MONITORING SPATIAL BEHAVIOR OF PASTORALIST SHEEP THROUGH GPS, LIDAR DATA AND VNIR IMAGE

Plaza, J.[1], Palacios, C.[1]; Sánchez-García, M.[2], Criado, M.[1], Nieto, J.[1], Sánchez, N[1,3]

[1]Faculty of Environmental and Agrarian Sciences. University of Salamanca, 37007 Salamanca, Spain – (pmjavier, carlospalacios, marcocn, jaimenl, nilda)@usal.es
[2]IIVV, University of León, 24071 León, Spain – mariosancia@gmail.com
[3]Department of Cartographic and Land Engineering. University of Salamanca, 05003 Ávila, Spain.

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ABSTRACT:

Global Navigation Satellite Systems (GNSS), such as the Global Position System (GPS), are currently used to replace the traditional pastoralism and to remotely control the movements and location of the herds. Besides, the use of this remote monitoring can benefit the understanding of grazing resource use and livestock management. In this work we investigated the herd behaviour in a Spanish organic farm of free pastoralist sheep with a joint use of different geodata sources. The area of study comprised approximately 900 hectares with a variety of land covers dedicated to pasture.
A herd of 300 head was monitored during 2009 and 2010. GPS data were acquired every 5 minutes. In addition, a comprehensive map of land uses/land covers (LU/LC) was retrieved through a supervised classification of a mosaic of orthophotographs (visible and near infrared bands, VNIR). Then, the digital elevation model (DEM) and the digital surface model (DSM) were obtained from a 2010 LiDAR (light detection and ranging) campaign, which allowed the retrieval of terrain attributes and vegetation parameters. The positioning and behaviour of the GPS-tracked sheep were analysed in terms of the retrieved topographic characteristics and land uses. The study of the most influential variables indicated that the slope and aspect were the topographic attributes that most exerted impact on the grazing activity, being the north direction the most preferable, as well as a gentle slope. Regarding the LU/LC, grassland areas were selected by the sheep, specifically in areas of short vegetation (i.e., outside shrublands and trees beyond 0,5 m high).

1. INTRODUCTION

Since the late 2010s, an increasing number of applications of the Global Navigation Satellite System (GNSS) have been developed to track animals in livestock monitoring. Smart livestock collars are useful for controlling and protecting flocks as well as for setting virtual boundaries, as an alternative to replace the traditional practices of pastoralism, which are nowadays declining. The widespread depopulation of rural areas and the abandon of rangelands for the benefit of intensive agriculture are making pastoralism of extensive livestock to demise. Therefore, GPS sheep monitoring is becoming a popular practice in many countries but also an object of research since its very beginning (Ganskopp, 2001; Pandey et al., 2009; Turner et al., 2001) since it also allows the assessment of animal behaviour, use of plant resources and interaction with the natural ecosystem.

In many of these studies, the positioning dataset is managed into a Geographical Information System with a reference map or aerial photographs together with broad resolution digital elevation models (DEMs) (Schoenbaum et al., 2017). In more recent studies (Venter et al., 2019), satellite images such as those provided by Landsat and Sentinel-2 missions were included to account for the vegetation vigour (through the Normalized Difference Vegetation Index, NDVI). Therefore, the ground-based sensors can be combined with remotely-sensed satellite images to understand animal-landscape interactions (Handcock et al., 2009). However, little research has performed using more advanced geodata, as the light detection and ranging (LiDAR) datasets, probably due to the scarcity of free data until recently. And yet, the LiDAR data seems precious to jointly study terrain and vegetation characteristics, particularly in mixed covers such as open forests devoted to pasture (the typical Spanish agroforestry system called dehesa, for example). LiDAR is an active remote sensing system that emits laser light to the ground and measures the amount of energy that is scattered back, together with the time to return. Hence, it is able to measure height and density of the vegetation lying on the terrain. The LiDAR have been extensively used, especially in the last years owing its increasing availability, to map forest and vegetation characteristics in combination with other remote sensing sources, such as aerial photographs (Su et al., 2016), thermal (Baccini et al., 2012) or microwave imagery (Baccini et al., 2012). In this work, we used a LiDAR airborne campaign from 2010 over an area of dehesa 900 has wide. The dehesa is a vegetal formation resulting from the human activity: the traditional forest exploitation of the holm oaks generates open spaces between the trees. In these areas, meadows and bushes serve as food for livestock. As in other natural grazing areas, the spatial-temporal heterogeneity of vegetation exerts a strong influence on the behaviour of grazing animals, modifying their spatial distribution. When these processes intensify in duration and intensity, important changes in the structure and plant communities' role occur. The creation of over- and under-grazed areas due to a uneven distribution of grazing can have immediate consequences on the efficiency of forage resource use, which in turn could affect the productivity and biodiversity of the grasslands (Herrera, 2018).

