international agenda. There are examples as follows: Conferences of Ministers on Forest Protection in Europe (MCPFE), held in Strasbourg in 1991, and the United Nations Conference on Environment and Development (UNCED) in Rio de Janeiro in 1992. Since then, international conferences and political processes have consistently emphasized the need to preserve forest ecosystems [2]. However, little attention has been paid to Mediterranean forests internationally beyond periodic concerns about forest fires [3], although Mediterranean forests, shaped by specific climatic conditions and complex topography, are particularly dynamic and fire-prone systems [4].

In Portugal, forests cover approximately 35% of the mainland territory, representing the dominant land use [5]. Accordingly, forest is the main land use in the Portuguese territory [6]. This forest comprises primarily native species, with oaks accounting for approximately 36% of the total and pines about 30%; eucalyptus, considered an exotic species in Portugal [7], occupies 26% of the forest area and the rest is occupied by species of lower expression. This forest composition has similarities with other areas of the Mediterranean basin, where the primary tree species are drought-resistant, evergreen hardwoods and conifers, dominated by oaks (Quercus) and pines (Pinus) [8], and contributes around 4.6% to the national GDP through sectors such as cork, pulp, and timber [5,9].

Despite their importance, Portuguese forests face increasing pressure from wildfires. Although fire is a natural component of Mediterranean ecosystems' ecological and evolutionary process [10], its frequency and severity have significantly increased over the past decades [11]. This trend is strongly associated with structural factors such as land abandonment, fuel accumulation, and, critically, land fragmentation. Forest ownership in Portugal is highly fragmented and predominantly private (91%), with very small average property sizes, limiting coordinated management and effective fire prevention [6,12]. Beighley and Hyde [11] estimate that about 80% of Portuguese forests are not properly managed, exacerbating the fuel load problem, and the fact that 20% of the territory has no owner or is unknown [6] also contributes to this situation.

Land fragmentation, combined with insufficient or unknown ownership information, constrains the implementation of integrated land use planning and landscape-scale interventions. At the same time, it is known that land use and occupation can influence fire behavior in several ways [13] and so the current socio-economic dynamics—namely rural depopulation and declining agricultural activity—have contributed to the abandonment of land, further increasing wildfire risk [11].

In this context, land use planning and cadastral systems play a central role. The Portuguese Geometric Registry of Rural Property (CGPR) provides essential information on property boundaries, ownership, and land use, supporting territorial management and policy implementation [14]. However, cadastral data in Portugal remain incomplete in many regions, and approximately 20% of the territory has unknown ownership [6]. This limitation raises concerns about the reliability of cadastral information as a basis for land use planning and fire risk mitigation.

Although the existing literature acknowledges that land fragmentation and incomplete cadastral systems are critical challenges in Mediterranean regions [15–17], there is a lack of quantitative studies assessing the magnitude of errors introduced by relying solely on cadastral data, particularly in wildfire-prone areas. Moreover, the relationship between land fragmentation, management practices, and wildfire dynamics remains insufficiently explored.

Considering the increased risk resulting from the current context of climate change and recognizing the value of local knowledge and active engagement of local communities to reduce fire risk [18], the main question raised is how to ensure that a balance between the

functioning of ecological cycles, the economic interest of producers and human activities is being promoted, overcoming the movement of population from rural to urban areas and changes in land use, with more agricultural and forested areas being unattended and not maintained [11].

Therefore, this study aims to evaluate whether cadastral information alone can accurately represent land fragmentation and management patterns in wildfire-affected Mediterranean forest areas. Specifically, it aims to evaluate the limitations of cadastral data in representing property structures, quantify the discrepancies arising from incomplete or missing information, and examine how these shortcomings influence fire prevention planning and land management strategies.

To address these objectives, a structured methodological approach is applied to a case study characterized by low population density, high land fragmentation, and significant wildfire occurrence. This context provides a suitable framework to better understand the interaction between cadastral accuracy, land management, and wildfire risk, contributing to more effective territorial planning.

This paper is structured in several chapters as follows. In Section 2, we present the state of the art regarding the previous research carried out in this field. Section 3 presents the case study, Section 4 the methodological approach and Section 5 the results and discussion. Finally, Section 6 presents the main conclusions of this work.

2. State of the Art

2.1. Land Use Planning and the Cadaster Role

Land use planning has evolved over towards more efficient and sustainable land management models, emphasizing the balance between economic development, environmental protection, and social needs. Sustainability is a core principle of landscape planning, requiring the integration of ecological, economic, and cultural dimensions [19].

The cadaster is of utmost importance but must be gathered with the knowledge about who manages the territory, when information on fragmentation is used as a basis for the design of territorial management instruments. Fragmentation has consequences on landscape corridors, biodiversity, and ecosystems [19].

Sklenicka [16] considers land consolidation, which enables ownership to be concentrated through individual plans and resultant changes in the land registry, as an instrument to remedy the effects of fragmentation. However, in some cases, land consolidation is not expressed in land registry as individual owners may manage dispersed parcels jointly, effectively altering the spatial distribution of the territory. This suggests that territorial planning should not rely solely on cadastral information, but should incorporate ownership and management structures, reinforcing the need for a multidisciplinary and inclusive approach.

