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The *Conquense* transhumance route in Spain described by 3D geographical information systems, GPS and remote sensing data

Javier Plaza[a,*], José Alfonso Abecia[b], Nilda Sánchez[a], María de los Ángeles Ramo[c], Francisco Canto[a], Jaime Nieto[a], Carlos Palacios[a]

[a] Faculty of Agricultural and Environmental Sciences, University of Salamanca, 37007 Salamanca, Spain
[b] Institute of Research in Environmental Sciences of Aragón (IUCA), University of Zaragoza, 50009 Zaragoza, Spain
[c] Faculty of Veterinary Sciences, University of Zaragoza, 50013 Zaragoza, Spain

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ABSTRACT

In semi-arid regions, such as the Mediterranean, seasonal changes in climate make the migration of ruminants essential for the efficient use of ecosystemic primary productivity. Transhumance is one of the oldest sheep husbandry systems which contributes to the conservation of natural biodiversity and to minimize the effects of climate change on livestock production. However, its use has decreased substantially, mainly because of livestock intensification. In Spain, particularly, interest in maintaining the traditional transhumant network has increased. Geotechnologies such as Global Positioning Systems (GPS) and Geographical Information Systems (GIS) might provide important information about the drove roads of the transhumant network. Therefore, in this study, we used several geotechnologies that described accurately and in detail the path followed by several sheep flocks and cattle herds in eastern Spain. Specifically, we monitored a *Merino de los Montes Universales* (MMU) sheep flock on the well-known Spanish *Conquense* route in Nov 2021. The flock traveled 349.8 km and climbed a total elevation of 1223 m in 23 days, moving 9–10 h per day. Maximum and minimum daily distances traveled were 19.06 km and 8.85 km, respectively, and the steepest slopes were encountered in the first few days of the journey, up to 60 %. The preferred land use/land covers (LU/LC) were scrublands, rainfed herbaceous crops, and rangelands. Indirectly, the study demonstrated the outstanding physiological aptitude of the MMU breed for withstanding the long journey, even when pregnant.

1. Introduction

Since pre-Roman times, cattle and sheep farmers deal with shortages of resources caused by marked seasonal differences in climate in the Mediterranean region, including hot, dry summers and cold winters (Ruiz and Ruiz, 1986). In semi-arid regions, those seasonal changes make animal migration systems important for the efficient use of ecosystemic primary productivity (Alerstam et al., 2003). Alternations between winter and summer pastures through seasonal migrations between northern and southern regions (Manzano-Baena and Casas, 2010; Ramo et al., 2018), known as transhumance, is one of the oldest sheep husbandry systems. Transhumant systems have been used for centuries all along the Old World (Olea and Mateo-Tomás, 2009) -at least for about 2500 in the Iberian Peninsula- because they permit optimization of grazing resource exploitation (Galanopoulos et al., 2011), especially in areas where productivity, limited either by climate or the soil, is not suitable for intensive or continuous use.

Those traditional practices remain common in some regions of the world such as Mongolia (Moktan et al., 2008) and sub-Saharan Africa (Motta et al., 2018) and, although this pastoral practice persists in some European countries such as Greece, Scotland, and Spain, it is done in a different manner and to a lesser extent than it had in the past (Bunce et al., 2006; Fernández-Giménez and Le Febre, 2006; Valamoti, 2007). Since the 1960s, the proportion of transhumant sheep and goat population decreased from 30 % to 7 % in the EU (Galanopoulos et al., 2011), which might have been caused by the increase in livestock intensification. Intensive livestock systems are commonly associated with high-input and more productive management systems, but also with biodiversity crisis and loss of environmental services in marginal areas that had been used for grazing (Pineda, 2001), diminishing in consequence traditional pastoralist practices such as transhumance. That trend should be reversed because transhumance plays an important role

* Corresponding author.
E-mail address: pmjavier@usal.es (J. Plaza).

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in conserving natural biodiversity (MacDonald et al., 2000) and in minimizing the effects of climate change on livestock production (Olea and Mateo-Tomás, 2009). Furthermore, in western European countries, popular opinion is against intensive livestock farming, and there is a desire for a return to extensive and more environmentally respectful practices such as transhumance (Bunce et al., 2004).