In order to manage the spatial distribution of grazing it is necessary to know which factors influence the response of the animals to the environment. The conditioning factors include the location of watering holes, the size and geometric shape of the rangeland, the environmental factors such as topographic slope, soils, meteorological variations (winds, temperatures, atmospheric pressure, etc.), the physiological state of animals and the social conformation of the herd. Hence, when analysing the distribution of grazing animals, the environment, the livestock and the interaction between them must be taken into account in order to have the necessary information for decision-making in the spatial and temporal management of grazing (Herrera, 2018).

This study introduces a strategy using both multispectral aerial imagery and LiDAR data to map land uses/land covers (LU/LC) and vegetation and terrain parameters, respectively, with a detailed spatial scale. The information derived is overlapped with the GPS locations of the herd to highlight relationships between the animal preferences and the inferred vegetation/terrain characteristics.

2. AREA OF STUDY AND LIVESTOCK CHARACTERISTICS

2.1 The dehesa landscape

The semi-arid Mediterranean climate, together with the marked topography and the poor quality of siliceous soils, are the main characteristics that have led to these areas being used for extensive livestock farming. The study area (Figure 1) is mainly located in a pastureland area, where other types of vegetation can be observed: holm oak dehesa, pastures, bushes (rockrose, heather and thyme) and oaks of different heights and densities. In addition, some small areas are used to cultivate dry land cereals. Figure 2 depicts a detail of the typical landscape of the dehesa system. This diversity allows the flock to choose very different scenarios for grazing.

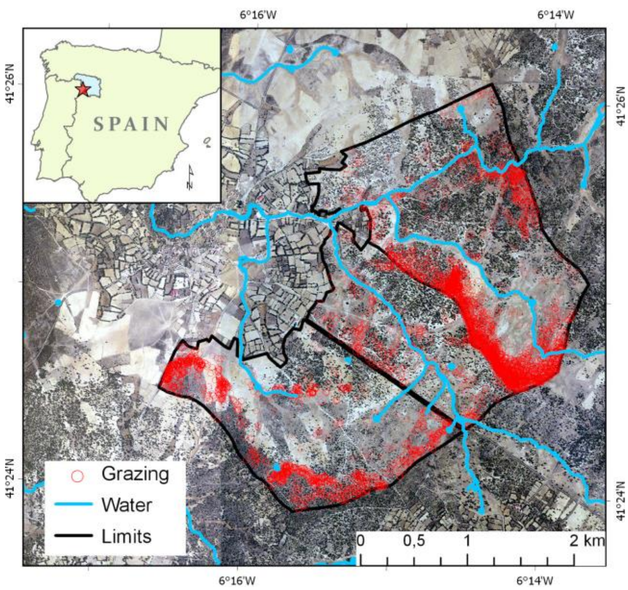

Figure 1. Location map, including GPS grazing positions of the sheep over the RGB ortophotographs.

Figure 2. Typical landscape of the dehesa, combining pasture with sparse trees (*Quercus ilex*).

The study area, whose boundaries are shown in Figure 1, has a communal use, i.e., the land belongs to the municipality, where all the residents have the right to include their animals in the territory. To organize the land use, the fences are distributed in different herds so that the animals do not mix. Apart from the fences (and one road) shown on the map, there are no other physical barriers that impede the free movement of the livestock.

2.2 Sheep herd and GPS collars

The monitored flock was of the churra breed: medium-sized rustic sheep, with meat-dairy aptitude, white coat with black or brown peripheral colouring of the ear tips, around the eyes, nose and distal parts of the limbs; in particular, they belonged to the "sayaguesa" ecotype. The herd consisted of 300 adult individuals that grazed without a shepherd but were led to a portable sheepfold every night.