In Portugal, cadastral systems have undergone several reforms reflecting their growing importance in spatial planning and land management [20]. However, despite these efforts, the country still lacks full cadastral coverage, remaining one of the few European countries without complete geometric cadaster [21]. This limitation compromises administrative efficiency, land tenure regularization, and the implementation of effective public policies, particularly in environmental management [17]. In 2018, Capoulas Santos [22], then Minister of Agriculture, Forestry and Rural Development, already recalled the fundamental role of the preparation of cadaster in the Forest Reform, since it is necessary to know the property in order to be able to organize it.

Spatial planning systems aim to coordinate land uses and promote sustainable development. In Portugal, this framework has been progressively developed since 1976, with the creation of territorial management instruments at national, regional, and municipal

levels [23]. However, significant challenges persist, including weak coordination between instruments, conflicts between land uses, and difficulties in integrating sectoral policies [24].

Effective land management depends on accurate and integrated information systems. The lack of reliable cadastral data, combined with fragmented ownership structures, limits the capacity to design and implement coherent territorial policies.

"The cadaster is a fundamental and indispensable instrument for the State to pursue its constitutional and legal duties, namely concerning land policy and spatial planning" [25,26]. Its purpose is to serve as an information tool, freely accessible to all, with the purpose of speeding up and making more economical all territorial and real estate administration processes, facilitating inspections, licensing, expropriations, and promoting more equity in taxation [14]. Multilateral organizations, such as [17], emphasized that the absence of updated land registries compromises the administrative efficiency of the territory, hinders the regularization of land tenure and ownership, reduces legal security, and limits the implementation of effective public policies. Moreover, this scenario affects the capacity of States to promote environmental conservation, since the uncertainty regarding land ownership hinders long-term planning actions. Nevertheless, Portugal continues to be one of the few European countries that still does not have geometric cadastral coverage [21].

There is no single cadaster model in Europe; each country uses a different methodology, which varies with the result of the influence of their culture and history [21]. The coverage of the territory by cadaster systems in digital format is also very variable. According to Beires et al. [14] only 10 countries had 100% coverage (France, Italy, Austria, the Netherlands, Denmark, Belgium, Sweden, Finland, the Baltic Republics and the United Kingdom), 4 countries had less than 50% coverage (Greece, Romania, the Czech Republic and Scotland) and the rest were in intermediate positions.

In 2021, a questionnaire was carried out in preparation for the Conference "Cadaster—contributions for a low carbon economy and society, 2021", which was attended by 35 countries, and aimed to provide a report on the state of Land Management Systems. One of the issues discussed was the level of digitalization of the institutions responsible for land registration and cadaster. The result was that 25 of the attending countries had a level of data digitalization above 75%; 7 of the countries (including Portugal) with a level of digitalization between 50 and 75% and 1 country with a level of digitalization below 50%, with 2 no-turns.

2.2. Land Fragmentation: Causes, Impacts and Measurement

Land fragmentation is a global phenomenon affecting agricultural and forest systems [15,26]. It results from a combination of socio-cultural, economic, and political factors and is characterized by the division of land into small, scattered parcels with multiple owners [16,26].

Fragmentation has significant negative impacts on productivity, economic viability, and sustainable land use [27,28]. It increases production costs, reduces efficiency, and hinders mechanization and infrastructure development [26,27]. Additionally, it complicates the implementation of coordinated land management practices and policy measures. In fact, land fragmentation has been portrayed as a constraint on agricultural production and, more broadly, rural development in many countries across the globe, with significant links between land fragmentation and agricultural efficiency [29].

Heider et al. [26] state that inefficiencies like the loss of productive land because of fences, ditches, or hedgerows (which additionally are an impediment to mechanization), the incremental use of pipes and electrical wiring for automated drip irrigation, and time loss increase production costs and are some of the drawbacks linked to high land fragmentation.

Several methodologies have been developed to measure land fragmentation. Traditional indices, such as the Simmons and Januszewski indices, are widely used to assess

parcel distribution and farm structure [22,30–34]. More recent approaches incorporate geographic information systems and multi-criteria methods to provide more comprehensive assessments [28,35,36]. However, despite methodological advances, the spatial characterization of fragmentation patterns remains limited.

The relationship between land fragmentation and wildfire dynamics has gained increasing attention. Studies suggest that fragmented landscapes may influence fire behavior, although the relationship is complex and context-dependent [37,38]. One key element when defining a forest fire prevention policy is to identify the role of land fragmentation in forest management and wildfire dynamics. Land cadastral fragmentation significantly increases the risk and severity of forest fires, particularly in Mediterranean regions [39].

Historically, Mediterranean landscapes were characterized by a mosaic of actively managed agricultural and pastoral areas, which contributed to reducing fire spread and intensity. However, rural abandonment and declining land management have altered this structure, increasing fuel continuity and wildfire risk [11].

Fragmentation can act both as a barrier and a driver of fire spread, depending on land use and management practices. In highly fragmented but actively managed landscapes, fire risk may decrease; conversely, in abandoned and unmanaged areas, fragmentation may exacerbate fire hazards.

Despite the growing body of literature, several gaps remain:

1. Lack of quantitative assessment of errors associated with incomplete cadastral data in representing land fragmentation, particularly in Mediterranean forest contexts;
2. Limited empirical studies in Portugal, especially those combining cadastral data with field data collection to accurately characterize fragmentation patterns;
3. Insufficient understanding of the relationship between cadastral accuracy, land fragmentation, and wildfire risk, particularly in operational terms for fire prevention planning.

