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Sustaining altitude pastures in mountain landscapes–a fuzzy cognitive model approach

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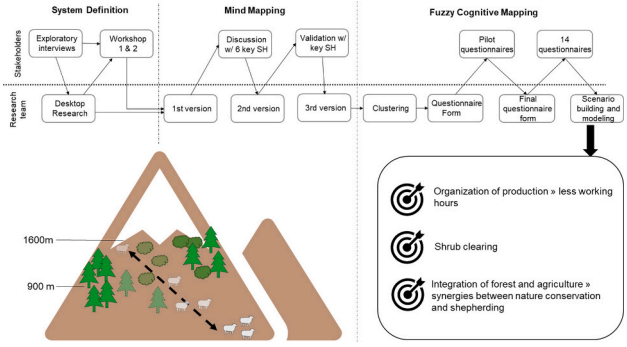
HIGHLIGHTS

- Use of mountain pastures contributes to preserve landscape and reduce fire risks.
- Fuzzy Cognitive Map allows to model local knowledge and identify causal relations.
- Non-monetary values are more relevant than income in driving altitude pasture use.
- There are synergies in conservation and pastoralism but no integrated landscape strategies.
- PDO label has positive impacts but lacks a clear link with the mountain area.

GRAPHICAL ABSTRACT



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ABSTRACT

Similarly to other European mountain areas, in Serra da Estrela the grazing pressure has been reducing due to social and economic drivers that have pushed shepherds and sheep to the foothill, or plainly out of the sector. Shrub encroachment on commons and other previously grazed land is one of the most tangible effects of pastoral abandonment in Serra de Estrela. The impacts of the resulting increase in landscape continuity and biomass availability were made clear in the severe fires of 2017 and 2022. As fire risk is likely to increase with climate change, it becomes urgent to understand what strategies can be deployed to keep fragmentation in these landscapes. Key actors such as shepherds should be involved in this discussion to understand their perceptions, points of view and reasons for abandoning upland pastures. In this study, we use fuzzy cognitive mapping to identify the key variables and mechanisms affecting the pastoral system according to local shepherds. In our study, we developed with local stakeholders a framework outlining the local pastoral system. Based on that, we carried out the fuzzy cognitive mapping collecting 14 questionnaires. We found that shepherds' income is a central issue, but that it is highly dependent on many factors. Increasing the Common Agricultural Policy payments alone is not enough to incentivise the use of upland pastures. More targeted strategies, such as more support for shrub

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clearing, and direct payments conditional to transhumance are more impactful. Despite a contentious discourse between conservation and shepherding values in Serra da Estrela, we find that shepherd's values are aligned with biodiversity conservation and a potential nature-based solution for minimizing fire risk through woody fuel management. This opens up possibilities for new governance strategies, that put Serra da Estrela's social, environmental and cultural values at its core.

1. Introduction

In mountain areas all over the world, due to the particularities of slope and climate variation along the altitude gradient, grazing has been the dominant farming activity (Dörre, 2016; García-Ruiz et al., 2020). These mountain pastoral systems are characterized by an efficient and adaptative use of natural resources, providing a wide range of benefits other than food provisioning (Dean et al., 2021; MacDonald et al., 2000). Namely, they contribute to shrub control creating unique open mountain landscapes, with high biodiversity values and with lower risk of wildfires.

Marginalization trends felt throughout Mediterranean mountains in the late 20th century and continuing in the 21st century resulted in fewer people, fewer animals and less used agricultural land, and thus a clear trend of land abandonment (Jiménez-Olivencia et al., 2021; Pinto et al., 2023). Abandonment of agricultural land presents an opportunity for allowing ecological succession, and rewilding is growing in popularity as a way to restore ecological processes trough minimal human interference (Carver et al., 2021; García-Ruiz et al., 2020). Studies show that rewilding can improve mountain ecosystem services such as water regulation, soil retention (Bruno et al., 2021), and carbon storage (Palli et al., 2023). However, rewilding pastoral mountain landscapes also means shrub encroachment and higher contents of biomass. The control of biomass accumulation is particularly relevant in fire-prone regions, as its accumulation contributes to increase fire connectivity and fire intensity, what has showed devastating impacts when the landscape has on beforehand high rates of forest cover (Calheiros et al., 2022; Nadal-Romero et al., 2016). Climate change scenarios in Mediterranean Europe indicate that there will be higher average temperatures and especially higher summer temperatures, low precipitation with the strongest reduction in spring rains, and therefore warmer and drier summers – the perfect combination for extreme fire risks (Ruffault et al., 2018; Turco et al., 2014). Due to these trends and the risks associated with increased biomass, other authors argue for need to preserve open farmed areas in a mosaic with the forest and shrub areas (García-Ruiz et al., 2020; Lasanta et al., 2015). In mountain areas extensive grazing is the most prominent agricultural activity and it has been shown to be efficient in controlling or at least reducing shrub encroachment, reducing the biomass available for burning in the event of a fire. More, the presence of pastureland introduces discontinuity in the landscape, disrupting the fuel connectivity (Lecina-Diaz et al., 2023). Thus, maintaining a minimum level of grazing intensity, as in ancient silvo-pastoral systems, seems to be a good nature-based solution for managing wildfire risks. Further, grazing contributes to preserve biodiversity and the mountain landscape character appreciated by locals and visitors.