Information on grazing location is essential for understanding the foraging behaviour of free ranging herbivores (Gordon, 1995). However, such data are difficult to collect by direct observations because a substantial proportion of grazing occurs between dusk and dawn and/or out of sight of the observer (Hulbert et al., 1998). To achieve this aim, two prototype animal tracking devices were available. They consisted of a GPS sensor, a data storage unit, a GPSR SIM card and a long-life battery (one week). In addition, they had an antenna for receiving the satellite signal and the telephone signal. Most of the elements of the device were inside a hard-plastic case with a hermetic seal, which protected them from both shock and moisture. The receiving antenna was placed on top of the collar, protected by insulating material.

The devices used were CONAN GPS prototypes, which belongs to the GMV Innovating Solutions S.L. group, with an accuracy of 2.5 m, in optimal conditions. Geolocation data were collected every 5 minutes and sent daily to a Machine to Machine (M2M) platform via a GPRS connection.

The GPS collars were placed on two healthy adult sheep selected randomly from a flock of 300 individuals. Each time the battery was changed, the GPS-collar was placed on other randomly selected sheep, so that the behavior of the individual would not affect the data set.

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3. DATA COLLECTION, PROCESSING AND METHODS

3.1 GPS data

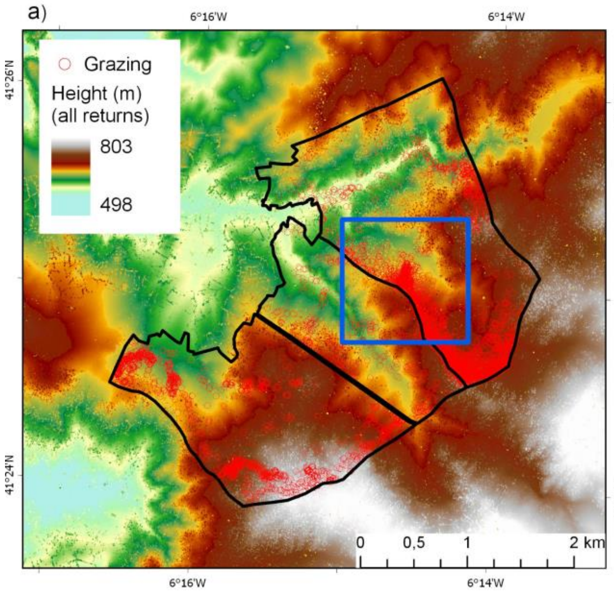
The geolocation information was collected, allowing the daily routes drawn by the sheep to be observed. 12649 records were gathered by the GPS devices. The records were collected over a total of 87 days: 63 days from February to December 2009 (scattered days of February, April, July, October and December), and 24 days from January 2010. Thus, al the seasons were considered. It was necessary to debug the initial data set, initially removing those erroneous points whose coordinates indicated a location far from the study area. Once the database was validated, the distance and time between each consecutive record was calculated, thus obtaining the speed of movement of the sheep between each point of the daily route.

The herd was recorded during different moments of the day and the database was divided according to the speed of movement. To do this, simultaneously with the data collection by GPS devices, field work was carried out to observe the behaviour of the flock and to record videos of the monitored sheep without altering their usual behaviour. Each video was carefully analyzed to determine how long it took to go through a specific distance. This information was compared with the GPS data collected and finally a criterion was established to divide the dataset. The grouping was based on the speed between two consecutive positions: less than 0.043 ms^{-1} for "resting", 0.043 to 0.4 ms^{-1} for "grazing", and more than 0.4 ms^{-1} for "moving" (Sánchez et al., 2010). Therefore, 5350 positions corresponded to resting activity, 3009 to moving and 4290 to grazing. These activities were usually distinguished in the related literature (Mora-Delgado et al., 2016; Venter et al., 2019), but only the grazing behaviour implies specifically the act of consuming grass.

3.2 LiDAR data

The LiDAR campaign took place in 2010 by the Agriculture Technological Institute of Castilla y León (ITACYL, available in http://ftp.itacyl.es/cartografia/02_Altimetria/023_LIDAR/), with a spatial density of 2 m and an accuracy of 15-20 cm for Z and 10-15 cm for XY (Figure 3a).

a)



b)

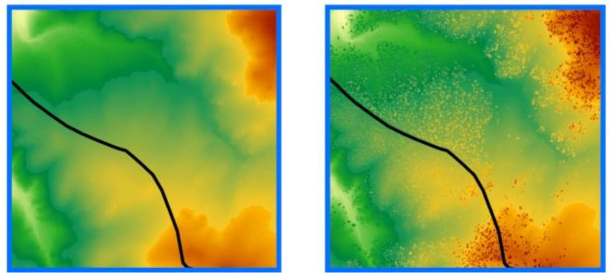


Figure 3. (a) LiDAR dataset with a point cloud density representation, and (b) detail of the rasters DEM (left) and DSM (right).