By integrating cadastral information with field-based data collection and spatial analysis in a wildfire-prone Mediterranean case study, this research directly addresses these gaps and provides an empirical assessment of the reliability of cadastral data for territorial planning and fire prevention. Furthermore, the study contributes to improving the understanding of how inaccuracies in property and management information may affect landscape-scale wildfire mitigation strategies and sustainable land management policies.

3. Study Area

According to Portuguese General Directorate for the Territory (DGT), the Geometric Cadaster of Rustic Property is in force in 118 municipalities of the mainland and in 10 municipalities of the autonomous regions of the Azores and Madeira, reaching almost half of the 308 municipalities at national level (Figure 1). Despite efforts to expand cadastral coverage—namely the public tender launched in 2009 for three operational areas [14]—significant gaps remain, particularly in rural and forested regions.

The parish of Alferce, located in the municipality of Monchique (Algarve, southern Portugal), was selected as the study area due to its direct relevance to the research objectives. The area combines apparent high land fragmentation, incomplete cadastral information, and significant wildfire occurrence, providing suitable conditions to evaluate whether cadastral data alone can accurately represent land structure and management patterns in fire-prone Mediterranean landscapes. Alferce was the most affected parish in the municipality during the major wildfire events of 2003 and 2018.

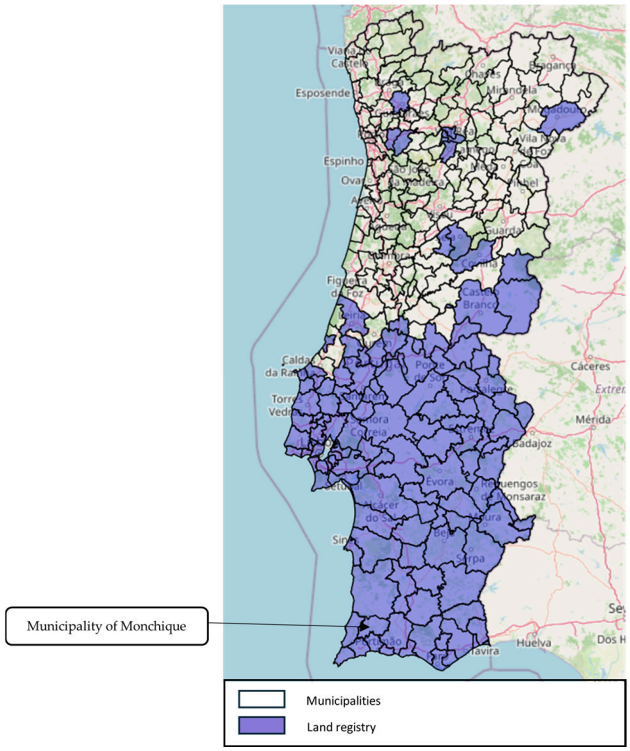

Figure 1. Adaptation of the cadastral map. Source: DGT (Accessed on 13 May 2026, available at: https://snic.dgterritorio.gov.pt/geoportal/map/9773cc68f32c4b85b8af6b3912038685).

Socio-demographic dynamics in Alferce contribute directly to land management challenges. The parish has experienced a marked population decline (−79% between 1960 and 2021) and presents a high aging index (537 elderly per 100 young people in 2021) [40]. These trends are associated with land abandonment and reduced active management, which increase fuel accumulation and influence wildfire behavior. The decline of primary sector activities further reinforces the disengagement from land-based practices, exacerbating fragmentation effects.

Based on cartography, a comprehensive and detailed analysis of the landscape focusing on the climate and location, relief and morphology, geology, pedological units, land capacity and use, hydrographic network, as well as aspects related to land use has been performed [41–46]. From this biophysical perspective, the area is characterized by steep and rugged terrain, with slopes predominantly above 25%, limiting accessibility and constraining efficient land management. Soils are mainly lithosols (≈86%), and land capability is largely classified as class "E" (≈94%), restricting agricultural use [47]. Consequently, land cover is dominated by forest (≈62%) and shrubland (≈29%), with eucalyptus representing the predominant species (≈80% of forest area), which is associated with higher fire hazard.

These characteristics—apparent fragmented ownership, incomplete cadastral information, land abandonment, and high fire susceptibility—make Alferce an appropriate case study to address the research questions. In particular, the study area provides a relevant context to assess the limitations of cadastral data in representing property structures, quantify discrepancies resulting from incomplete information, and analyze how these limitations may affect fire prevention planning and land management strategies in Mediterranean forest systems.

4. Methodology

This study was based in a careful collection of information allowing the importance of both cadastral information and information on the plots managers to be highlighted,

through qualitative and quantitative research, based on bibliographic research, and in the analysis of interviews (the interviews were carried out in Alferce parish in June 2022. The interview script was approved by the Algarve's University data protection officer (Júlio Fernandes) in 21 January 2022 and the interviewed gave their informed consent to the interview and data treatment.) previously carried out, within the scope of the BRIDGE—Bridging science and local communities for forest fire risk reduction project (https://zenodo.org/communities/bridge_community/about, accessed on 20 January 2025) developed between 2021 and 2024 in the Municipality of Monchique, Portugal.

The study adopts a case study approach to evaluate the extent to which cadastral data accurately represent land fragmentation and management patterns in wildfire-prone areas. The methodological framework follows a structured workflow comprising four main stages: data inputs, data processing, analysis, and outputs (Figure 2).