Among the Mediterranean regions, transhumance was more widespread in the Iberian Peninsula because of its climatic, topographic, and anthropological peculiarities (Ruiz and Ruiz, 1986). Most winter grazing areas are in southern regions where the mean temperature is >6 °C in the coldest month, and summer pastures are in northern areas where the mean temperature does not exceed 17 °C in the hottest month (Manzano-Baena and Casas, 2010). This bidirectional North-South migration of sheep flocks involves walking several hundred kilometers on traditional livestock tracks known as royal drovers' roads or drove roads. Presumably, those paths run along ancient natural pathways that, initially, had been followed by wild herbivores and, later, the first shepherds, which has contributed to the maintenance of connectivity between the different habitats of the Iberian Peninsula (Manzano-Baena and Casas, 2010). The network of drove roads in Spain was strategically designed in the Middle Ages to improve the wool market (Gómez-Sal and Lorente, 2004); e.g., a major active drove road known as the *Conquense*, which is traveled twice a year by *Merino de los Montes Universales* (MMU)-breed sheep (Ramo et al., 2018).

Nevertheless, transhumance is currently facing both a productive context in which profitability prevails and a series of social, economic and productive limitations that explain the current situation of the activity in Spain. With regard to the social limitations, the lack of manpower and the difficulty in finding professional shepherds, the lack of generational succession, the harshness of the labor activity and the lack of associationism among livestock farmers stand out (MAPA, 2012). Concerning economic and productive limitations, it is worth mentioning the loss of profitability due to the decrease in the price of livestock in relation to the increase in the cost of inputs and the rent of private farms; the increasing price of transporting livestock; the low price of meat and the depreciation of wool, among others.

Fortunately, interest in maintaining the Spanish transhumant network has increased because it provides an essential link between mountain systems and lowlands, and because of its historical importance, value for recreation and tourism (Bunce et al., 2006; Pineda, 2001). Although Spain is the only country that has a network of legally protected drove roads for the movement of herds and flocks, data on the status of these drove roads and their true extent are very limited because many have been modified or destroyed, or knowledge about their whereabouts has been lost (Bunce et al., 2006; Manzano-Baena and Casas, 2010; Oteros-Rozas et al., 2013). Spanish national, regional and local governments try to revalue these practices launching new policies that aim to re-open old routes while maintaining and improving those in use. As an example, the LIFE Project "LIFE CANADAS" ("Living drove roads to reconnect spaces of the Natura 2000 Network", https://www.lifecanadas.es/), whose objective consists of carrying out conservation and ecological restoration actions in a part of the livestock routes of the Community of Madrid and in the *Conquense* Royal Drove Road, in the Community of Castilla - La Mancha, in order to recover its ecological role and improve connectivity between areas of the Natura 2000 Network (Life Cañadas, 2020).

Geotechnologies might soar these efforts since they provide important information about the drove roads. For example, they can document the topographic attributes and biotic composition of the terrain, and they can track the geolocations and time of walking animals through miniaturized devices carried by them. Among others, Global Navigation Satellite Systems (GNSS), especially Global Positioning Systems (GPS) mounted in collars, have been very useful in tracking and monitoring cattle (Ganskopp, 2001; Pandey et al., 2009) and for studying the behavior of grazing sheep (Andriamandroso et al., 2016; Plaza et al., 2022b) and the circadianity of specific behaviors displayed while grazing (Plaza et al., 2022a). To study the contour, slope, aspect, or any other topographic attribute, the geolocations recorded by the devices can be integrated into Geographical Information Systems (GIS) and overlaid on reference maps such as Digital Elevation Models (DEM) or orthophotographs (Putfarken et al., 2008; Schoenbaum et al., 2017; Turner et al., 2001). In addition, to quantify vegetation cover, remote images such as those from satellite missions Landsat or Sentinel-2 can be used as a GIS base layer (Venter et al., 2019). That geotechnical combination might provide an accurate assessment of the route followed by the animals and, thereby, identify the specific characteristics of a drove road in a transhumant migration.