Designing public interventions to support these minimum levels of grazing, no matter at which scale, requires an understanding of the process and of the drivers of land abandonment, and how they play together. These drivers in general terms are known. However, their particular combination and intensity within the specific contours of each context can elicit different responses from local actors (Gorddard et al., 2016). And ultimately, the preservation of pastoral systems and of altitude pastures is dependent on the existence of shepherds and their willingness to have their herds in the mountain area.

This paper presents the results of applying Fuzzy Cognitive Modelling (FCM) in a remote mountain area in Portugal, aiming to better understand why shepherds progressively stopped using altitude pastures and which strategies can be most effectively applied to motivate them to return to these practices. FCM integrates stakeholders' knowledge and perceptions of a given process. This way, with FCM it is possible to reveal causal relations between drivers and impacts particular to a given biophysical and socio-cultural context. FCM uses fuzzy-graph structures that represent causal reasoning and allow to unveil direct and indirect feedback mechanisms within the system (Özesmi and Özesmi, 2004).

1.1. Serra da Estrela

The landscape and vegetation of Serra da Estrela (Fig. 1) is influenced by human activities together with its biogeological characteristics, which resulted in a diverse and complex territory (Jansen, 2011). The Natural Park of Serra da Estrela (*Parque Natural da Serra da Estrela*) extends over 88,850 ha and unofficially sets the limits of Serra da Estrela. The "heart" of the massif and of the park is a central plateau located at roughly 1600 m. The central plateau has a long history of transhumance and holds endemic species and important habitats. One of them, the "cervunal" that can only be maintained if grazed (Carvalho and Marques, 2020; Jansen, 2011; Ribeiro and Monteiro, 2014).

The transhumance movement connects summer pastures in high-altitude, with the lower plateaus and valleys, more suited for agricultural and silvopastoral activities. Through this vertical movement up and down the mountain, the herds fertilized the land and maintained an open landscape between 900 m and 1600 m (Carvalho and Marques, 2020; Jansen, 2011). This open landscape management made it possible to maintain biodiversity associated with pastures and preserve endogenous vegetation, whilst contributing to reduced fire risk in forest areas (Monteiro et al., 2021). Further, it is the grazing in these pastures that connects the value chain of Serra da Estrela Protected Designation of Origin (PDO) cheese to the mountain landscape. This PDO cheese is described in planning and strategy documents as the most important territorial asset of Serra da Estrela and is often sported as a key product for territorial development, having also an increasing market value (Dinis and Simões, 2021; Inácio et al., 2020). To obtain the PDO certification, the cheese ought to be made with the raw milk of autochthonous sheep breeds. Sheep need to be kept in an extensive regime, but its defined production area goes well beyond the mountain altitude pastures, including large areas of lowland pastures (Jansen, 2011).

2. Material and methods

This study is based on Fuzzy Cognitive Mapping (FCM) which was built upon several participatory-based steps illustrated in Fig. 2: 1) System definition, 2) Mind Mapping, and 3) Modelling. This modelling technique is rooted in Neural Networks which aims to reproduce mental models of stakeholders (Axelrod, 1976; Jetter and Kok, 2014; Kosko, 1986). FCM has been applied to a range of different socio-ecological systems and aims to build a network of concepts connected with causal relationships that are identified by stakeholders according to their perception of the problem, belief, and knowledge of the mechanisms at play (Özesmi and Özesmi, 2004). The FCM is also employed to explore further how the system is potentially affected by bundle changes of factors and building different scenarios (Gray et al., 2012; van Velden et al., 2020).

2.1. System definition

Stakeholders involved in these first steps include shepherds,

associations managing the commons, breed associations, local associations, cheesemakers, municipal technicians, researchers, local businesses, the regional directorate of agriculture, and the national forest institute, in a total of 37.

Between April and December 2021, 25 exploratory interviews were done, to identify the key players and the relevant elements at play in the system and define the relationships between the different elements. The 1st workshop was held on June, 23rd 2021 to discuss with 26 stakeholders the role of pastoralism for the resilience of the Serra da Estrela to climate change. The resources used in pastoralism, as well as the pressures this activity is subject to, were discussed. The 2nd workshop took place on November, 23rd 2021 with 7 participants, focused on the vulnerabilities of the territory, and was prefaced by 11 questionnaires on the main biophysical drivers affecting the territory.

2.2. Mind mapping

1st version: The outcomes of the interviews and workshop discussions were summarized and drawn into an initial mind map of the pastoral system. Complex concepts and relationships were simplified to fit in a visual representation easy to be understood and discussed with local stakeholders.

2nd version: The first version of the map was shown and discussed in one-on-one meetings with 6 key stakeholders: 4 shepherds, 1 shepherd and cheese processor, and 1 association managing the commons. These inputs led to a revision of the included concepts, their meanings and their relations, and a new version of the mind map.

3rd version: The mind map was finally discussed and validated with a former director and now technician of the Regional Office of Agriculture, who was able to provide a system view and comprehensive understanding of the local issues related to agriculture and the environment, in January 2022. After, the research team reviewed once again the mind map drawing its final version (Fig. 3).