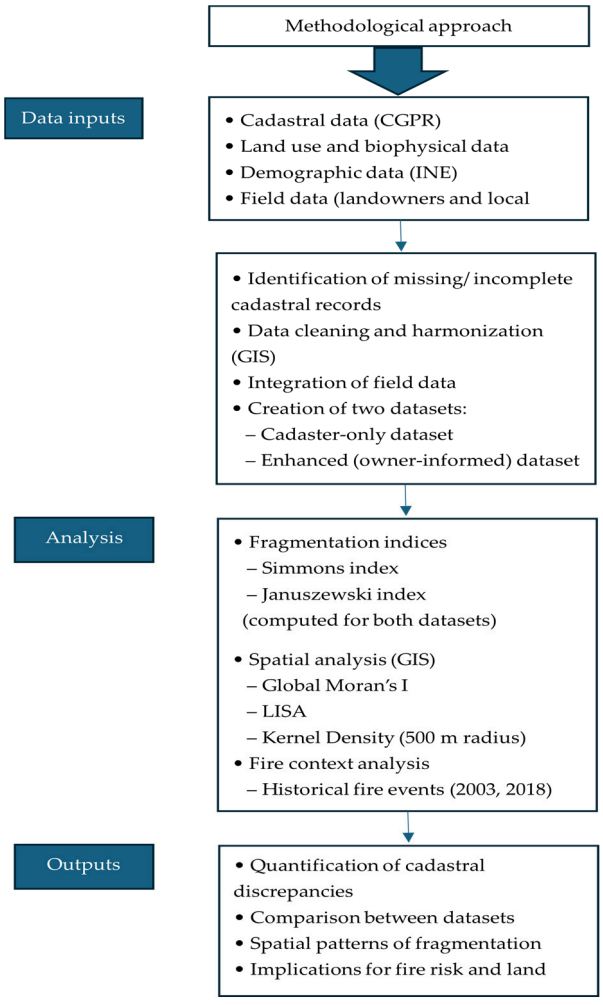

Figure 2. Methodological steps of the analysis.

4.1. Data Inputs

Cadastral data was obtained from the Geometric Registry of Rural Property (CGPR), complemented with land use and biophysical data, and demographic data from the National Institute of Statistics [40]. In addition, field data were collected through direct contact with landowners and local stakeholders to complement incomplete cadastral records.

A total of 23 landowners were surveyed using a convenience sampling approach, justified by the low population density, limited accessibility to landowners, and incomplete ownership records in the study area. Convenience sampling is one of the non-probability

sampling techniques, which is a way of selecting participants from the target population based on ease of access [48]. While non-probabilistic sampling methods may not ensure the same level of representativeness as random sampling [49], these kind of techniques are usually used in preliminary analysis or pilot studies. Although limited in size, this sample provides critical information to validate cadastral data. To mitigate potential bias, respondents were selected across different locations and parcel sizes, and information was cross-validated with available institutional sources where possible.

4.2. Data Processing

The first step consisted of identifying missing or incomplete cadastral records within the CGPR dataset. These gaps were then addressed through the integration of field-collected information. All datasets were processed in a GIS environment using QGIS software (QGIS Development Team, Open Source Geospatial Foundation, Chicago, IL, USA), including data cleaning, harmonization, and spatial alignment.

Two datasets were subsequently created: (i) a cadaster-only dataset, based exclusively on CGPR data, and (ii) an enhanced dataset, incorporating owner-informed corrections and additional information. This distinction constitutes the basis for the comparative analysis.

Figure 3 summarizes the data processing and validation framework adopted in this study, illustrating how cadastral information was assessed, complemented with field data, and transformed into the comparative datasets used for fragmentation analyses.

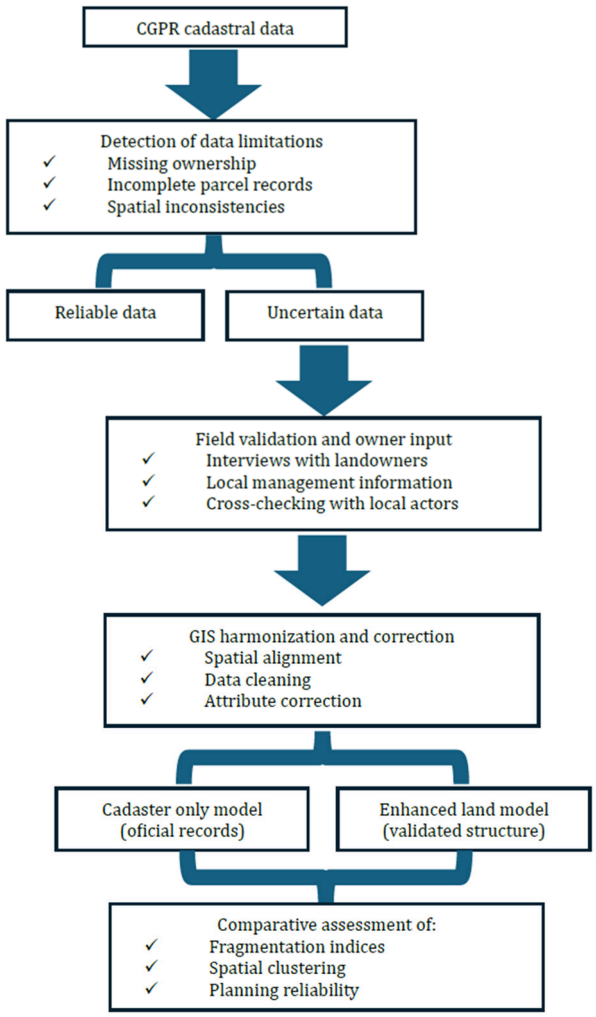

Figure 3. Data processing and validation framework.

