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RESEARCH ARTICLE

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Characterization and challenges of livestock farming in Mediterranean protected mountain areas (Sierra Nevada, Spain)

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Abstract

Aim of study: To characterize and analyse the extensive livestock farming systems in environmental protected area and propose strategies for their sustainable improvement.

Area of study: Sierra Nevada Protected Area (Spain).

Material and methods: Data were collected from a sample of 85 farmers and 48 experts. The information from farmers was expressed in 35 variables, 23 of which were qualitative and 12 quantitative. A multivariate analysis was conducted.

Main results: The principal components explained 71.2% of the total variance and the k-means cluster analysis identified three groups: C1 (38 farms), medium-size farms with a predominance of goats and relative dairy specialization; C2 (12 farms), large-size farms with extensive grazing lands, a high proportion of meat purpose animals and managed by young and dynamic farmers and C3 (35 farms), medium-size farms with a high proportion of meat purpose animals and undeveloped business management. The main problems reported were: insufficient pastures for livestock, stagnation of product prices, lack of generational renewal and need for social recognition of livestock farming. These obstacles could be overcome by implementing measures aimed at improving feed self-sufficiency -and thus reduce production costs- increasing income through social recognition of farming, achieving product differentiation, and strengthening short marketing channels. This would be favoured by an increase in associationism and specialized training.

Research highlights: Farm management and marketing are important for improve these farming systems. The extensive livestock farming continues to be an important activity in European protected mountain areas.

Additional key words: grazing systems, multivariate analysis, ruminant, national park.

Abbreviations used: CA (cluster analysis); EU (European Union); LU (livestock units); PCA (principal component analysis); SNPA (Sierra Nevada Protected Area).

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Introduction

In the protected natural areas of the Mediterranean basin, including the Spanish region of Andalusia, the coevolution of plants and animals has led to a wealth of landscapes and biodiversity (González-Rebollar & Ruiz-Mirazo, 2013). Extensive livestock systems are essential to maintain many environmentally valuable habitats for other species, as highlighted by Olea & Mateo-Tomás (2009). Extensive ruminant farming is also one of the main traditional economic activities in these protected natural areas. It provides employment and anchors the rural population.

However, in recent decades extensive farming has been abandoned in these protected areas, many of which are marginal (Cocca *et al.*, 2012). In Spain, Riedel *et al.* (2013) reported a decline in farming activity in a Natural Park located in NE Spain which resulted in technical changes in farm management and land use and reducing grazing periods. These changes can negatively affect the sustainability of such protected areas, not only economically and socially but from an environmental perspective too. In this sense, decreased grazing has degraded the environment through (i) loss of autochthonous breeds adapted to this feeding system (Hoffmann, 2011); (ii) shrub encroachment (Riedel *et al*., 2007; O'Rourke *et al.*, 2012); (iii) increase of wildfire hazards (Mena *et al.*, 2016); and (iv) significant changes in the composition and abundance of flora –biodiversity decreases with habitat homogenization (Blanco-Fontao *et al.*, 2011)– and loss of landscape heterogeneity (Newman *et al*., 2014). Thus, according to Riedel *et al.* (2013) further abandonment of farming and/or intensification should be prevented in these areas.

In Spain, around 13% of the area is protected by law under several landscape designations. Sierra Nevada Protected Area (hereinafter SNPA) in Andalusia is one of the protected mountain areas in Europe with the greatest biodiversity. Extensive livestock farming is a traditional activity in SNPA (MITECO, 2015) creating direct employment and enhancing the circular economy. It is also a fundamental pillar of the area's gastronomy and traditions and the presence of livestock attracts naturalist, gastronomic and photographic tourism. However, the autochthonous breeds and the farming systems in this protected area are in danger of disappearing (Horcada *et al.*, 2016). The main causes are the farms' low profitability, lack of generational renewal and insufficient differentiation of local products, whose high quality is not appreciated in the agri-food market. Mena *et al.* (2016) also reported that the accumulation of scrubland led to a greater risk of wildfires and Robles *et al.* (2016), in a study with transhumant livestock in SNPA, showed that non-grazing increased biomass but tended to decrease biodiversity, especially of small grasses.

In order to avoid the decline of extensive livestock farming, the European Union (EU) Common Agricultural Policy established several agri-environmental support programmes that focused on the more marginal and protected lands, such as mountain areas (Beaufoy & Marsden, 2011). However, these agri-environmental programmes have failed to maintain activity in the areas for which they were set up (Gardner *et al*., 2009), nor have they generated significant environmental improvement (Jones *et al.,* 2016). Different approaches are needed to describe the livestock production systems correctly on a local scale in order to propose alternatives or strategies to improve their management (Morgan-Davies *et al.,* 2014).

The purpose of this work was to characterize and analyse the extensive livestock farming systems in SNPA and propose strategies for improving them in a sustainable manner.

Material and methods

Study area

The study area is situated 37°20' – 36°56' latitude N and 3°35' – 2°40' longitude W, in the region of Andalusia (Spain), covering 172,238 ha (86,355 ha of Natural Park and 85,883 ha of National Park), at altitudes between 3,479 and 300 metres.

The climate is predominantly Mediterranean, although being a high mountain area it also has characteristics of a cold continental climate or Dsc according to the Köppen classification (Kottek *et al*., 2006). The SNPA contains 5 of the 6 bioclimatic belts existing in the Mediterranean region (MITECO, 2017).

The flora comprises more than 2,100 phanerogams with almost 65 endemic taxa. There are approximately 200 species of vertebrates (123 birds, 43 mammals, 20 reptiles, 7 amphibians and 6 fish) and over 15,000 species of invertebrates, 300 of which have been identified as endemic species. Such characteristics make SNPA a plant and animal diversity hotspot in the Mediterranean area (MITECO, 2015).