2.3. Fuzzy cognitive mapping

Clustering: Concepts and connections were aggregated into clusters, following a qualitative aggregation procedure (Özesmi and Özesmi, 2004; Targetti et al., 2021). The aggregation was necessary to develop the questionnaire and facilitate the visualisation of the network of relations between the elements of the pastoral system and the evaluation by stakeholders.

Questionnaire: The questionnaire form was piloted with two respondents after which the questionnaire was revised. 14 stakeholders answered the questionnaire between November 2022 and March 2023. These include sheep shepherds that use altitude pastures (5), shepherds that only stay in the lowlands (4) and also goat shepherds (3), and technical staff from associations that work closely with shepherds (2) to capture diverse perspectives. The questionnaire was guided by the overall question "Which entities should be involved and strategies adopted to maintain the natural pastures in altitude?". The mind map developed in the participatory process was showed, together with an explanation of the goals of the research and an example of how connections should be weighted. Then respondents were asked to draw the connections between the concepts that they considered relevant, identify if the connection was positive or negative (i.e. an increase of factor A determines an increase in factor B or vice versa), and assign a weight between 1(little importance) and 5 (very strong importance) to each connection. The questionnaires took between 1.5 and 2 h to be filled in.

Modelling: Each questionnaire corresponds to a fuzzy cognitive map and each was converted into a quantitative adjacency matrix in which the weights attributed by the interviewees were transformed into values varying between −1 and 1. Each FCM was processed independently and then the average values of the outputs were calculated. This approach was selected to attribute the same value to each individual questionnaire and to keep track of the different stakeholders' views (Forman and Peniwati, 1998). The model estimates the equilibrium values of the variables after several iterations (25, in this study). The equilibrium values give a relative indication of the relevance of the different factors in the current setting of the variables (i.e. business as usual). By 'forcing' different factors to a high level, the quasi-dynamic behaviour of the system and the impact of these factors can be inferred (van Velden et al., 2020). This approach allows to consider the range of direct and indirect connections between the concepts included in the network and therefore allows the building of different scenarios (Jetter and Kok, 2014). Network indices such as indegree (sum of weights of the connections affecting a factor), outdegree (sum of weights of the connections of a factor towards other factors) and centrality (sum of indegree and outdegree) were calculated for each questionnaire and then averaged. Network indices allow us to differentiate between transmitter variables (capable of influencing), receiver variables (influenced) and ordinary variables. They are defined by the cumulative strengths of connections either exiting (outdegree) or entering (indegree) the variable. The analysis was made using the FCModeler package in RStudio version 4.3.1 (Turney and Bachhofer, 2016).

Scenario building: Scenarios were developed to infer how different variables affect the system. In our study, we were mostly interested in understanding what mechanisms could increase the interest of farmers towards the utilization of upland pastures. The modelled scenarios were built based on the discussions from the participatory process. The three scenarios "CAP" (Common Agricultural Policy), "strategies", and "PDO" aimed to explore the possibility of maintaining the utilization of upland pastures by i) increasing the level of the current CAP payments (per head and per pasture area); ii) implementing a range of mechanisms suggested by the stakeholders; iii) supporting more the Serra da Estrela cheese PDO scheme; respectively.

3. Results

3.1. Defining the system

During the first two steps of this research (system definition and

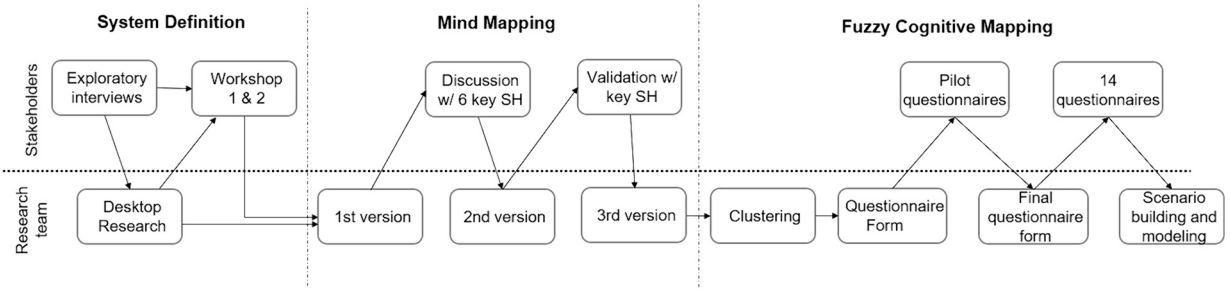

Fig. 1. Location of the Natural Park of Serra da Estrela (PNSE) and of the PDO cheese production area,. Top: hypsometry of the area. Bottom; Land cover and land cover changes based on CORINE Land Cover [90-18].