4.3. Analysis

Land fragmentation was assessed using the Simmons and Januszewski indices [22,30–34], which, according to [50] are the most used indices to measure property fragmentation. These indices were computed for both datasets (cadaster-only and enhanced), following standard procedures described in the literature, allowing direct comparison of fragmentation levels under each scenario.

Spatial analysis was conducted using QGIS software (QGIS Development Team, Open Source Geospatial Foundation, Chicago, IL, USA). Kernel Density estimation was used to analyze the spatial concentration of parcels and ownership structures. A 500 m search radius was adopted for Kernel Density, as it reflects the local scale of parcel distribution while ensuring spatial generalization, while Global Moran's I and Local Indicators of Spatial Association (LISA) were applied to identify spatial clustering patterns.

The Global Moran's I statistic [51] is employed to determine the existence of spatial clusters [52]. The index ranges from −1 (perfect inverse autocorrelation) to +1 (perfect positive autocorrelation), where values near zero suggest a lack of spatial pattern [53]. Autocorrelation relates to the level of similarity between the values of a variable with spatial references. The conceptual framework for this analysis is rooted in Tobler's First Law of Geography, which assumes a distance–decay relationship—whereby the covariance between observations decreases as the geographic distance between them increases [54].

The LISA—local Moran I—measures the level of spatial autocorrelation at each parcel. Its results are affected by the definition of weight, data transformation, and extreme values [55] and tries to show where spatial patterns are located within a studied area.

Wildfire analysis was integrated into this stage by overlaying historical fire events (notably 2003 and 2018) with land use and fragmentation patterns, enabling the assessment of how cadastral limitations influence the representation of fire-prone areas.

4.4. Outputs and Interpretation

The results include (i) the quantification of discrepancies between cadastral and enhanced datasets, (ii) the comparison of fragmentation indices, (iii) the identification of spatial patterns of fragmentation, and (iv) the assessment of implications for fire risk and land management.

4.5. Methodological Limitations

The main limitation of this study relates to the use of a convenience sample of 23 landowners, which may introduce bias and limit statistical generalization. However, this approach was necessary to address gaps in cadastral data and is consistent with exploratory and case-study-based research. Results should therefore be interpreted as indicative, although they provide robust insights into cadastral inaccuracies.

Uncertainties associated with missing cadastral data and owner-reported information were mitigated through cross-validation and spatial consistency checks, although some degree of uncertainty remains.

5. Results and Discussion

5.1. Landowners' Socio-Demographic Characteristics

The results of the survey allowed the characterization of landowners. The information gathered by the survey corroborates the idea that the age range of forest producers is quite advanced: 65% of the owners interviewed are 65 years or older, 22.5% are 55 to 64 years old, 7.5% are 45 to 54 years old and only 5% are under 45 years old [22].

It was also found that, in the sample surveyed, 70% of the owners were male and only 30% were female. Regarding the level of education, 7.5% of the owners cannot read/write,

40% have only completed the 4th grade, and approximately 17% have only completed the 6th grade; that is, 64.5% of owners do not go beyond the second cycle of elementary school [22].

Additionally, more than half of the forest owners (77%) have a number of properties equal to or less than 6, and the others have a wide variety of properties ranging from 7 to 30 plots [22].

These socio-demographic characteristics are consistent with previous studies on Portuguese forest ownership, which emphasize ageing rural populations, low educational levels, and difficulties in generational renewal [11,22]. Such conditions may limit active land management capacity and contribute to land abandonment, reinforcing wildfire vulnerability in Mediterranean rural landscapes.

5.2. Cadastral Parcel Structure

The relevance of understanding the issue of property fragmentation is intrinsically related to a more comprehensive understanding of land management. The development of territorial management instruments without full knowledge of land tenure structure is an obstacle to efficient land management. When the cadaster is analyzed with only the information on how many land plots there are and their dimensions, at first glance, the territory appears to be very fragmented. Figure 4 details the land plots' registry in Alferce parish.

Figure 4. Map of the cadaster of the Alferce parish.

Table 1 presents the summary statistics of the cadaster of the Alferce parish. The summary statistics refer to the original cadaster data without GIS processing operations of clipping the parcels according to the parish limits. Therefore, all the parcels that were codified with the parish references were considered, although some of them are partially outside the geographical parish limit. The total number of parcels is 1690 and the average area is 5.66 hectares. However, the median is 0.97 hectares. The coefficient of variation is 310%.

Table 1. Summary statistics of the Alferce's land register parcels.

Indicator	Value
Total parcels (number)	1690
Total area	9568.40
Average (area)	5.66
Median (area)	0.97
Standard deviation (area)	17.55
Coefficient of variation (area) (%)	310
Max. area	422.32
Min. area	0.0043

The large difference between mean and median parcel area, together with the high coefficient of variation, reveals a highly heterogeneous land structure. Similar fragmentation patterns have been reported in other rural regions [15,16,26], where historical inheritance processes and rural socio-economic dynamics contributed to parcel subdivision. However, the present results suggest that cadastral interpretation based exclusively on parcel geometry may overestimate the effective degree of management fragmentation.

5.3. Spatial Analysis of Parcels Distribution

Figure 5 shows the density of land plots in the parish of Alferce, using the kernel method, which estimates the density of a distribution at specific points, using empirically observed points [56]. Using the QGIS software, version 3.38, it was possible to assign a geographic point in the center of each of the land plots and the density of land plots within a radius of 500 m was determined for each point [22].