The area, approximately 60% of which is public property, enjoys several forms of environmental protection: Biosphere Reserve, Natural Park, National Park, Special Protection Area (SPA) of the EU Birds directive, and Site of Community Importance (SCI).

Different ruminant species are raised on the farms located in the SNPA: cattle, sheep and goats. The predominant sheep breed is *Segureña*, but it is crossed with *Castellana* and *Merina*. Goat breeds include *Murciano-Granadina* and *Malagueña* (both dairy breeds), generally crossed with *Blanca Andaluza* or *Celtibérica* (both meat purpose). Cattle crosses are common, although the *Pajuna* breed is frequent as well as other, more selected, non-autochthonous breeds such as *Limousin, Charolais* and *Avileña*. All three ruminant species are raised for meat but goats are also raised for milk or mixed-purpose production.

In SNPA animals normally graze natural pastures of herbaceous and shrub species. At the end of spring, animals usually move from the valleys up to the summits (1500-3000 metres) seeking natural pastures with a high ecological value (short transhumance). An example of these pastures in SNPA is the "Borreguiles". They are small (less than one hectare), humid, high mountain pastures associated with snowmelt. The wide herbaceous diversity hosts many endemic and unique species. They are rich in organic matter, increasing soil fertility (Robles *et al*., 2016). In autumn the animals go down to the valleys (500-1000 m) where they spend winter and spring. Although feeding management is based on grazing, most of the animals receive a daily supplement of concentrate feed during lactation. The animals graze on both private and public land owned by the municipality or the SNPA itself.

Selection of farms, data collection and multivariate analysis

Data were collected in 2013 from a sample of 85 farms representing approximately 23% of the farms in the socioeconomic catchment area of SNPA. They were chosen randomly for the sample, based on the official census of livestock farms (CAPMA, 2012).

A questionnaire was designed for farmers to answer through personal interviews conducted on site. The questions were grouped in the following categories: Farmer and farm data, Farmer's activities, Land for livestock, Herd characteristics, Reproduction management, Feeding management and Farm trends (the complete questionnaire is included in Table S1 [suppl]).

The questionnaire provided 35 variables. There were 23 qualitative variables, with 2 options (18 variables), 3 options (4 variables) and 4 options (1 variable), and 12 quantitative variables. The qualitative variables were expressed as percentages and each option was converted into binary (0, 1).

A two-step multivariate analysis was conducted: a principal component analysis (PCA) and a cluster analysis (CA) (Hair *et al.*, 1998). The purpose of the PCA was to reduce the number of variables and thus the dimensions of the problem (Lesschen *et al.*, 2005; Ruiz *et al.*, 2008). Since the variables in this study were qualitative and quantitative, an optimal scaling analysis was used as PCA (Hair *et al.*, 1998; Madry *et al.*, 2013).

Before performing the multivariate analysis, the number of variables was reduced and those with a low coefficient of variation (< 50%) were excluded because of their low discriminatory capacity (Hair *et al.*, 1998). The correlated variables were also excluded as the authors considered them to be more important for defining the production system (Lesschen *et al.*, 2005). Of the 35 variables used in the study, 26 were discarded. The first 3 were eliminated because they had a low coefficient of variation (Farmer's age, Continuous grazing and Supplementing with concentrates) and the other 23 were eliminated because they were correlated with the most important variables. The remaining 9 were: Production purpose, Predominant animal species, Hay supplementation, Total land area, Public land, Transhumance, Number of livestock units (LU), Cropland and Farmer's occupation. In order for the Principal Components (PCs) to be sufficiently representative of the set of variables, eigenvalues had to be greater than 1 (Ruiz *et al.*, 2008).

At first, the optimal scaling analysis was carried out with the 9 variables that remained after the reduction process but two were discarded (Farmer's occupation and Cropland) because they introduced "noise" in the estimation of the parameters linked to the most interesting variables for the study, and once they disappeared, the goodness of fit increased. PCs were obtained by discriminating and explaining the maximum variance following the criterion of eigenvalues being greater than one (Hair *et al.*, 1998).

After the PCA, the farms were classified by k-means CA according to the PCs obtained (Hair *et al.*, 1998; Lesschen *et al.*, 2005; Castel *et al.*, 2011). The authors were very well acquainted with this livestock system and considered that the k-means CA was more suitable than the hierarchical analysis (Madry *et al.*, 2013), which was also conducted but the results have not been included. The hierarchical analysis confirmed the result of the k-means.

Once the different clusters were obtained, they could be described and then compared using one-way ANOVA for each of the original quantitative variables. With this process the multivariate analysis was confirmed (Madry *et al.,* 2013). For each qualitative variable (binary), a Chi-square test was performed. A Student's T test was done to determine the direction of the dependency relationships with the clusters and to obtain the standard errors. When the qualitative variables had more than two options, each option was transformed into binary (0, 1) and the Student's T test was conducted.

In relation to the post hoc analysis, for the quantitative variables the Least Significant Difference, Bonferroni and Tukey tests were performed when variances were homogeneous. If they were not homogeneous the Tanhane and Games-Howell T2 tests were performed. All statistical analyses were carried out with the IBM SPSS Statistics 20 statistical package, Chicago.

Prioritization of problems and development of improvement strategies

In the first phase, a group of 10 experts (technicians, farmers and managers from the protected area) drew up a list of problems and potential solutions related to the existing livestock systems in Sierra Nevada. In the second phase, four working groups were organized, one for each agricultural region in SNPA, with 43 prominent livestock farmers and 48 experts (technicians, veterinarians, agricultural and forestry engineers, etc.), both from SNPA. Four 5-hour sessions were organized where the situation of livestock farming in SNPA was presented describing the main problems identified and possible solutions. Later, these working groups classified the five main problems and corresponding solutions which could be scored on a scale from 1 to 6 (1, very important; 6, unimportant). The objective was to prioritize problems and solutions.