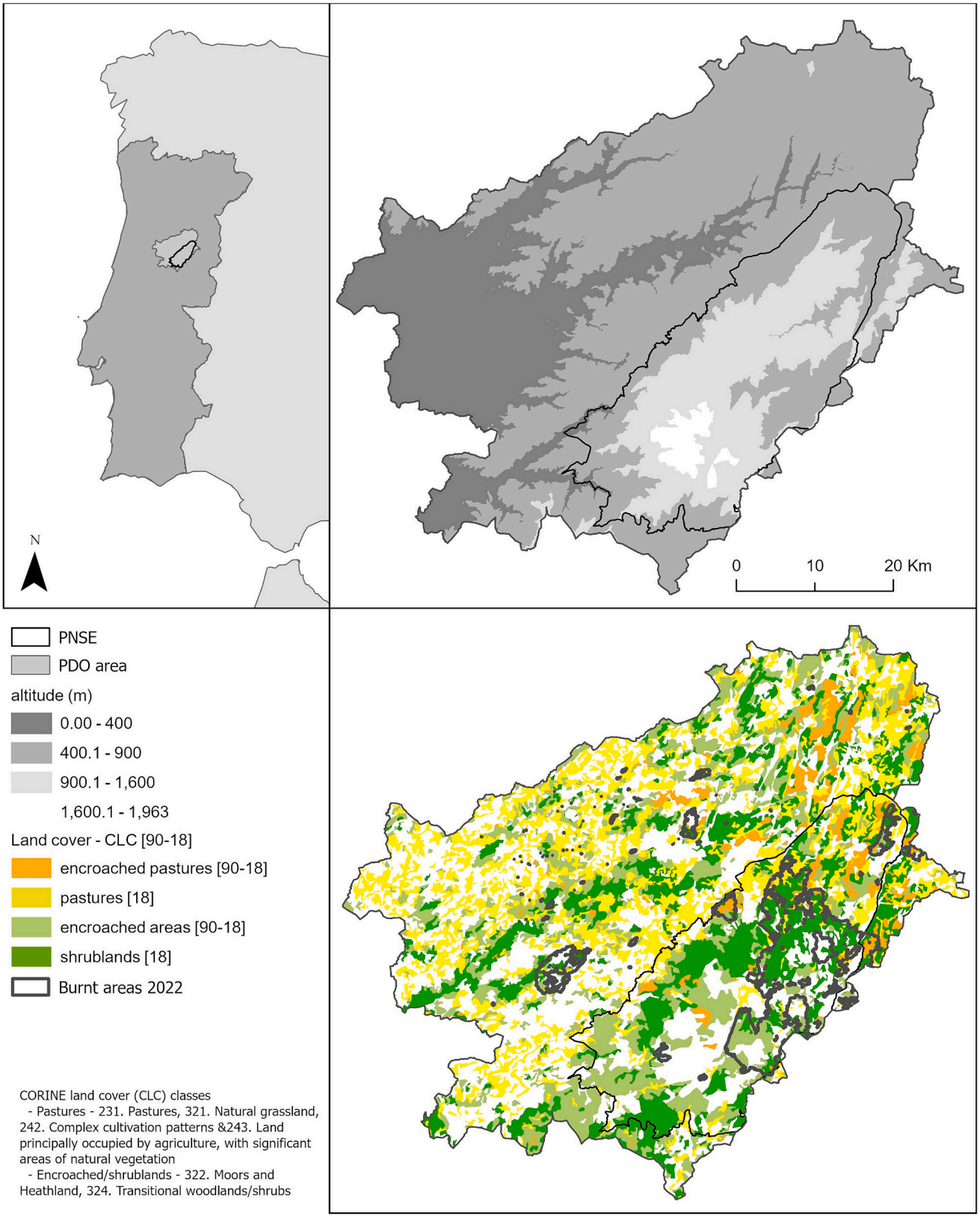

Fig. 2. Flowchart of the participatory construction of a Mind Map (MM) and Fuzzy Cognitive Mapping for altitude shepherding in Serra da Estrela. It shows the steps performed by the research team (bottom) and the steps made together with stakeholders. SH – stakeholder.

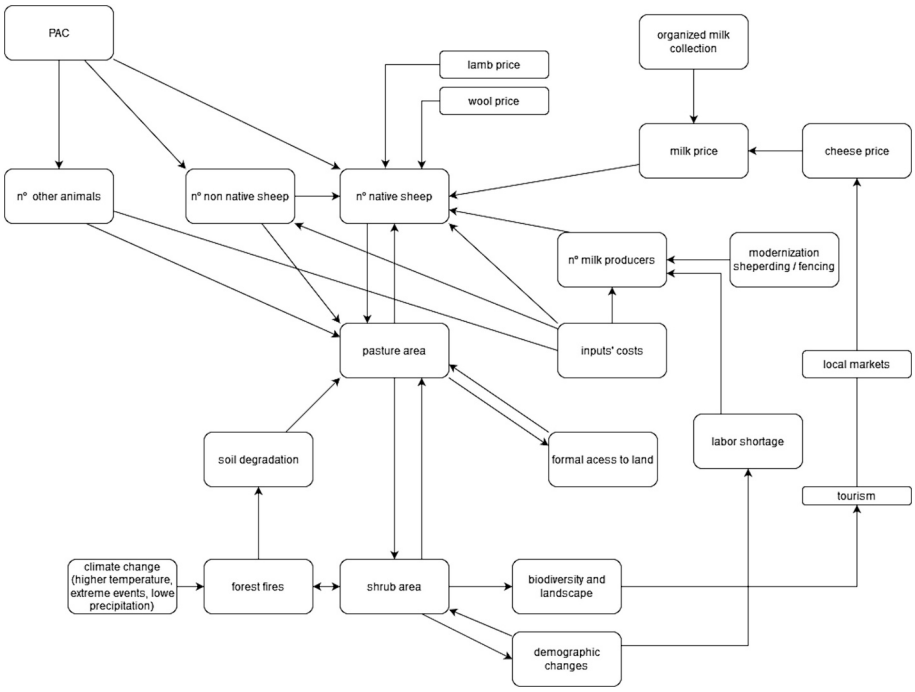

Fig. 3. 3rd and final version of the mind map of the pastoral system in Serra da Estrela. Key variables and connections were identified with and validated by stakeholders.