Zanon et al. (2022) used GPS tracking devices to identify the movements of ewes during transhumance and estimate the maintenance energy requirements of the animals. Motta et al. (2018) used a combination of GPS-tracking technology and a questionnaire-based survey to assess animal welfare and shepherd experience in the seasonal migration within the Adamawa Region of Cameroon. In addition to using GPS to track the flocks, Ntassiou et al. (2018) used GIS and orthophotographs to calculate the correlation between the progression of the animals and the natural energy contained in the vegetation; however, few have used these geotechnologies to study a transhumance route in an effort to prevent the disappearance of traditional livestock farming practices that are sustainable and beneficial from economic, social, and environmental perspectives (Oteros-Rozas et al., 2014). The objective of this study was to confirm whether geotechnologies provide an accurate description of the path followed by migrating livestock; specifically, the drove roads of transhumance. An additional objective was to update the knowledge about one important transhumant route in the Iberian Peninsula. The white paper of the Spanish transhumance (MAPA, 2012) suggested many supporting measures to develop and dynamize this practice. Among many others, it proposed the GIS systems to map and identify current and potential areas and tracks devoted to transhumance, as well as to integrate them in GIS online platforms to make this information available to users and general public. Therefore, this research seeks to support this objective by geolocating a transhumant route path and describing both its topographic attributes and its environment. To that end, in Nov 2021, we used some geotechnologies that might describe accurately and in detail the path followed by a flock of MMU sheep, which was tracked on its north-to-south path on the *Conquese* transhumance route.

2. Material and methods

2.1. Sheep flock

The MMU breed is derived from the Merino breed and is in danger of extinction (Spanish Ministry of Agriculture Fisheries and Food, 2019). Its morphological and genetic characteristics are identical to the Merino breed, but is differentiated from the latter by its geographical area of origin (Los Montes Universales, Teruel, Spain) and by the coverage of the fleece of the MMU, the distal regions of which have no wool, mainly because of the transhumant movements they undergo annually. In addition, the MMU is a medium-sized, highly rustic breed. In this study, the MMU transhumant flock comprised 3000 reproductively mature animals (Fig. 1), and the mean body weight (±standard deviation) of ewes and rams were 56.62 ± 6.06 kg and 81.50 ± 5.70 kg, respectively. Most of the ewes were in the last month of their pregnancy. Around 50 female goats were included in the flock, as well as several castrated bucks, that obey the commands of the shepherds.

During the route, shepherds were asked to maintain a record of deaths, missing animals, abortions or lambings.

2.2. The Conquense route

The flock followed the so-called *Cañada Real Conquense* (Royal Drove Road, RDR) transhumance route, which begins in the *Sierras de Tragacete*

Fig. 1. *Merino de los Montes Universales* transhumant flock at an early stage of the *Conquense* route. Traditionally, the flocks contain several head of goats, usually castrated males, that obey the commands of the shepherds.

and *Albarracín* in *Teruel*, passes through *Cuenca* and *La Mancha* before reaching the *Sierra Morena* and *Condado de Jaén*. The RDR are the traditional paths of transhumance in Spain, which were regulated by the royal edict of King Alfonso X in 1273 (Martínez-Fronce, 1992) and have an official width of 90 Castilian yardsticks (72.22 m). Modern Spanish legislation (Act 3/1995 on Livestock Trails) decreed that the maximum width of the RDR is 75 m (Spanish Head of State, 1995).

On 1 Nov 2021, the animals were gathered in the small municipality of *Guadalaviar*, *Teruel*, Spain (40°23′18′'N - 1°42′49′'W, at 1302 m a.s.l.), which is where the *Conquense* route to the south traditionally begins. The flock traveled 23 d until they reached an extensive area of open pastures in the municipality of *Vilches*, *Jaén*, Spain (38°21′28′'N - 3°24′9′'W, at 548 m a.s.l) (Fig. 2).

2.3. GPS data collection and processing

Five days before the transhumance, GPS collars were placed on two healthy, randomly selected ewes, which allowed the animals to adapt to the collars and were worn until the animals reached the end of the route. One of the collars provided the input data and the other served as a backup in case of loss of the other device or depletion of the batteries.