Results

Results obtained from the principal component analysis

Three PCs were obtained from the optimal scaling analysis. PC1 was named *Farm size* and included Total land area, Public land and Number of LU (livestock units); PC2 was named *Productive orientation* and included Production purpose and Predominant animal species; and PC3 was named *Feeding management* and included Hay supplementation and Transhumance. The weight (eigenvectors) of each of the three PCs is shown in Table 1. The proportion of explained variance for each PC is also shown in Table 1; the total explained variance is 71.2%.

Retained clusters and identified livestock farming systems

The k-means cluster analysis provided three groups with perfectly distanced centroids, grouping farms with clear common characteristics in each cluster (Fig. 1). The descriptive characteristics of the main variables are presented in Tables 2-3, together with the results obtained in each of the clusters.

Table 1. Principal component analysis. Eigenvalues, eigenvectors and proportion of explained variance for each dimension, obtained from the optimal scaling analysis

	Dimension		
	1 **Farm size**	**2** **Production orientation**	**3** **Feeding management**
Eigenvalues			
Production purpose	-0.563	**0.759**	-0.061
Predominant animal species	-0.584	**0.742**	0.095
Hay supplementation	-0.285	-0.150	**0.638**
Total land area	**0.782**	0.341	0.280
Public land	**0.672**	0.451	0.375
Transhumance	-0.246	-0.196	**0.694**
Number of LU	**0.588**	0.341	-0.166
Eigenvectors of the PCs	2.209	1.623	1.148
Proportion of variance (%)	31.6	23.2	6.4

LU: livestock units. PCs: principal components. Eigenvalues in bold correspond to the variables assigned to each principal component.

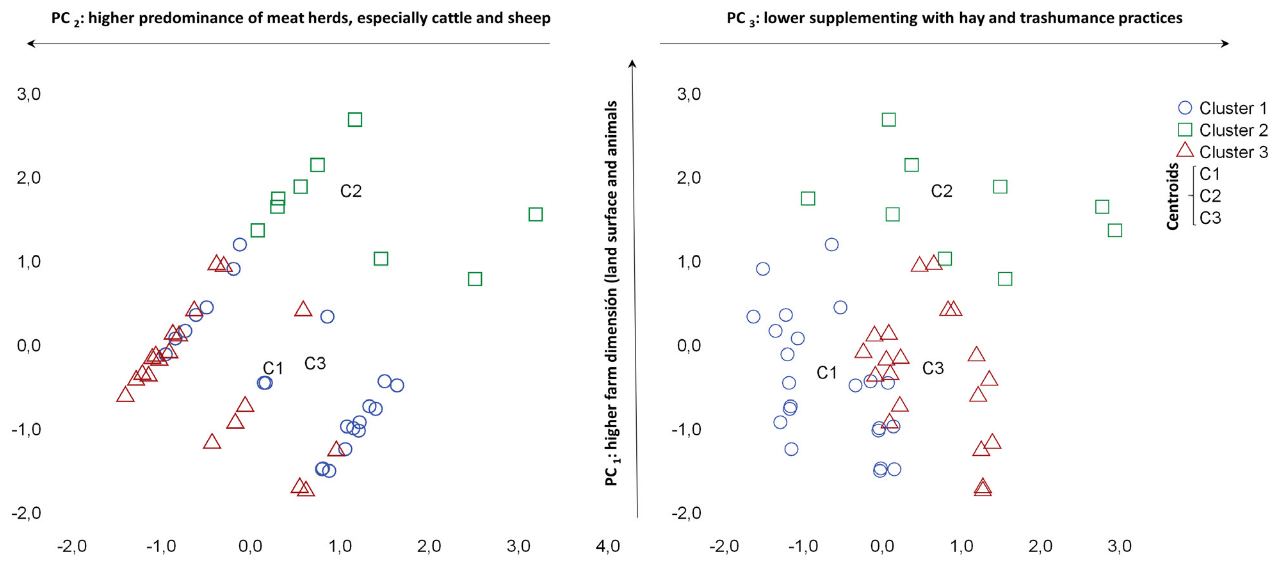

Figure 1. Clustered farms plotted according to the principal components 1-2 and 1-3 and centroids.

Table 2. Land and herd variables (means and standard error).