The warmer colors (orange) refer to the areas of higher land plot density and the cool colors (blue) refer to the areas of lower land plot density. As can be seen in the map, the points with the highest density of land plots are located in the village of Alferce and in the locality of Umbria, reaching 140 land plots within a radius of 500 m, which means that the areas with the greatest fragmentation exist near the larger population centers.

The Moran statistics focused on the area of the parcels. An Edges and Corner (Queen Contiguity) spatial continuity matrix was selected. The value of Global Moran I index obtained was 0.3665 (p = 0.001), meaning the existence of spatial autocorrelation.

The Global Moran's I index tests statistical significance against the null hypothesis of spatial randomness and it varies between 1 (strong positive correlation), 0 (spatial randomness), and −1 (strong negative correlation) [57].

The local Moran Lisa is shown in Figure 6 and presents the spatial clusters that are statistically significant. A high–high cluster (indicating positive spatial autocorrelation where a unit with a high attribute value is surrounded by neighbors with similarly high mean values [58] is present in most of the forest area while a low–low cluster (representing positive spatial autocorrelation characterized by a convergence of low attribute values [58] is present in both urban areas mentioned before.

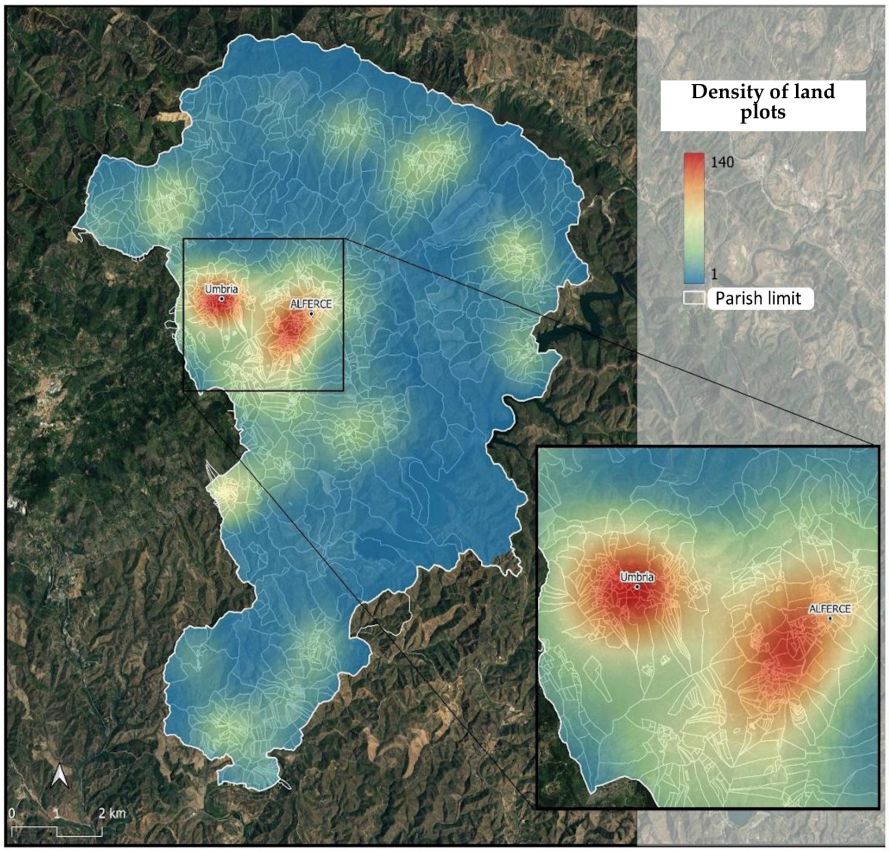

Figure 5. Density map, Kernel method (land plots density).

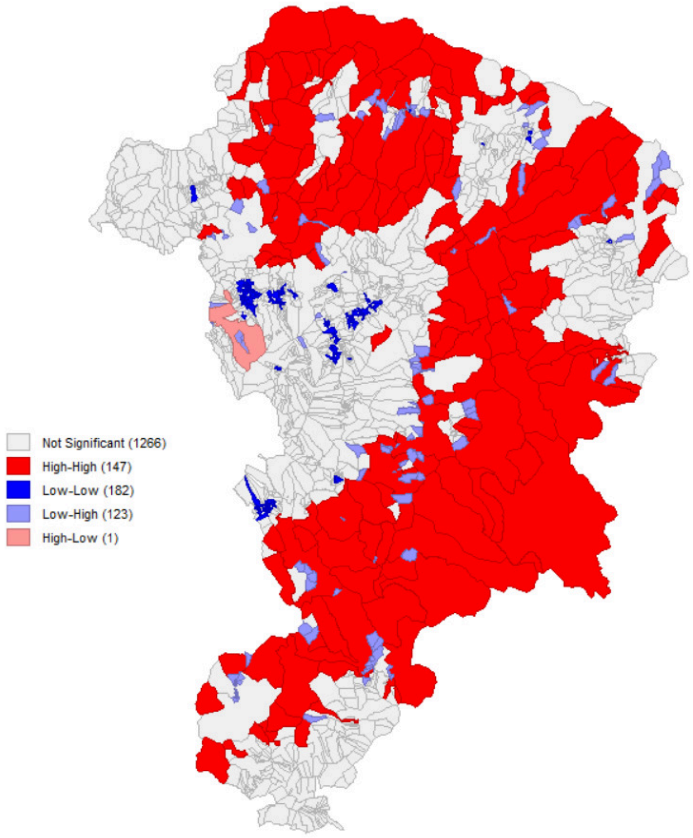

Figure 6. The local Moran (LISA)-spatial clusters.