The tracking system consisted of a DMS-CattleSat 1.5 GPS sensor and a UBX-R3 receiver chip (Domodis, Cordovilla, Spain) that record data every five minutes (except if the animals were not moving; i.e., if they remained in the same position for five minutes, to save batteries). The location accuracy error was less than two meters. These components, together with a long-life battery, and an antenna for receiving the satellite signal were housed in a hard-plastic case (115 × 64 × 40 mm) that had a hermetic seal (Fig. 2), which protected against shock and moisture. The collar weighed 290 g and is a non-invasive technique that is commonly used to monitor the movements of livestock. Although ethical approval was not required for this research, the study was approved by the Animal Experiments Ethics Committee of the University of Zaragoza (Ref. PI29/21: "Use of external devices to monitor temperature, heart rate and activity of sheep"), following the Spanish Policy for Animal Protection (RD 53/2013), which complies with the European

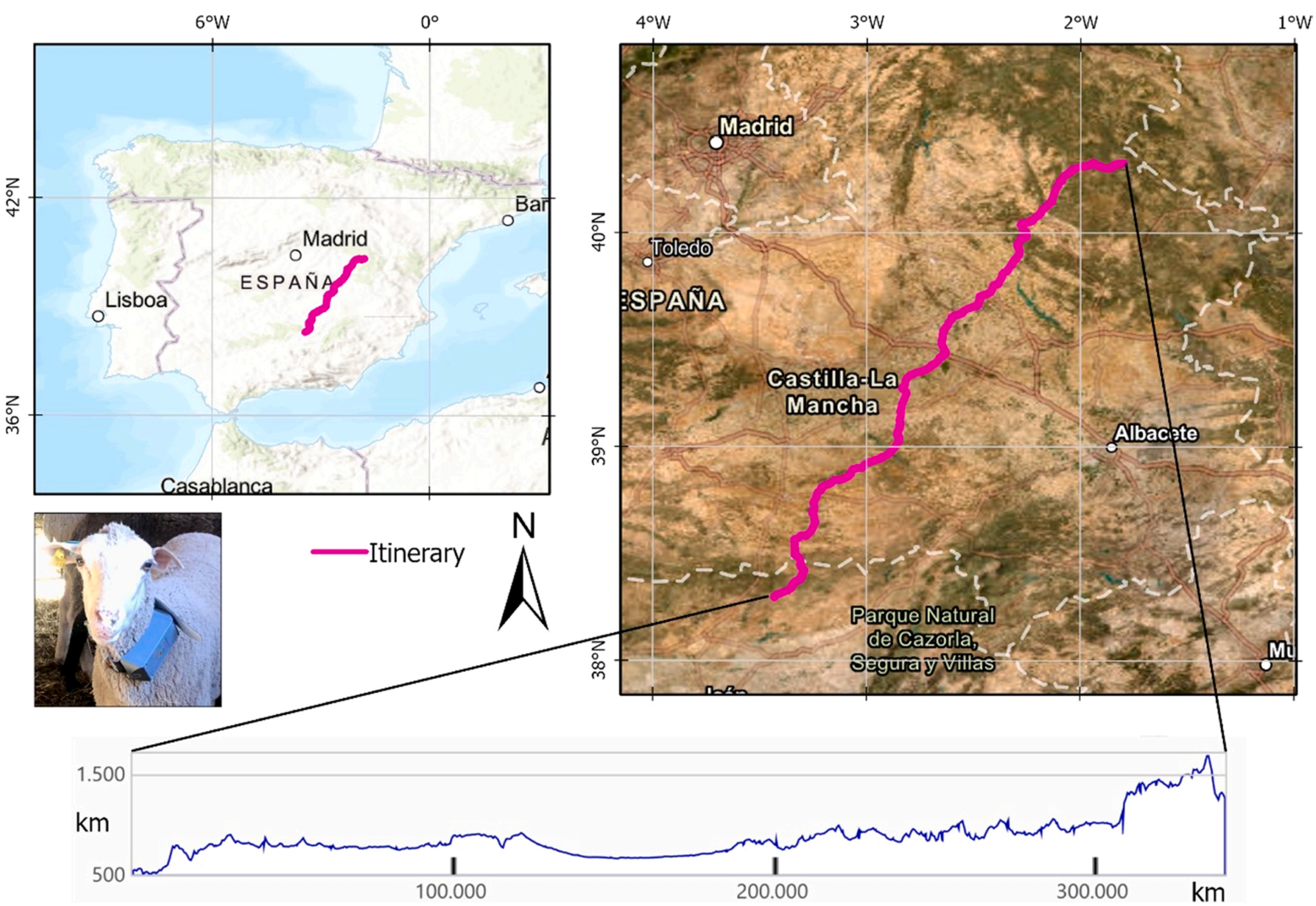

Fig. 2. Location of the *Conquense* transhumance route in central Spain and the elevation on the route of the animals over 23 d. Photo of a *Merino de los Montes Universales* sheep wearing the GPS collar.