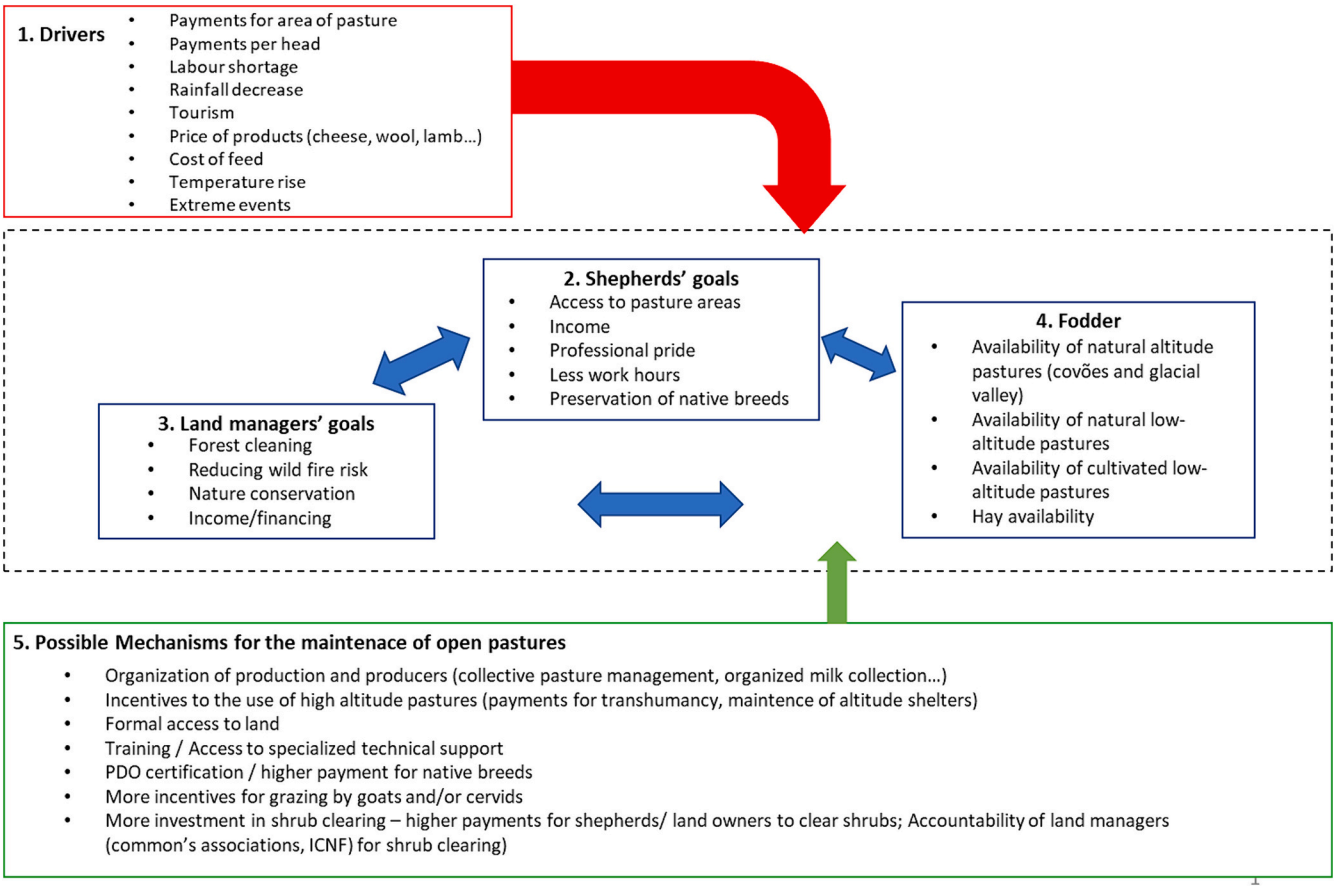

Fig. 4. Clustering of the identified variables into 4 clusters: 1- Drivers, 2 - Shepherd's Goals, 3. Land manager's goals; 4. Fodder & 5. Possible mechanisms for the maintenance of open pastures.

mind mapping), participants highlighted the loss of local knowledge, landscape degradation and abandonment of the mountain territory, and especially of altitude pastures, as relevant threats. Participants further expressed their concern for wildfire risk and fire hazards, depopulation, increasing temperatures and changes in precipitation patterns. Based on the information provided including relations between components of the system, the research team drew a mind map of the system that focuses on "altitude pastures", those located above 900 m. These altitude pastures are the key connector between the mountain landscape and the value chain of the local cheese (Fig. 3).