Prior to extract any derived product, a workflow of refinement and editing was conducted over the .las files, including cleaning overlapping and outliers' points, deleting duplicates, noise point detection, and reclassifying. All this pre-treatment was performed in ArcGIS Pro 2.4 together with the LAStools LiDAR processing toolbox (https://rapidlasso.com). The LiDAR point cloud, once refined, was converted into two raster datasets, one corresponding to the digital elevation model (DEM) (Figure 3b, left) and another to the digital surface model (DSM) (Figure 3b, right). In both cases, the elevation value is interpolated, but for the first, the ground data was selected, whereas for the latter, a filter of the first return signal was applied. In some cases, it was reported an underestimation of the tree crown height by the first return of the signal, since there is a low probability of a small-footprint laser pulse intercepting the apex of a conic crown (Lim et al., 2003). This is not the case for the trees in this area, mainly *Quercus ilex*, which have a rounded, typically plain crown (Figure 2). The spatial resolution of both raster files was set to two meters to fit the original point density.

As terrain variables, several features based on the DEM were tested, including watershed, slope, aspect and flow direction and accumulation. After a preliminary assessment, the slope and the aspect were selected as main attributes. Besides, the Canopy Height Model (CHM) was calculated by subtracting DSM minus DEM. In order to discard any possible correlation between all datasets retrieved from the same LiDAR cloud, a previous analysis of spatial correlation (Pearson's R) between slope, aspect and CHM was performed. No significant correlations were obtained between aspect and slope (R=0), aspect and CHM (R=0.01) and CHM and slope (R=0.15)

Finally, the vegetation height and the terrain slope and aspect of each grazing position of sheep was extracted.

3.3 Aerial photographs and classification map

Four orthophotographs from the ITACyL were mosaicked to cover the study area. Since two series of orthophotos (one with visible, RGB bands, and other with a NIR band) were available, the final mosaic integrated four visible-NIR bands (VNIR). The spatial resolution was 25 cm.

To investigate the LU/LC in the area, a supervised classification was tested using the ArcGIS Pro 2.4 schema of pixel-based classification with the Support Vector Machine algorithm. To reinforce the classification, the NDVI between red and NIR bands was calculated and used as a reference map in the process. The proposed legend tried to highlight the most frequent scenarios for grazing activity, i.e., coverage of trees and/or shrublands, rainfed crop areas, grasslands and pasture, roads and tracks, and rocky-asphalt patches. The accuracy of the resulting map was assessed through a confusion matrix using a ground truth dataset of 100 points. The samples were randomly distributed and their real LU/LC was visually determined on the VNIR images. Statistics of predicted *vs.* observed values were therefore extracted (Foody, 2002; Lillesand and Kiefer, 1999).

As for the rest of datasets, each GPS position was overlapped with the classified map, and each class was extracted for each record.

3.4 Dominant factors influencing grazing

Spatial and temporal patterns of livestock behaviour and utilization of the landscape are affected by biotic and abiotic factors (Schoenbaum et al., 2017). The geodata selected in the previous sections afforded several mapping products, which in turn described the main factors that were suggested as the main factors related with the grazing locations in this study, i.e, DEM (aspect and slope), CHM (vegetation height) and the classification map (LU/LC). Other factors, although considered, did not produce a clear pattern, and therefore were discarded. For example, a preliminary outlook to the grazing positions revealed that no clear relationship with the water bodies (mainly small creeks and pools) existed (Figure 1). In fact, the field observations support this behaviour: in general, the sheep did not show an active search for water points where they could drink. Furthermore, this is consistent with the characteristics of the churra breed and its variants (Haraway, 2007). Thus, the "water" factor was discarded. Likewise, no artificial boundaries (except the main road in the area) acted as a limiting factor.

It should be highlighted that the field observations did not act as a validation dataset, but only as a way to understand the animal behaviour, including their positions, speed and movements, as well as their preferences.

The influence of these factors was studied over the database generated by the result of each factor in the 4290 grazing positions. In order to harmonize the different dataset spatial resolutions and accuracies, a final spatial resolution of 1 m was selected for the whole analysis. Histograms and statistics of each series allowed the retrieval of the preferred conditions by the sheep to graze.