Union Directive 2010/63 on the protection of animals used for experimental and other scientific reasons.

GPS data were downloaded from the Domodis tracking system (http://www.loc.gpsganado.es/index.php), which provided a "*.txt" file each day. Before any other analyses, the coordinate database was examined and refined. It should be taken into account that the monitored path traversed mountain ranges that produced unexpected signal-shadowed areas. Therefore, all daily segments were pooled and cleaned to identify defective, repeated, misnumbered, or outlier GPS data. Thereafter, the raw "*.txt" files had to be converted to the GIS shape format so that it could be analysed in ArcGIS Pro 3.0.2. The GPS supplies each location in geographic (longitude and latitude) coordinates, which can be transformed in ArcGIS into projected coordinates (X,Y) in the European cartographic system (Universal Transverse Mercator, UTM). However, these specific devices did not record the Z coordinate; therefore, the altimetric information was extracted by laying the geolocations on an external DEM map (see next section). The topographic features (distance, elevation, and slope) between consecutive positions of the route were calculated by means of their (X,Y,Z) coordinates, as follows (Eqs. 1–3):

$$d = \sqrt{(X_2 - X_1)^2 + (Y_2 - Y_1)^2} \quad (1)$$

$$\Delta Z = Z_2 - Z_1 \quad (2)$$

$$Slope(\%) = \frac{\Delta Z}{d}100 \quad (3)$$

were 1 and 2 were two consecutive positions, and d, ΔZ were the distance and elevation increment between them, respectively.

After calculating the distances between each two consecutive XY locations and their corresponding Z value, 3D profiles were constructed.

2.4. Remote sensing data

Two main data sources coming from remote sensing datasets were selected to complete the analysis. As aforementioned, the altimetric information was not available from the GPS records, so the required Z data came from the Shuttle Radar Topography Mission (SRTM), commissioned by the National Aeronautics and Space Administration (NASA) and the National Geospatial-Intelligence Agency (NGA). The elevation records were obtained by interferometric radars of the space shuttle Endeavour (Farr et al., 2007). In our study, version SRTM 3.0, which provided regularly spaced DEM grids of 1 arc-second (approx. 30 m) was used. This DEM was overlapped with the GPS location to extract the SRTM-based Z data.

To better understand the route landscape and its natural and agricultural environment, a map of land uses/land cover (LU/LC) was needed. These maps depict what covers the surface and how the land is used. The LU/LC map used in this study was created through the integration of official geospatial sources in Spain that have high geometric, semantic, and temporal detail, which is known as the High-Resolution System for Information on the Terrains Occupation in Spain (HR SIOSE, www.siose.es) and is produced by the National Geographic Institute and the National Centre of Geographic Information of Spain (IGN-CNIG). The SIOSE data model describes the geographical elements of land cover and land use based on the geometric source of the Cadastre, which delimited the land parcels and buildings (SIOSE 2022). The result was a vectorial map that had > 60 LU/LC categories of which 20 were agricultural and eight were shrubs, forests, or pastures. The most recent version of the SIOSE of the study area was produced in 2017. The LU/LC of each GPS location was extracted from that map.

3. Results

Regarding the events related to the flock during the route, three ewes lambed and one goat kidded during the route. Moreover, three abortions were recorded and six animals were found dead.

3.1. Topography

The flock traveled 349.8 km and climbed a total elevation of 1223 m in 23 days, moving 9–10 h per day. The daily distance traveled ranged from 19.06 km to 8.85 km, and the latter occurred on the first day of the transhumance. Most of the steepest slopes were encountered in the first few days of the journey, up to 60 %. That portion of the route was in the most mountainous area (Fig. 1 and Table 1). In the early stages, the sheep ascended and descended >500 m (Fig. 3) and encountered slopes of up to 80 %. In the middle stages of the trip (days 12–14), the route crossed into the southern plateau of the Iberian Peninsula, where the slopes (approx. 10 %) and elevations (<100 m) become gentler and the path became easier to travel (Table 1). On the first day of the transhumance, the sheep encountered substantial changes in elevation as they crossed one of the peaks of the Iberian Mountain Range (Fig. 4a) and this stage was the shortest because it required the most effort from the sheep. At the end of the journey (days 21, 22, and 23), the route passed through an elevated, steep area that bridges the pass between the southern plateau and *Andalucía*, which acts as a natural border between the two regions (Fig. 4b). The 3D view illustrates how the transhumance route takes advantage of the natural topography such as passes and defiles to cross the mountain ranges.