Variables	Total (n = 85)	Cluster 1 (n = 38)	Cluster 2 (n = 12)	Cluster 3 (n = 35)
Total land for livestock (ha) ***	429 ± 65.0	226 ± 40.0 [b]	1,541 ± 215.7[a]	268 ± 61.1[b]
Farmer's own land (ha)	58 ± 25.1	27 ± 12.1	17 ± 9.1	104 ± 59.2
Proportion of own land (%) *	18 ± 3.3	17 ± 4.4[ab]	2 ± 1.0[b]	25 ± 6.2[a]
Rented land (ha) **	123 ± 33.8	108 ± 34.1[b]	379 ± 199.4[a]	50 ± 15.3[b]
Public land (ha) ***	249 ± 53.1	90 ± 19.3[b]	1,145 ± 242.9[a]	113 ± 22.6[b]
Cropland (ha)	5 ± 1.0	4 ± 1.2	7 ± 5.0	4 ± 1.1
Cropland for cereals (%)	33 ± 5.1	42 ± 8.1	25 ± 13.1	26 ± 7.5
Cropland for grazing (%)	28 ± 5.0	24 ± 7.0	25 ± 13.1	34 ± 8.1
Cropland for hay (%) **	21 ± 4.5	37 ± 8.0[a]	8 ± 8.0[b]	9 ± 4.8[b]
Use of stubble own or other (%)	16 ± 4.0	24 ± 7.0	8 ± 8.0	11 ± 5.5
Prevalent species (%)				
Cattle	34 ± 5.2	29 ± 7.5	50 ± 15.1	34 ± 8.1
Sheep	32 ± 5.1	24 ± 7.0	25 ± 13.1	43 ± 8.5
Goats *	34 ± 5.2	47 ± 8.2[a]	25 ± 13.1[ab]	23 ± 7.2[b]
Only one species (%)				
Cattle	32 ± 5.1	26 ± 7.2	50 ± 15.1	31 ± 8.0
Sheep	15 ± 3.9	16 ± 6.0	8 ± 8.0	17 ± 6.5
Goats *	22 ± 4.5	37 ± 7.9[a]	8 ± 8.0[b]	11 ± 5.5[b]
Purpose (%)				
Meat ***	72 ± 4.9	53 ± 8.2[b]	83 ± 11.2[ab]	89 ± 5.5[a]
Dairy	9 ± 3.2	16 ± 6.0	8 ± 8.0	3 ± 2.9
Mixed *	19 ± 4.3	32 ± 7.6[a]	8[b] ± 8.0[b]	9 ± 4.8[b]
Farmer has changed breeds (%) **	11 ± 3.6	5 ± 3.7[b]	42 ± 14.9[a]	7 ± 4.8[b]
No. cattle (♀) ***	29 ± 5.8	22 ± 8.5[b]	85 ± 23.1[a]	17 ± 4.6[b]
No. sheep (♀)	131 ± 22.9	111 ± 34.6	171 ± 75.7	138 ± 32.7
No. goats (♀) *	110 ± 18.1	158 ± 30.8[a]	93 ± 49.1[ab]	64 ± 20.7[b]
Total LU (♀) ***	63 ± 5.5	60 ± 8.1[b]	122 ± 18.7[a]	46 ± 4.7[b]

[a, b]: Values with different letters on the same row were significantly different: *: p<0.05, **: p<0.01, *** p<0.001.

Livestock farming systems in the SNPA had some common characteristics which are described below. On average, farmers are fifty years old. Almost half of them work only with livestock and the rest also work in crop farming. The land used is mostly rented or public; 69% of the farms only raise one species and 72% of the farms work with meat-purpose breeds. Although cropland is limited (5 ha per farm on average), one third of the farmers usually grow cereals for sale. Around 80% of the farms have continuous grazing and a similar proportion use supplementation with concentrates. More than 80% of the farms sell animals to intermediaries and about 80% of the farms producing milk do not process it on the farm; 90% of the farmers are not members of a breed association.

Taking into account farm differences and according to the cluster analysis conducted, the groups have the following characteristics:

—C1. Medium-size farms with a predominance of goats and relative dairy specialization (38 farms). Cluster C1 is made up of medium-size farms, both in terms of number of head as well as in surface area, using rented and public land in similar proportions; 50% of farms raise animals for meat and the other 50% for milk, to a greater or lesser extent; 79% of farms raise only one livestock species, goat in 37% of the cases, meaning a significant workload for the farmer (daily milking is required) and more investment in facilities. Most farms practise short transhumance. A large proportion of farmers (68%) use hay supplementation, produced on the farm in one third of the cases, illustrating the importance given to feed self-suficiency. Most parturitions take place in spring-summer; 75% of farmers intend to continue their farming activity.

—C2. Large-size farms with extensive grazing lands, a high proportion of meat purpose animals and run by young and dynamic farmers (12 farms). Cluster C2 is made up of large-size farms, in terms of number of head and surface area, and they mainly use public lands. Most farms raise animals for meat and in 66% of cases they raise one species, mainly cattle, and 8% of the farms work only with goats. The majority of farms practise short transhumance but a third of them practise long-transhumance. Most farms supplement with externally-sourced hay. Parturitions take place mainly in winter. Farmers' average age is 40 years, and

Table 3. Management, sociological, marketing and farm trend variables means and standard error)**.**

Variables	total (n= 85)	cluster 1 (n = 38)	cluster 2 (n = 12)	cluster 3 (n = 35)
Stocking rate (LU ha^-1)*	0.6 ± 0.10)	0.8 ± 0.19[a]	0.1 ± 0.03[b]	0.5 ± 0.13[ab]
Continuous grazing (%)	84 ± 4.1	78 ± 7.0	83 ± 11.2	91 ± 4.9
Hay supplementation (%) ***	45 ± 5.4	68 ± 7.6[a]	58 ± 14.9[a]	14 ± 6.0[b]
Concentrates supplementation (%)	84 ± 4.0	84 ± 6.0	67 ± 14.2	89 ± 5.5
Transhumance long or short) (%) ***	68 ± 5.1	89 ± 5.0[a]	83 ± 11.2[a]	40 ± 8.4[b]
Long transhumance (%) **	9 ± 3.2	8 ± 4.4[b]	33 ± 14.2[a]	3 ± 2.9[b]
Short transhumance (%) ***	64 ± 5.3	87 ± 5.6[a]	58 ± 14.9[ab]	40 ± 8.4[b]
Continuous mating (%) **	70 ± 5.0	55 ± 8.2[b]	67 ± 14.2[ab]	88 ± 5.6[a]
Parturitions (%)				
Spring-Summer	48 ± 5.8	49 ± 8.6	22 ± 14.7	55 ± 9.1
Autumn	29 ± 5.3	29 ± 7.7	22 ± 14.7	32 ± 8.5
Winter *	23 ± 4.9	23 ± 7.2[ab]	56 ± 17.6[a]	13 ± 6.1[b]
Age of farmer (years) *	48 ± 1.2	49 ± 1.6[a]	40 ± 2.6[b]	50 ± 1.9[a]
Farmer's occupation (%)				
Only livestock	46 ± 5.4	45 ± 8.2	42 ± 14.9	49 ± 8.6
Crop farming	38 ± 5.3	42 ± 8.1	33 ± 14.2	34 ± 8.1
Construction	6 ± 2.6	8 ± 4.4	8 ± 8.0	3 ± 2.9
Other	15 ± 3.9	8 ± 4.4	33 ± 14.2	17 ± 6.5
Animals sold directly to abattoir (%) [1]	10 ± 3.5	14 ± 5.8	18 ± 12.2	3 ± 3.0
Milk to make craft cheese (%) [2]	21 ± 8.5	17 ± 9.0	50 ± 50.0	25 ± 25.0
Farmers belong to a breeders' association (%)	10 ± 3.2	5 ± 3.7	17 ± 11.2	12 ± 5.6
Changes in facilities (%)	24 ± 4.8	26 ± 7.2	25 ± 13.1	21 ± 7.7
Farm will continue (%) *	68 ± 5.5	75 ± 7.3[ab]	92 ± 8.3[a]	48 ± 10.2[b]