4. RESULTS AND DISCUSSION

4.1 Vegetation height

The visual inspection of the CHM in Figure 4 suggested a clear preference of the sheep for out of high vegetation covers.. Other authors (Schieltz et al., 2017) had also found an inverse relationship with the vegetation height, and it is well known that sheep will graze near to the ground whereas other cattle, such as cows, on taller grasses.

To numerically investigate the vegetation size influence, a threshold of 0,5 m was applied. FAO defines the "shrubs" category as "woody perennial plants, generally of more than 0.5 m and less than 5 m in height on maturity and without a definite crown" (FAO, 2004). Therefore, less than 0.5 m was considered as grasslands, from 0.5 to 3 m as shrubs and bushes, and more than 3 m as trees (the *Quercus ilex* is not a very tall tree, as seen in Figure 2). Besides, the accuracy of the lidar dataset hampered a more detailed classification of the vegetation height.

Only 13% of the locations took place under trees and 9% over shrubs, whereas a 78% of the locations over grassland were chosen en masse. It seemed that trees and shrubs, even their vital importance in the dehesa system and their function as shelters, are not the preferred areas for feeding. It was shown that the pasture grown under more mature trees appears to be of lower nutritive value (Percival and Knowles, 1983). However, this fact should be further investigated adding an analysis of the pasture quality and palatability in the area.

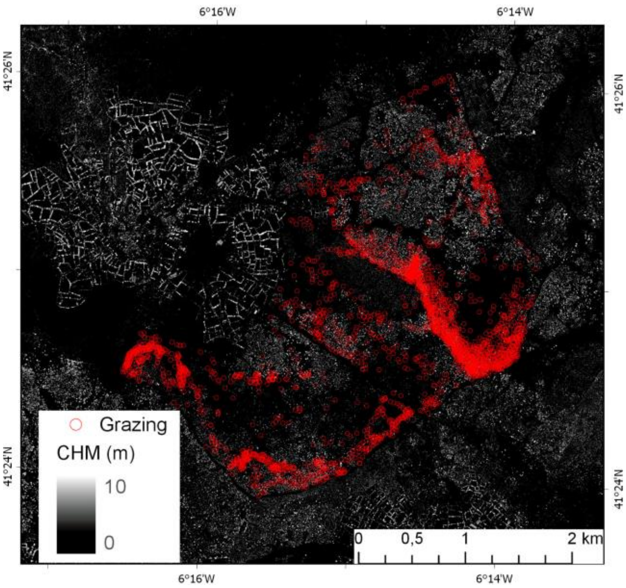


Figure 4. CHM over the study area, with the GPS positions.

4.2 Aspect

The aspect accounts for the slope direction and varies, following the ArcGIS Pro algorithm, from 0 to 360º. Figure 5 shows the aspect map with the northern directions (considered in ArcGIS varying from 292,5º to 67,5º) coloured in white, overlapping most of the GPS positions of the sheep. Its histogram (Figure 6) corroborated the predominance of northern directions. In fact, those directions accounted for the 65% of the total positions, supporting the north drift that drives the flock to graze, probably in the seek of more leafy and abundant pasture. As seen in Nadal-Romero (2014), south-facing slopes are typically less vegetated due to a very large water stress, whereas north-facing slopes in the Mediterranean climates preserve more the humidity and consequently the vigour and greenness of grass.

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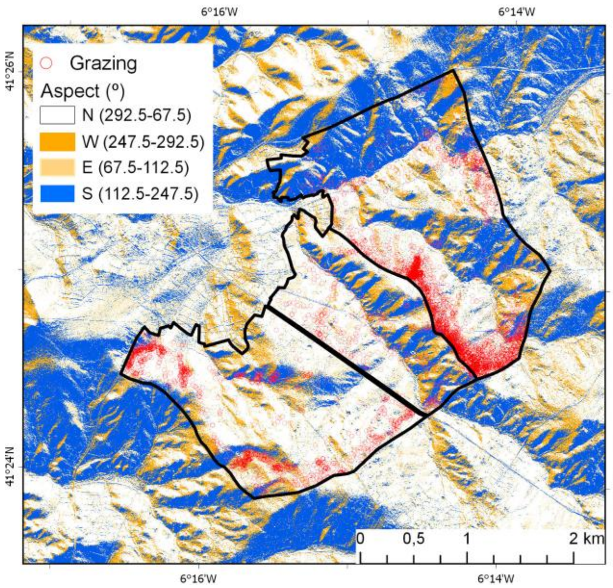

Figure 5. Aspect map with the GPS positions.