3.2. LU/LC

The most common LU/LC on the route (Figs. 5 and 6) fell within one of five classes; i.e., "scrublands", "olive trees and vineyards", "rangelands" (crops and natural vegetation such as pastures), "woodlands" (coniferous and evergreen trees), and "rainfed crops" (herbaceous). The route included other types of habitats, but in small amounts. The preferred LU/LC were scrublands, rainfed herbaceous crops, and rangelands (Fig. 6), and the flock feed on low vegetation such as pasture, herbaceous crops, and shrubs.

4. Discussion

In this study, geotechnologies allowed us to describe the actual geographical route followed by the transhumance flock and its topographic features and the vegetation cover, which offers new insights into the physiology of transhumant breeds and their foraging habits on the route. To our knowledge, this is the first description of the *Conquense* route based on those technologies, which have provided essential information that might help in restoring the old sustainable livestock farming practices that are part of the cultural heritage of society, which might mark a turning point in a return to more extensive productive systems.

Sheep walked a mean daily distance of 15,194 m (Table 1) and encountered continuous positive and negative slopes. The flock faced elevation increments (ΔZ) that were between 300 and 600 m for 11 d, and on five days increments were >600 m (Table 1). On seven days, the sheep walked along relatively horizontal profiles, which coincided with the middle stages of the route on the *La Mancha* plateau. Based on the method of Robbins (1993) for calculating the energy needs of walking sheep based on the slope they walk, the energy consumption of the flock on the 16 d that had the steepest inclines was 90 times higher than it was on the seven days when they walked on more gentle terrain, which was important because the ewes were in their last month of pregnancy. This evidences how the MMU breed is well adapted for walking long distances to access more abundant resources (Ramo et al., 2018). In one study, walking stress significantly influenced the growth, physiological response, and hematobiochemistry in Malpura ewes, and demonstrated that some breeds can adapt to long-distance walking, and that adrenal and thyroid gland hormones play a significant role in that adaptation

Table 1
Topographical characteristics (distance, elevation, and slope) of each of the stages of the *Conquense* route in central Spain.

Journey	Date	TD (m)	TΔZ (m)	MAΔZ (m)	MDΔZ (m)	MPS (%)	MNS (%)
1	11/01/21	8854.85	873.96	92.09	-42.46	60.00	-53.71
2	11/02/21	15,503.02	917.78	157.24	-163.62	20.00	-18.47
3	11/03/21	14,712.79	750.88	97.56	-38.28	60.00	-80.00
4	11/04/21	17,253.22	556.86	27.54	-23.13	56.61	-18.84
5	11/05/21	12,792.85	470.25	23.03	-38.24	13.49	-15.89
6	11/06/21	13,925.83	706.11	30.43	-34.45	22.36	-23.27
7	11/07/21	12,859.75	563.83	56.71	-43.81	15.68	-26.67
8	11/08/21	12,746.12	435.11	20.07	-19.77	34.32	-18.92
9	11/09/21	18,675.87	597.06	46.48	-34.15	14.50	-11.73
10	11/10/21	13,769.23	416.15	41.96	-40.11	12.53	-13.82
11	11/11/21	12,801.16	468.49	31.62	-31.16	11.85	-11.36
12	11/12/21	16,271.79	253.76	22.72	-20.51	6.67	-10.00
13	11/13/21	15,926.34	61.61	3.76	-2.47	5.00	-4.21
14	11/14/21	16,932.66	61.79	9.77	-3.52	4.00	-4.30
15	11/15/21	16,527.90	210.01	6.38	-10.98	31.50	-26.14
16	11/16/21	17,115.95	449.61	38.81	-26.04	20.00	-15.79
17	11/17/21	19,056.93	396.10	38.62	-24.22	19.37	-10.48
18	11/18/21	13,876.47	191.54	13.12	-9.95	10.49	-10.90
19	11/19/21	18,905.23	205.81	15.78	-18.97	3.02	-4.71
20	11/20/21	14,728.25	277.23	21.74	-18.46	8.00	-8.27
21	11/21/21	15,234.01	427.01	22.68	-20.19	12.03	-19.00
22	11/22/21	13,934.90	579.32	44.34	-28.92	14.46	-20.57
23	11/23/21	17,047.24	855.55	132.28	-94.26	13.10	-18.96
Mean		15,193.58	466.34	43.25	-34.25	20.39	-19.39