From the revision of scientific and gray literature we made, such a map of the system of drivers affecting the altitude pastures was never published before. It is a novel knowledge informative about the multiple factors to be considered when dealing withthe use of the altitude natural pastures. The system shows to be highly complex, and includes factors of biophysical nature, as soil erosion, fires and climate change, factors related with the market, with CAP payments, factors related with the organization of the production, and also related with the landscape, as shrub encroachment. In a more peripheric position there are factors like the demography and tourism pressures. The system in Fig. 3 shows, not only what is influencing the use of the natural pastures in altitude, but also how the different factors interact with each other.

The final mind map was clustered into 5 clusters which include 29 variables in total (Fig. 4). The concept of pasture area was split into different elements as it was a relevant factor to fully understand the pastoral system. Thus, in a later phase "pasture area" turned into three separate types of pasture: "altitude pasture" (above 900 m), "low altitude pastures (semi-natural)", and "low altitude pastures (sown)". 'Drivers' comprise external factors affecting the territorial system. Shepherds' goals and fodder resources are at the "core" of the system, together with land managers' goals, since often the stakeholders framed the interests of the commons and of the PNSE as antagonistic to the shepherds. Cluster 5 comprises a mix of already ongoing mechanisms, such as PDO, and of mechanisms suggested by the stakeholders in the participatory definition of the problem that could benefit the use of altitude pastures.

3.2. System functioning

Many variables score as transmitters, but with relatively low outdegree values meaning a low capacity of influencing the system. There are no clear drivers of the system, either internal or external. Instead, we have a reactive system, with seemingly little capacity for self-influencing. The number of fuzzy cognitive maps that considered each variable a transmitter and receiver is shown under #q transmitter and #q receiver, respectively in Table.

"Shepherds income" has the highest centrality and indegree value, meaning that it is dependent on many factors, and not exclusively on CAP policies or the market value of the shepherding products. In fact, the price of products, i.e. selling price of milk, wool and lamb, has little impact on the pastoral system, scoring a low outdegree value.

The high centrality of "fire risk" and "nature conservation" indicates there is a perceived connection between these and the pastoral system. Contrary, we see low outdegree scores for "formal access to land" and "labour shortage", concepts added by the stakeholders and held to great relevance during the first step of the study. The same happens for "tourism", which was often painted in the stakeholders' discourse as either an antagonist of pastoralism or on the contrary as the "next" main local activity. However, we find very little capacity to influence the system.

Out of the considered external drivers, clustered in 1-Drivers, it is the "temperature" that influences the system the most, followed by PAC payments – "support for the use of high-altitude pastures" and "support for shepherding".

3.3. Scenario analysis

For this analysis, we ran three different scenarios based on different mechanisms to understand their impact on the use of altitude pastures. Fig. 5 shows the percentage of change the run scenarios caused in the system, each compared with a no-change scenario. In Scenario 1 the variables *payment per head* and *payment per pasture* area were fixed to 1. These incentives caused little change to the system, affecting mainly cultivated lowland pastures, hay production and shepherds' income (% change 1.4, 1.3 and 1.2, respectively). Increasing the current PAC support to pastoral systems benefits the overall system, but does not contribute in a relevant way to the use of altitude pastures (<1 %).

In Scenario 2 we modelled mechanisms mentioned by the stakeholders as able to contribute to the use of altitude pastures. Out of the 7 mechanisms present in the cognitive map, we opted to focus on the top 3 with the highest outdegree score, i.e. those which have shown to have higher capacity to influence the system. These are i) support for shrub clearing, ii) organization of production and iii) support for the use of altitude pastures, see Table 1. Because the "PDO certification" is a mechanism already established, we opted to analyse it separately from the others in Scenario 3.

Scenario 2 also has a higher impact on low altitude pastures (4,17 % and 2.5 %) than in altitude pastures (2.3 %). However, it also contributes to the reduction of the risk of fire (4.94 %) and cleaning forests (3 %) as well as fewer worked hours (4.98 %). To understand the impact of each mechanism, we modelled them individually. Fig. 6 shows that each mechanism individually has little impact on the system. "Organization of the production" contributes to fewer worked hours and use of cultivated low altitude pastures, whereas "support for shrub clearing" and "support for the use of altitude pastures" mostly impact the reduction of fire risk.

In Scenario 3, "PDO certification" seems to be beneficial mainly to the preservation of native breeds and shepherds' income, but also low altitude pastures. However, it brought little changes to the mountain landscape.

Looking at the scenarios collectively (Fig. 5) we see that it is "Strategies" that can induce the most change to the system, and to the mountain landscape in particular through the use of altitude pastures, cleaning of forests and decreasing fire risk.

4. Discussion

Preserving altitude pastures is particularly important in fire prone mountain areas, where a mosaic landscape can contribute to reducing fire risk. This study examined the willingness to use altitude pastures in Serra da Estrela by analysing the role of the value chain of the Serra da Estrela PDO cheese, an important territorial asset historically connected to the mountain area. Following a participatory definition of the system, we found a complex and diffuse system dependent on many variables. Therefore, it is not surprising that action for preserving the use of these pastures is not an easy task and the right policy tools have not been set in place yet.