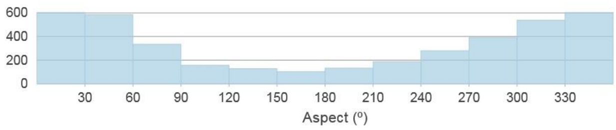

Figure 6. Histogram of the aspect at the GPS positions.

4.3 Slope

The values of slope (in percentage) for the grazing locations showed a normal distribution, with a mean value of 6,63% and quartiles Q1=3,59%, Q2=5,30% and Q3=7,80%. Except for isolated rocky scarps and several small valley cliffs in the main river, the slopes in the area are very gentle. If a limit of 6% is taken as threshold, 58% of the locations are under it. Accordingly, it seemed that the sheep chose low slopes to graze. Sheep may use all slopes regardless the steepness, but when the terrain is rough, the animals most trail through the area, making little use of the available forage (Vallantine, 2016). Similarly, we found that if they had no constrains in their free displacements, sheep would choose near-flat areas to graze. Nonetheless, the use of slopes may be associated to other biotic/abiotic features than the slope *per se* (Ganskopp and Vavra, 1987), so other factors may such as soil, minerals, quality of graze and many others may be masking the real effect of the slopes and should be investigated.

4.4 LU/LC

The accuracy assessment of the LU/LC map (see Appendix 1) afforded a statistic of kappa = 0.76 (a value of 1 is considered for the best possible classification) and an average accuracy of 84%. This limit fits the theorical limit stablished in the first steps on remote sensing imagery classification: “the minimum level of interpretation accuracy in the identification of LU/LC categories from remote sensor data should be at least 85 % (Anderson et al., 1976)”. Therefore, the results of the LU/LC would be considered overall acceptable. The best classified LU/LC is the trees-shrubland, with more than 90% of accuracy, closely followed by grassland. On the other hand, the worst one were the roads, probably confused with either the rainfed and grassland areas, since they are mainly dirt roads.

The most common LU/LC in the area is the grassland (50.4%), followed by trees-shrubland (20.4)%, rainfed areas (19%), rocks-asphalt (7.1%) and roads (3.1%).

The classification map (Figure 7) pictured very well the mix between grasses and sparse trees that characterizes the dehesa. Also, areas of rainfed cereals are scattered along the map. A common practice in this agrosystem is profiting the most open areas to sow cereals under the trees, so that the livestock may be provided of fodder anytime. Moreover, in the case of the churra sheep studied here, the cereal stubble is grazed over the summer.

The percentage of LU/LC used by the sheep is 56% for grassland, followed by 22% for rainfed crops and 13% for trees/shrub areas. These numbers confirm the results of the vegetation height, emphasizing the sheep preference for grasses and prairies, and avoiding woody plants. Again, as seen with the slope factor, this result may be contradictory with the common idea of the sheep eating any kind of vegetation in case of need (as well as over almost any slope). Here it is confirmed that, in case of having different scenarios, they preferred grasses and forbs. This result coincides with an study in the neighbouring area of northeast of Portugal (Castro and Fernández-Núñez, 2016), in which goats and sheep feeding strategies were compared. They found that the diet of goats had a significantly higher content of shrubs and trees species than sheep (whose rates were 6% and 10% respectively), and that the sheep diet comprised 84 % of herbaceous plants.

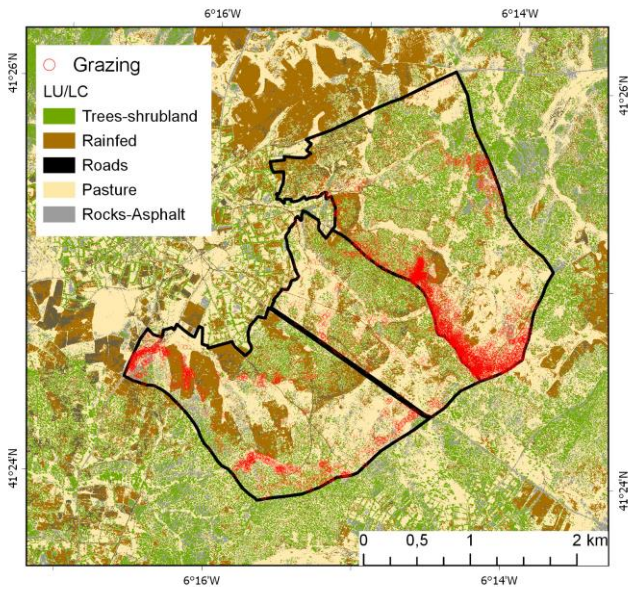

Figure 7. Classification map.