[1] The other farmers sell the animals through intermediaries. There is no cooperative or association to sell animals. [2] Only for dairy purpose farms. The variable "Farmers fatten their weaned calves (%)" is not placed on the table because only one farmer from C2 answered affirmatively. [a, b] Values with different letters on the same row were significantly different: *: p<0.05, **: p<0.01, *** p<0.001.

for this reason this is the most dynamic and entrepreneurial group. The farmers surveyed have changed animal genetics and most of them intend to continue farming.

—C3. Medium-size farms with a high proportion of meat purpose animals and undeveloped business management (35 farms). Cluster C3 is made up of medium-size farms, in terms of number of head and surface area, and mainly use public lands. Although the proportion of lands owned by farmers is not high, it is much greater than in other groups (25%), favouring grazing on the farm. Only 50% practise short transhumance and no farmers practise long transhumance. Most farms raise animals for meat; 59% of the farms raise only one species meat-purpose sheep are the predominant species (goats make up 11%). Hay supplementation is used by only 14% of the farms in this group, and hay is sourced externally. Most parturitions take place in spring and summer. Only 50% of the farmers intend to continue with their activity, mainly because the the demand for lamb is scarce and poses serious marketing challenges. Moreover, the farmers in this group are more traditional and are unable or unwilling to modernize their farms.

Prioritization of problems and development of improvement strategies

The results of the assessment made by the leading farmers and experts of the most important problems for the farms in SNPA and their solutions are presented in Table 4. The most noteworthy problem is related to the low prices for meat and milk. It is considered to be one of the underlying causes of the farms' lack of profitability. This is one reason why fewer young people wish to undertake livestock farming in the protected area (second most important problem). The third most important problem is the lack of social recognition of livestock farming. All three problems refer to socioeconomic aspects of farming in SNPA. The other two challenges are more directly related to livestock management in a protected area: lack of available pastures for livestock and restrictions of use.

As for the solutions proposed, the first two are directly related to improving profitability: product revalorization and differentiation and involvement in associations to strengthen marketing efforts. Availability of pastures and improvement of infrastructures (roads, facilities, water sources) are considered third in order of priority because they are related to the management

Table 4. Prioritization of problems and solutions by 43 livestock farmers and 48 experts in Sierra Nevada Protected Area (mean values).

Problems	Value[1]
Stagnation in sales prices for products meat and milk)	1.7
Young people do not want to become livestock farmers	2.8
Scarce social recognition of livestock farmers	3.1
Lack of pastures for livestock	3.5
Restrictions of the National Park	3.8
Solutions proposed	
Added value or differentiation of animal products from the National Park	2.3
Encourage involvement in associations in the livestock farming sector	3.1
Improve availability of pastures and infrastructures	3.2
Improve advisory services and specific training in the sector	3.5
Increase social recognition of extensive livestock farmers	4.1

[1] Range 1-6 in decreasing order of importance.

of the protected area. The fourth challenge is to improve technical advisory services related to grazing livestock management, such as specific training for farmers in pasture improvement, product processing, and marketing. The fifth priority is better social recognition for farmers, which can be achieved by disseminating information about the key role played by pastoral farming in the provision of ecosystem services.

Discussion

The discussion is structured in two sections. The first section presents the main technical and socioeconomic aspects of the farms studied and the second proposes some improvement strategies.

Technical and socioeconomic aspects of the farms

Herd characteristics

In general, livestock diversity has positive complementary effects on the use of resources, economic sustainability and biodiversity, as reported in other mountain areas of Europe (Bernués *et al.*, 2011; Rosa *et al.*, 2012; Zabel, 2019). In the present study, only 32% of the farms raise more than one species, perhaps because farmers own only small areas of land and tend to seek some degree of specialization to facilitate animal husbandry. The proportion of farms with two species reaches 40% only in C3, where livestock management is extensive and farmers own larger areas of land. In all 3 groups more than 25% of the farmers raise only cattle (50% in C2) and 37% raise only goats in C1. The proportion of farmers that raise only sheep is below 20% in all groups. This may be because in recent decades, meat sheep farming in Spain has moved from the mountain areas to the plains of the lowlands where production systems are intensified (García-Martínez *et al.*, 2009; Bernués *et al.,* 2011). However, in some mountain areas sheep are still a predominant species because they are adapted to the pastures (Salcedo & García-Trujillo, 2006; Martini *et al.*, 2014; Ruiz *et al.*, 2016). In C1, goats are the predominant species, and are generally milked, although the production system is more extensive than in other Spanish mountain areas where goats are clearly dairy purpose animals (Castel *et al.*, 2011; Mena *et al.*, 2017). As stated in the methodology, the study farm breeds are not autochthonous, but they are well adapted to grazing. In general, animals are crosses between different breeds.