A key finding is that although the income of shepherds is a central issue, a higher margin alone does not seem to be enough to increase the use of altitude pastures. The results show that increasing CAP payments has little impact on the altitude pastoral system. This illustrates the insufficiency of current CAP schemes in addressing land abandonment, also in mountain landscapes, through the promotion of agricultural activities (Dolton-Thornton, 2021; Jiménez-Olivencia et al., 2021; MacDonald et al., 2000). Another used strategy to increase the competitiveness of extensive pastoral systems trying to aggregate value to the associated products through quality schemes such as Geographic Indication labels (Belletti and Marescotti, 2011; Cei et al., 2018). We found that the PDO label in Serra da Estrela cheese positively contributes to the preservation of native breeds and to the income of shepherds. However, despite the strict code of practice, there is no clear connection

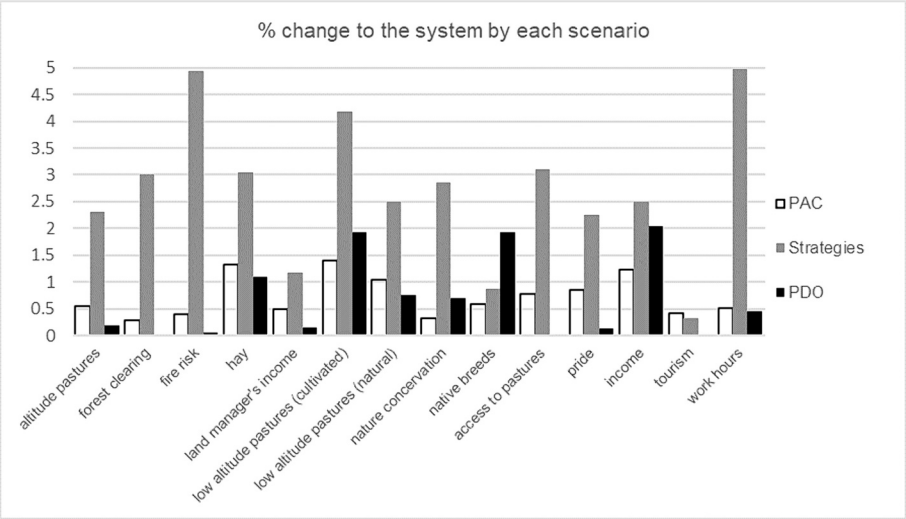

Fig. 5. Percentage of change induced by each of the scenarios when compared with a no-change scenario.

Table 1
List of variables organized in decrescent order according to their centrality. Transmitter variables have a zero indegree value. Receiver variables have a zero outdegree value. Variables with a non-zero indegree and outdegree, are "ordinary variables", and are not contemplated in this table. #q corresponds to the number of questionnaires that consider the variable as a transmitter or a receiver.

Variable		Centrality	Outdegree value	Indegree value	#q transmitter	#q receiver
Name	Abbreviation					
Shepherds income	shp_inc	10.429	1.071	9.357	0	7
Altitude pastures	altpast	7.457	1.643	5.814	0	2
Access to pastures	past	7.314	2.243	5.071	0	3
Low altitude pastures (natural)	lowpast_n	7.271	1.357	5.914	0	3
(decrease in) Fire risk	fire	7.057	0.629	6.429	0	9
Low altitude pastures (sown)	lowpast_c	6.729	1.086	5.643	0	4
Nature conservation	nat_con	6.429	0.500	5.929	0	11
Forest clearing	fclear	6.286	1.386	4.900	2	4
Hay	hay	5.914	0.929	4.986	0	6
Land manager's income	land_inc	5.629	0.486	5.143	0	8
Support to shrub clearing	s_clear	5.400	5.329	0.071	13	0
(maintenance of) native breeds	nativ	5.300	1.143	4.157	0	6
PDO certification	PDO	4.286	4.286	0.000	14	0
Organization of production	organ	4.229	4.229	0.000	14	0
(increase of) Temperature	temp	4.043	4.043	0.000	14	0
Support for the use of high-altitude pastures	s_alt_past	3.971	3.971	0.000	14	0
Support for shepherding	s_shp	3.843	3.786	0.057	13	0
(decrease of) precipitation	preci	3.800	3.800	0.000	14	0
Training	traing	3.800	3.743	0.057	12	0
Payment per head	PAC_head	3.600	3.600	0.000	14	0
(decrease of) Work hours	workh	3.600	0.586	3.014	0	9
Climate extreme events	extre	3.586	3.586	0.000	12	0
Labour shortage	labour	3.286	3.286	0.000	13	0
Payment per pasture area	PAC_past	3.257	3.257	0.000	14	0
Formal access to land	formal	2.814	2.814	0.000	12	0
Pride	pride	2.414	0.514	1.900	2	9
Product's price	price	2.114	2.043	0.071	12	0
Feed cost	fodder	1.814	1.814	0.000	12	0
Tourism	trsm	1.529	1.443	0.086	9	0

with the mountain area and production now tends to accumulate in the lowlands. Simply increasing shepherd's income whether through direct CAP payments or by valorising the final product seems inadequate in sustaining altitude pastures.