These spatial patterns reinforce the relationship between historical settlement dynamics and land fragmentation. The concentration of smaller and fragmented parcels around population centers reflects traditional subsistence-based land occupation patterns [59,60]. From a land management perspective, this finding is particularly relevant because it demonstrates that fragmentation is not spatially random but strongly associated with socio-ecological dynamics that may influence wildfire prevention strategies and accessibility for management interventions.

5.4. Land Fragmentation Based on Ownership

Our analysis of the Alferce parish land fragmentation is based on the surveyed owners.

By analyzing the information of the owners, the maximum and minimum number of rustic land plots per owner are 23 and 1, respectively. In addition, it is verified that each owner has an average of 7.3 land plots and a median of 4 land plots. Regarding the area owned, each owner owns an average of 7.42 ha and a median of 27.00 ha, with the largest area of 285.03 ha and the smallest area of 0.10 ha [22] (Appendix A). It should be stressed that, in the Algarve, the minimum crop unit for forest lands, established to prevent the division of rural properties into plots of land with smaller areas and to enhance the economic scale and the economic and financial profitability, is 8 ha [61].

Using the shapefile of the cadaster made available by the municipality of Monchique and the geographic information system software (QGIS 3.22) it was possible to create an attribute allowing to categorize (by random colors) the rustic land plot belonging to each of the 23 participating owners (coded as P1-P23).

The result can be seen in Figure 7 [22], which includes all the rustic and urban land plots in the parish of Alferce. The total number of rustic land plots is 1719, occupying about 9538 ha, with 1672 of rustic land plots and 46 urban land plots. Figure 7 emphasizes the properties of the participants—168 rustic land plots, occupying 1247.02ha (about 13% of the study area).

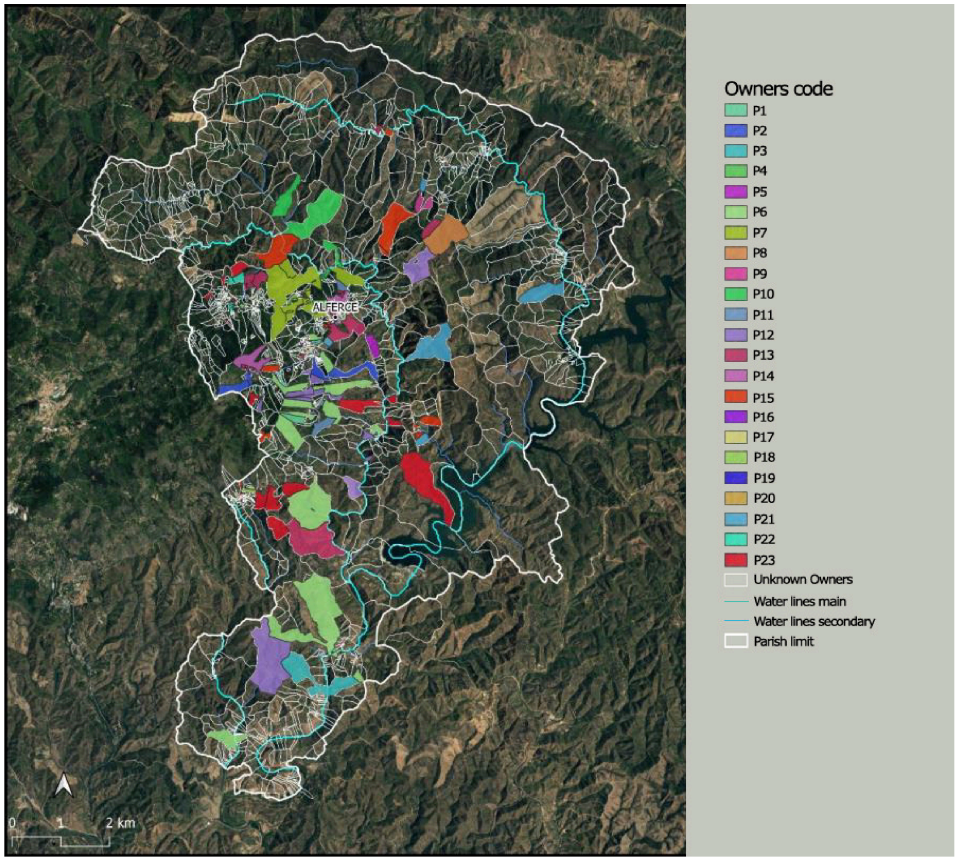

Figure 7. Property location map by owner.

With this knowledge, two fragmentation indices (Simmons' and Januszewki's) were calculated, which consider the size and number of plots.

When the indices were calculated for the total area occupied by these properties without the owner information, the results for Simmons (FI) and Januszewki (K) were 0.03 and 0.11, respectively, which means a very fragmented territory. However, adding this knowledge and weighting the indices of each holding, using the % of the holding's surface in the total area occupied by these properties, the FI and K indices considerably increase to 0.37 and 0.41, respectively.