In the last decades, more productive breeds have been introduced in 11% of the study farms for crossbreeding. This proportion is highest in C2 (42%). The main breeds that have been introduced are *Murciano-Granadina* goats and *Charolais* or *Limousin* cattle.

Regarding herd size, the average number of LU in the study area was similar to the conventional flocks of sheep and herds of goats in southern Spain (Mena *et al.*, 2016), the organic sheep flocks in southern Spain (Ruiz *et al.,* 2016) and the sheep flocks in the Pyrenees (northern Spain) (Bernués *et al.*, 2005). Other countries have a wide range of flock sizes, for example, in France between 28 and 192 LU (Peglion *et al.*, 2016). In the Pyrenees (northen Spain) cattle herds are even larger (between 70 and 280 LU farm^-1) (Bernués *et al.*, 2005), as is the case with some herds of the *Avileña* cattle breed in the central part of Spain (between 91 and 171 LU farm^-1) (Martin-Collado *et al.*, 2014). Likewise, the mixed herds of sheep and cattle studied by Gaspar *et al.* (2008) in open woodland agroecosystems of southeastern Spain (*Dehesas*) are large (159 LU).

Goats are the predominant species in C1, although in many farms there are also cattle and sheep. The mean herd size (60 LU) is slightly higher than in other mountain areas of southeastern Spain (Castel *et al*., 2011; Gaspar *et al*., 2011) and Greece (Arsenos *et al*., 2014). However, in the French mountain areas of the Rhône Alps and Midi-Pyrenees regions (southern France) the goat herds are smaller (less than 20 LU $farm^{-1}$) (Guinamard, 2015). This is because the production of *fermier* cheese is common in these areas and generates high added value.

Reproduction management

Concerning reproduction management, 70% of farms practise continuous mating, therefore parturitions are predominantly concentrated in spring-summer in sheep and goat farms (C3 and C1 respectively) and in winter where cattle are predominant (C2). Continuous mating is practised in 88% of farms in C3, 67% in C2 and 55% in C1. In other parts of Spain, the same reproductive management is practised; for example, in the *Dehesa* areas with cattle and sheep (Milán *et al*., 2006). However, in the Pyrenees (northern Spain) this only takes place in 8% of sheep farms (Riedel *et al*., 2007).

Goats are the predominant species in C1 where the proportion of farms practising continuous mating is the lowest of the study (55%). However, this is high in comparison to the goat farms of other Spanish mountain zones where animals are specialized in milk production and kid towards the end of the autumn and have a longer milking period than the goats in this study (e.g. Castel *et al*., 2011).

Feeding management and grazing

Grazing is continuous in 84% of the herds and in general the stocking rate is average (0.6 LU ha^{-1}), although it is lower in C2 (0.1 LU ha^{-1}). The extensive sheep systems of the Pyrenees mountains (northern Spain) (Bernués *et al*., 2005) and southern Spain (Salcedo & García-Trujillo, 2006; Ruiz *et al*., 2016) have a stocking rate similar to the study area average. In Spanish cattle herds, the average stocking rate is around 0.3 LU ha^{-1} (Milan *et al.,* 2006; Martín-Collado *et al.,* 2014). In dairy goat systems of Spain, France and Italy, the stocking rate ranges from 0.1 to 0.3 LU ha^{-1} (Ruiz *et al*., 2009).

Due to the general intensification taking place in the livestock mountain systems in Europe (Battaglini *et al*., 2014), there has been a reduction in grazing and therefore on-farm natural resources are partially substituted by off-farm inputs. In the study farms, some concentrate is generally supplied in the lactation periods (84%). Hay is supplied when grass is scarce, namely in C1 and C2 during the non-transhumance period when herds stay on the farmer's own land (only 20 ha). In C3, with 104 ha of own land, hay is supplied by no more than 14% of the farms.

As in other grazing livestock areas of Spain (Mena *et al.,* 2016; Ruiz *et al.,* 2016), there is little cropland for animal feed (5 ha on average). The situation is the same in France where the cropland available for mountain livestock farming systems is between 3.5 and 8 ha (Peglion *et al*., 2016). Only a third of the farmers grow cereals to be sold and an even smaller proportion of farmers grow crops for forage or hay (28% and 21% respectively).

Short-transhumance is an important feeding resource in all groups, as in other mountain livestock systems, for instance in the mountainous areas of northern Italy (Cornale *et al*., 2014) or in dairy sheep farms in the Pyrenees (O'Rourke *et al*., 2016), where short transhumance is practised. In addition, some traditional Spanish livestock farms, especially in the mountain areas, still practise long transhumance (Olea & Mateo-Tomás, 2009; Bernués *et al*., 2011), although this has been decreasing gradually in recent decades as in other areas of Europe (Galanopoulos *et al*., 2011; Daugstad *et al*., 2014, Starrs, 2016). The environmental benefits of this practice are also noteworthy; transhumance allows lowland pastures to rest during the summer, favours biodiversity and reduces shrub encroachment.

However, not all groups can practise it or obtain the same benefits. Transhumance can be beneficial for the meat-purpose farms in C1 (50%) and for almost all the meat-purpose farms in C2 and C3. Nevertheless, in C3, where farmers' own land covers the largest area, transhumance is less important than in the other groups; in C2, where cattle is predominant and farmers are younger, long transhumance is relatively important. Regarding to the dairy farms in C1, they are better adapted to short transhumance, and reproduction should be programmed to keep milking requirements to a minimum in summer when the animals have to move to high mountain areas where milking infrastructures are not available.