Other studies have found that income is not the main driver for abandoning mountain farming. Instead, values such as sense of place were more determining (Hinojosa et al., 2016). In Serra da Estrela, shepherds react more to non-monetary values, as the organization of production to reduce their working hours, the preservation of local breeds and strategic shrub clearing. Another example is providing appropriate shelter and other comforts for shepherds, to allow for transhumance more in agreement with current livelihood standards. This seemingly simple measure can be at odds with the conservation objectives of the Serra da Estrela Natural Park that refrains from approving building reconstructions within the park area. There are potential environmental damages due to overgrazing, yet extensive pastoral systems play a crucial role in maintaining a diverse landscape, fostering higher biodiversity (Navarro and Pereira, 2015), and reducing biomass and landscape continuity (Lecina-Diaz et al., 2023)—vital factors in promoting fire-resilient landscapes (Calheiros et al., 2022; Novara et al., 2011; Spadoni et al., 2023).

In other areas, payment for grazing services has worked in

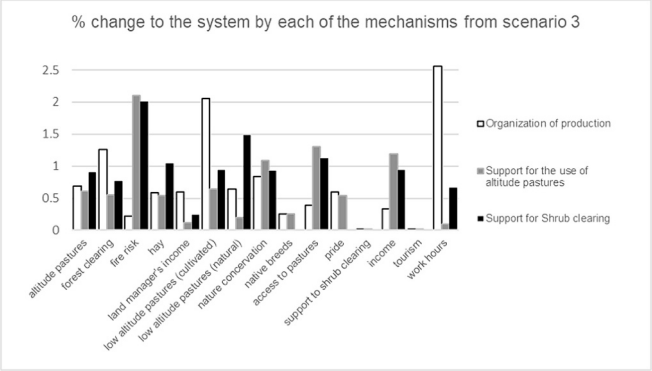

Fig. 6. Break down of how the three mechanisms modelled in Scenario 2.

maintaining desirable grazing pressure in target areas (Varela et al., 2018). Sustainable grazing might not be enough to control shrub populations alone, and even less in already encroached areas (Lasanta et al., 2024). Thus, a key aspect in ensuring the use of altitude pastures is shrub clearing in specific areas. Animals, alike people, need roads to move. Without being used or kept, paths encroach, further reducing connectivity and movement between pastoral areas. Strategic paths ought to be clear, directing herds to target land parcels of interest, in terms of nature conservation, landscape and fire risk reduction. The results of the FCM support that shepherds understand the intricate connection between pastoralism and conservation. Yet, policy frameworks and local governance are not taking advantage of these synergies, lacking integrated strategies that frame extensive pastoralism as a component and shaper of the landscape and not a threat. Similar to arguments made for other Mediterranean extensive systems, the preservation of open landscapes through extensive grazing needs conservation mechanisms that transcend case-specific solutions (Esgalhado et al., 2020). Instead, policy frameworks ought to acknowledge the value of these systems. Considering the political willingness to find and invest in nature-based solutions (European Commission, 2015), maintaining grazing in key areas seems like a cost-effective intervention to manage fire risk in mountain areas.

Using FCM it is possible to gather and model local knowledge, allowing for a level of understanding of a system's dynamics that would be hard to capture in other ways. However, it is a demanding process. Building a collective mind map is a slow and complex process, to have the right wording and be respectful of various perspectives. This approach allows for a picture in time, as peoples' perceptions and judgements can change over time. Further, the questionnaire is long, and requires capacity of abstraction and means that shepherds more comfortable with letters and numbers were favoured in relation to others, and limited the number of possible respondents.

5. Conclusions

The use of FCM made it possible to reveal the relative weight of the different drivers of use or non-use of altitude pastures and which ones are determinant to avoid or reverse processes of land abandonment in mountain areas. This study represents an advancement in understanding the intricate dynamics of mountain land abandonment, seen from the perspective of key stakeholders, the shepherds. These findings are likely applicable beyond the region in focus, and surely helpful to grasp similar processes in other Mediterranean regions of Europe.

The results show that the economic incentive appears to be less determinant than the proper support to shepherds in their activity, by the cleaning of mountain transhumance paths and organization of the production. Mountain topography presents a paradox regarding abandonment trends. On one hand, there is a cultural attachment and sense of belonging that motivates shepherds to persist in the mountain. Further, there is acknowledgement of the potential for altitude pastures under climate change. However, it is needed to overcome the challenges imposed by isolation and difficulties in establishing networks and cooperation structures across the territory.

This issues a clear message to policy makers at different scales: in order to keep altitude pastures open and therefore preserve the landscape and reduce risks of extreme fires, more attention needs to be given to the territorial dimension. FCM has also shown to be a detailed process which requires time and close contact with the local stakeholders and particularly the shepherds. But having a model which can show what will happen in different scenarios, is powerful in showing causal relationships that even the actors involved may not be aware off. Following this study, the awareness of the role of territorial stewardship will hopefully increase among the relevant policy actors, from the local to the national level.

Eventually, what this case shows is that it might be less difficult to revert land abandonment in altitude pastures, at least partially, than often it is considered. Efforts for local landscape stewardship and coordination in supporting pastoralism, seem to be the solution.

CRediT authorship contribution statement

Catarina Esgalhado: Writing – review & editing, Writing – original draft, Methodology, Investigation. **Teresa Pinto-Correia:** Writing – review & editing, Methodology, Investigation, Conceptualization. **Stefano Targetti:** Writing – review & editing, Methodology. **Claude Napoléone:** Writing – review & editing. **Maria Rivera:** Writing – review & editing.

Declaration of competing interest

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

Data availability

Data will be made available on request.

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