These results constitute one of the main findings of this study, demonstrating that cadastral parcel analysis alone may substantially distort the perception of territorial fragmentation. Once ownership and management information are incorporated, fragmentation appears significantly lower than initially suggested by cadastral geometry alone. This finding supports the argument proposed by Sklenicka [16] that effective land management structures do not necessarily coincide with cadastral parcel divisions. Consequently, relying exclusively on cadastral datasets may compromise the design of territorial planning and wildfire prevention policies.

5.5. Fragmentation and Forest Fire Context

The number of surveyed farms is limited to 27 owners with 168 parcels and compassing an area of 1247.02 hectares. Nevertheless, there are gaps with lack of data in the territory.

The Portuguese government has made efforts to aggregate properties in what concerns forest management in different regions of the country. The creation of forest intervention zones (ZIF) back in 2005 introduced a new figure in the forest management process [3]. The fundamental objective of a ZIF was to promote sustainable management of forest areas. It would also make it possible to address issues such as the scale of forest exploitation, encouraging joint management, and increasing the size of forestry operations, which enables efficiency gains and discourages fragmentation. More recently, in 2020, the Plans for the Reorganization and Management of Landscapes are intended to plan and program the transformation of vulnerable forest territories to develop a multifunctional and resilient landscape, new economic activities, and remuneration for ecosystem services.

The results obtained in this study reinforce the importance of these policy instruments, particularly in territories characterized by incomplete cadastral information and fragmented ownership structures. The findings suggest that collaborative and landscape-scale management approaches may be more effective than strategies based exclusively on individual cadastral parcels. Moreover, improving cadastral accuracy and integrating local management knowledge can contribute to more realistic wildfire risk assessments and more efficient territorial planning in Mediterranean forest regions.

6. Conclusions

The parish of Alferce presents a complex interaction of geographical and climatic factors that has an impact on the population that lives there and on the management of its natural resources. Land use is characterized by a predominance of forests, especially eucalyptus and bushland.

It is important to consider these characteristics and factors for planning and decision-making related to the development and sustainability of this territory; information on land occupation and use should be complemented with information on the owners and/or managers of the space, because knowledge about their decisions will be decisive to understand the dynamics of the territory. Management plans for a given territory must take into account the objectives and aspirations of the people who intervene in the territory and for whom it is an important means of livelihood. It is not possible to think about the

forest (and the problem of fires) without considering its managers, since the forest does not happen disconnected from its management options.

Based on this study, it is possible to understand that the cadaster is an indispensable instrument for territorial knowledge, the development of policies in the scope of territorial management and for the decision-making related to the use and occupation of land. This way, it plays a fundamental role in the management and planning of the territory but should be complemented, for planning proposes, with landownership information. The main findings of this study are that what appears to be a highly fragmented territory at parcel level becomes significantly less fragmented when ownership aggregation is considered. In this context, the group of 23 landowners managing 1247 ha emerges as a "keystone" group for territorial management and fire prevention; targeting such aggregators may allow efficient landscape interventions.

Fragmentation of rural property is indeed a significant challenge, which can hinder the efficient management of the territory, the prevention of risks such as rural fires, and the implementation of agricultural and forestry development policies. However, based on the results of this study, there is a lack of information to better understand this problem. The results show that relying exclusively on cadastral parcel data may lead to misinterpretation of fragmentation patterns, reinforcing the need to integrate ownership data into planning tools. This constitutes the main theoretical contribution of the study, demonstrating that functional land management units differ from cadastral units and that ownership aggregation must be explicitly incorporated into territorial analysis and policy design.

The implementation of measures that promote sustainable forest management and economic diversification needs cadaster as a crucial tool for efficient planning and management of the territory, but community involvement and better knowledge of landownership structures are essential to ensure more sustainable and resilient development. From a policy perspective, planners should prioritize mechanisms that identify and engage key landowners, promote coordinated management, and improve cadastral systems by integrating ownership and management information.

This study has limitations related to the use of a convenience sample and the incomplete spatial coverage of ownership data. These factors limit the generalization of the results.

Future research should focus on expanding the dataset, improving cadastral-owner integration, and applying fragmentation metrics to the entire territory. Further work is also needed to better understand the relationship between land ownership structure and fire risk.

So, based on the results obtained in this study it is possible to establish some future lines of investigation:

- The expansion of this methodology to a larger sample and to other areas, and the inclusion of land use characterization.
- The analysis of spatial patterns and conditioning factors, particularly the drivers behind landowners' decision, as this knowledge will be decisive to understand the dynamics of the territory.

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Appendix A

Table A1. Owners' land plots information—number of land plots, total area (ha) and average area per land plot (ha).

Owner Code	Land Plots (N°)	Area (ha)	Average (ha)
P 1	1	6.06	6.06
P 2	6	37.82	6.30
P 3	3	49.59	16.53
P 4	4	8.09	2.02
P 5	1	8.42	8.42
P 6	23	285.03	12.39
P 7	16	109.05	6.82
P 8	2	42.78	21.39
P 9	4	8.13	2.03
P 10	7	82.34	11.76
P 11	3	13.03	4.34
P 12	18	148.31	8.24
P 13	23	104.17	4.53
P 14	3	27.00	9.00
P 15	19	90.18	4.75
P 16	1	0.10	0.10
P 17	1	0.98	0.98
P 18	2	2.28	1.14
P 19	2	0.26	0.13
P 20	1	0.14	0.14
P 21	8	74.31	9.29
P 22	6	8.91	1.48
P 23	14	140.06	10.00
Total	168	1247.02	7.42

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