Socioeconomic aspects

The main activity of the study farmers is livestock farming, and in almost half of the cases is the only activity. Crop farming is also important and other activities complement the family income, especially in group C2 (33% of cases), which includes the youngest farmers. However, these other activities could pose a threat and a loss of commitment from the farmers, who could eventually abandon the farm (Bernués *et al*., 2005).

Concerning the marketing of farm products, the animals in the study farms are always sold after weaning, except in only one case in C2, in which the calves are fattened on the farm. In almost all farms, animals are sold to intermediaries, especially in C3, as there are no cooperatives or associations to market the animals. This is common practice in many parts of Spain (Bernués *et al*., 2011).

As for milk production, in C1 many goat herds are milked and 17% of farmers with dairy purpose goat herds use the milk to make craft cheeses; this is a small proportion, but it should be taken into account that the majority of Spanish goat farmers sell whole raw milk to the commercial cheese industry instead of producing cheese themselves (Castel *et al*., 2010), unlike in other countries such as France where 20% of goat milk is used on the farm to make cheese (Idele, 2018).

The average age of farmers in *Sierra Nevada* is 48, slightly above that observed by Ruiz *et al*. (2011) for dairy goat and meat sheep farmers in Spain and by Martin-Collado *et al.* (2014) for extensive beef cattle farmers, and similar to the ages reported by Arsenos *et al*. (2014) in traditional goat farms in Greece or as reported by Riedel *et al*. (2007) for meat sheep farmers in Spain. The youngest farmers are in C2, where cattle are the predominant species, and most farmers share the view that the farm will continue in the future (92%). This perception is also strong in C1 (75%), where goats are predominant but less so in C3 (48%). The case of C3 is probably due to the relative predominance of sheep in this group (the number of cattle and goats is low); in the extensive sheep flocks of the protected area of Sierra de Guara (northern Spain), farm continuity is also a challenge (Riedel *et al*., 2007). Many meat-sheep systems in the Mediterranean are not economically profitable and face a very uncertain future with a high risk of further marginalization (Bernués *et al*., 2011). The lack of continuity of the farms is usually associated with low investment (Riedel *et al*., 2007) and the farmers in this study are reluctant to invest. Only 24% of the farmers have made changes in their facilities in the last decades. This is probably because most of the land used by livestock farmers in SNPA is rented or public.

Strategies for the improvement of systems

Based on the characterization of the sector and considering the problems and solutions prioritized by farmers and experts, strategies and actions were presented to improve livestock farming in SNPA.

The constant price crises for products of animal origin is a common problem in Europe (Crescimanno *et al.,* 2014; Pulina *et al*., 2018). Often the farmers are unable to cover the production costs with the sale of meat products and/or milk. This lack of profitability has a negative effect on generational replacement (Góngora *et al*., 2019). The solutions put forward by farmers and experts have been to diversify the products and to increase farmers' involvement in associations.

There is an increase in demand for craft goat cheeses (Raynal-Ljutovac *et al*., 2011; Ruiz *et al*., 2019) and there is also potential to set up new cheese-making facilities adapted to small-scale farming operations (FACE Net-work, 2017) through aids from the EU common agricultural policy. Thus, for dairy goat farms (mainly present in Cluster 1), the proposal is to increase local cheese-making and improve the marketing channels, preferably through a quality guarantee label and to create an association or cooperative. This marketing option is particularly interesting in this protected area as it is situated near highly populated towns and cities and two tourist areas, one on the Mediterranean coast and the other in *Sierra Nevada*, which is busy in the skiing season (López-i-Gelats *et al*., 2015; Alderighi *et al*., 2016; Martin & Ferreira, 2017).

For beef cattle farmers (predominant in Cluster 2), one of the first considerations for diversification is to improve the autochthonous *Pajuna* breed in the protected area. The meat quality of this breed has already been evaluated (Horcada-Ibañez *et al.,* 2016) and there is growing demand for it in the SNPA catchment area (MITECO, 2019). There is also a quality symbol for the breed (*Marca Raza Autóctona*) supported by Spain's Ministry of Agriculture, to protect and promote animal products from these breeds and can be used to market *Pajuna* meat (MAPAMA, 2018).

Escribano *et al*. (2016) proposed an improvement of the productivity and economic performance of the farms in the 'dehesa' (SW Spain and Portugal) by adding value to the products sold, *i.e.* finishing more calves, developing new products and/or participating in marketing efforts. Finishing calves is an interesting option but more difficult to carry out in the SNPA, since both the quality and quantity of the pastures available for cattle is lower than the 'dehesa' pastures.

The greatest challenge, as in other European mountain areas, is the dispersal and size of the sector (Battaglini *et al*., 2014; O'Rourke *et al*., 2016), which makes it difficult to complete the whole value chain (rearing, slaughter and marketing), and the only option is to encourage farmers to form associations.

In all three clusters, collaboration among livestock and arable farmers in the area has been proposed to increase local hay production and thus increase farms' feed self-sufficiency. Taking into account the limitations for growing crops in the mountain areas (Ruiz *et al.*, 2009), it may be more feasible to draw up collective agreements with local farmers to supply reasonably priced forage (Sulc & Franzluebbers, 2014). This collaboration could also encourage grazing on cropland, mainly olive groves (García Fuentes *et al.*, 2015), provided that it is controlled and causes no damage. This is especially interesting for sheep farmers, mainly present in Group 3, since sheep are better accepted by farmers who fear damage caused by livestock, especially goats.