As a summary of the influence of the terrain/vegetation features over the grazing positions, Table 1 shows the percentage of sheep positions for each feature. The most noticeable preference is related with the vegetation height (78%), followed by the aspect (65%), slope (58%) and LU/LC (56%). Combining two factors, the stronger combinations occurred for aspect with height (58%) and slope with height (55%). The combination of the four factors altogether represented a remarkable 21%.

%	Aspect (North)	Vegetation height (<0,5m)	Class (Grassland)	Slope (<6%)
Aspect (North)	65			
Vegetation height (<0,5m)	58	78		
Class (Grassland)	52	50	56	
Slope (<6%)	53	55	34	58

Table 1. Percentage of sheep positions after each dominant factor.

A final remark on the spatial distribution of the GPS positions is the concentration along the fence lines. This trend to spontaneously line up is a well-known behaviour recognized in the field, and also shown in the literature (Venter et al., 2019) Further geostatisticals analysis may complete the spatial patterns analysis found.

5. CONCLUSIONS

This preliminary study about the sheep behaviour made use of several geodatabases and tried to relate the spatial patterns developed by the flock with terrain and vegetation attributes. Much research has been done using GPS and GIS methodologies as reliable tools for monitoring herds behavior, but here a fairly novel technology, the LiDAR data, was applied to retrieve the factors under study. The LiDAR allowed an accurate estimation at high spatial resolution of biotic and abiotic factors, such as the vegetation height, not possible until now without field measurements.

In absence of other physical constraints, the study of the most influential variables indicated that the vegetation height, the slope and the aspect were the attributes that most exerted impact on the sheep grazing activity. Particularly, sheep: i) chose areas with short vegetation, open spaces out of scrublands and trees, ii) avoided steep slopes, higher than 6% , iii) preferred grazing in north-oriented slopes (between 292,5º and 67,5º), and iv) chose grasslands as their favourite LU/LC for feeding.

Further work should be done over the dataset, since the temporal and seasonal patterns, which are not perused yet, may enlighten some of the results. Diet composition of sheep changes seasonally, according to plant species availability. Light and temperature also affect severely. In addition, graze analysis concerning species, associations, nutrients and phenology should meet a complete analysis.

The Spanish dehesa is a balanced agrosystem that includes an open forest of evergreen *Quercus* genus with undercover herbaceous vegetation. It is a threatened system due to the urban pressure and the abandon of the traditional practices (shepherded pastoralism, trees pruning and cleaning for firewood, etc.). Since field surveys are notably time-consuming, instrumental technics, together with available geoinformation, represent a way to help livestock understanding and management. The final aim would be, once identified the preferences and predictors of grazing activities, a land suitability analysis in order to reorganize and redistribute a sustainable livestock use.

The knowledge of the behaviour of animals in free grazing helps to disseminate the environmental activities that ruminants carry out daily, such as the maintenance of the surfaces of low brush and the natural landscape, helping effectively to prevent fires and allowing a better movement of the animals. In the mountains and areas of public or communal ownership, the presence of animals in free grazing ensure the sustainability of the system safely and economically.

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Appendix 1

	Reference ground truth						
Classified	Trees-shrubland	Rainfed	Roads	Grassland	Rocks-Asphalt	Total	User’s accuracy (%comission)
Trees-shrubland	31	1	0	0	0	32	96.9
Rainfed	0	9	0	6	1	16	56.3
Roads	0	2	1	1	0	4	25.0
Grassland	1	1	1	39	0	42	92.9
Rocks-Asphalt	2	0	0	0	4	6	66.7
Total	34	13	2	46	5	100	
Producer’s accuracy (%omission)	91.2	69.2	50.0	84.8	80.0		
% Average	**84**						
Kappa	**0.76**						

Table A. Accuracy assessment values for the confusion matrix of the LU/LC