In order for livestock farming to be sustainable and beneficial for the ecosystem, it is necessary to determine optimal stocking rates and grazing periods for managing these diverse rangelands. For farmers in Clusters 1 and 3, with medium-size herds and higher stocking rates, the lack of pastures to feed livestock is a big challenge. In these cases it would be important to improve availability of pastures and infrastructure, to avoid overgrazing in some areas (especially if the size of the herd increases to be more competitive) as well as the underutilization of areas less accessible or less adapted for livestock. Drinking points, shelters or fences may be beneficial and should be supported by the protected area management team. A strategy to overcome the lack of pastures is to manage reproduction so as to adapt the animals' greatest nutritional requirements to the season when most natural pasture is available (Castel *et al.*, 2011; Mena *et al.*, 2016). This involves control of the mating periods, especially in C3.

Short transhumance, even long transhumance in some cases, as well as mobile grazing are one of the best ways to use natural resources and manage the landscape (Manzano-Baena & Salgado-Herrera, 2018), is but, as observed by Daugstad *et al.* (2014), these practices are in decline. Aware of its importance, in some regions in Spain the local government has supported transhumance through economic support and regulation to overcome excessive burocracy (Junta Extremadura, 2017), an interesting idea that could be replicated in SNPA. Besides, there are innovations that can facilitate transhumance. In this sense, Ntassiou *et al*. (2016) proposed the use of contemporary technological means, such as GIS, aiming to the accurate visualisation of information in order to determine the most cost-effective design for their project of transhumance.

An interesting option is to negotiate with the managers of the protected area to increase grazing areas or limit restrictions. This can be channelled through collective requests. It is necessary to engage farmers in the conservation of natural areas (Pardini & Nori, 2011) in collaboration with other stakeholders: park authorities, ecologists and representatives of other economic sectors and social groups, etc. (Bernués *et al.*, 2005; Beaufoy & Poux, 2014; O'Rourke *et al.*, 2016).

Another problem pointed out by farmers and technical experts is the lack of social recognition of extensive livestock farming. According to Riedel *et al.* (2013) livestock should be promoted as a vegetation management tool for environmental services and must be increasingly recognized by society. In order to achieve such recognition, the externalities of traditional livestock farming practices, such as conservation of the environment and maintenance of the rural population (Bernués *et al*., 2011; Sturaro *et al*., 2013; Beaufoy & Poux, 2014; Bernués *et al.*, 2014), should be recognized and paid for, helping to increase the farms' profitability and favour generational replacement. An excellent example is the successful development of the Grazed Fuelbreak Network project in Andalusia (Spain) for the prevention of fire through grazing (Ruiz-Mirazo *et al*., 2011; Mena *et al.*, 2016). This solution is especially interesting for C3 where sheep farming is relatively more important than in the other groups.

The new EU quality schemes should be established, based on environmental indicators such as biodiversity, carbon footprint and water use, which would enhance promotion and sale of farm produce and improve society's perception of extensive livestock farming (Bernués *et al*., 2011, 2019; Beaufoy & Poux, 2014). It is important to generate truthful and objective information on the contribution of ruminant livestock systems to climate change. Although it is true that ruminants produce large amounts of methane from enteric fermentation -ruminants are blamed for 80% of the greenhouse gases emissions (GHG) in livestock systems- it is likewise true that grazing can increase carbon sequestration and compensate for emissions (Manzano & White, 2019). On the other hand, most publications related to GHG emissions from ruminants refer to feedlots where animals feed on cultivated grasslands, which is very different from the use of natural grazable resources produced in Mediterranean ecosystems with low use of non-renewable energy. This is a key issue for ruminant systems in protected areas in order for them to turn grazing into a positive externality.

On the other hand, investment in training, advisory services and research in extensive mountain livestock systems is proposed, especially in feeding management for grazing animals and product differentiation. In farms with milking goats, basically in C1, farmers have to learn how to use genetics to seek a balance between productivity and rusticity as well as in reproduction control, in an attempt to use natural pasture optimally.

Likewise, it is important to provide them with training and guidance in cheese processing and marketing through short channels. Products (cheese, milk and meat) can be marketed using official quality brands, such as organic production.

Cattle farmers are important in all groups but more in C2. They should increase the use of the *Pajuna* autochthonous breed, best adapted to the area and with increasing market demand. In order to close the production cycle, it is necessary to guide farmers in calf fattening in the field, either on the farm with sufficient grazing resources or through livestock associations to fatten calves on rented pastures.

Finally, sheep are present in all clusters but with relatively more importance in C3. The reproduction system should move away from continuous mating and reproduction should be managed in order to increase lamb production in seasons when they are paid a better price and to take advantage of lower feed costs when spring or early summer pastures are used.

In all cases, in order to obtain higher prices, direct sales to local restaurants may be an option, as well as to ski resorts or big cities nearby, for which specific strategic marketing advice is needed.

In closing, livestock farming in the Natural Park of Sierra Nevada is still extensive in terms of reproduction management, pasture-fed livestock and local transhumance to summer mountain pastures. However, differences between farms are observed, mainly in predominance of species and production purpose, the importance of transhumance, stocking rates and farmers' age. Extensive livestock farming is an opportunity to collaborate with the conservation and promotion of protected areas but it is in danger of extinction. The main problems faced by the farms are related to livestock feeding management and marketing of farm products. To overcome this situation, measures need to be taken to improve feed self-sufficiency thus reducing production costs; to increase income through social recognition of extensive livestock farming; product differentiation and short marketing channels. This could be strengthened through involvement in associations, training and specialized advisory services. In order to overcome the difficulties mentioned and guarantee the success of the measures proposed, commitment is required from livestock farmers and technical experts, SNPA managers, the public administration, consumers and the general public.

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