TD: total distance, TΔZ: total Z coordinate increment, MAΔZ: maximum ascending Z coordinate increment, MDΔZ: minimum descending Z coordinate increment, MPS: maximum positive slope and MNS: minimum negative slope

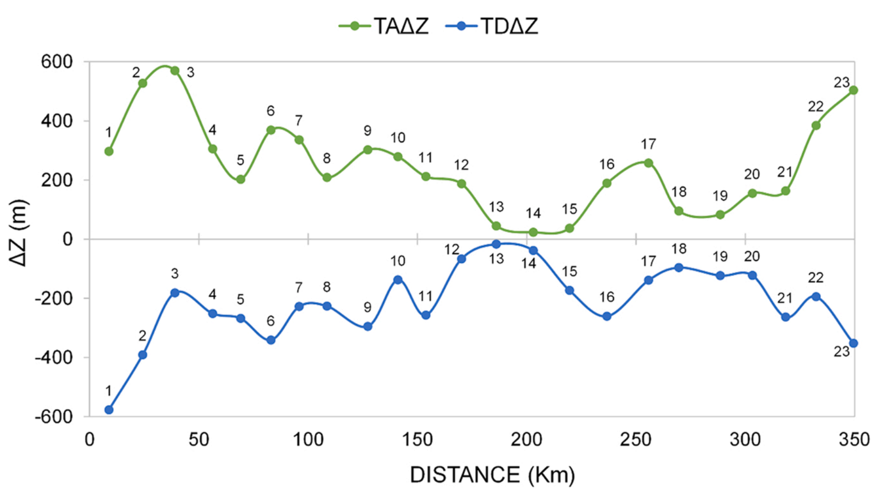

Fig. 3. Z increments traveled by the *Merino de los Montes Universales* flock on the 23 d of the *Conquense* route in central Spain. ΔZ: Z coordinate increment, TAΔZ: total ascending Z coordinate increment, TDΔZ: total descending Z coordinate increment.

(Sejian et al., 2012). In addition, in adapting to the walking stress, the reproductive hormone status of the ewes was not affected.

Serranito et al. (2021) identified a set of genes that might have an important role in adaptation to changes in aridity and elevation in sheep and goats, and some of those genes are involved in lipid metabolism, hypoxia, stress/lung function, seasonal patterns, and neuronal function. In the region of our study, traditional pastoralism has been largely based on transhumance and, because flocks most commonly have been kept at mountain elevations, natural selection has occurred. Even though transhumance has continued to be abandoned, it has significantly influenced how sheep and goats have evolved genetically. Indeed, a recent discovery in an excavation close to the start of the *Conquense* route confirmed that this transhumance to *Jaén* has been used since at least 2500 years ago (Burillo-Mozota and Ibáñez-Hervás, 2022), which implies centuries of genetic selection.

The LU/LC map created in this study indicated that on the route the sheep foraged on pasture, herbaceous crops, and shrubs, particularly (Fig. 6). The drove roads are de facto ecological corridors that provide a refuge for plants and animals. Furthermore, migrating flocks disperse seeds, which connect habitats and preserve biodiversity through endozoochory and epizoochory. An earlier study on the same road and the same flock estimated that each sheep excreted an average of 375 seeds per day (Quintín et al. (2018)). Extrapolated to the flock level (n = 3000 sheep), about 27,000,000 seeds would have been dispersed on the transhumance (1,125,000 seeds/day). The transhumance flocks are fundamental to the maintenance of those ecological corridors, which now follow paths that have a different character, quality of cover, and generally a low degree of preservation because of urbanization and the abandonment of rural areas (Bunce et al., 2006). Fortunately, the route followed in this work is practically free of human intrusions, fences, roads or recreational areas, since it is under the control of the regional governments, and by the nature 2000 network and a LIFE project, coordinated by the Autonomous University of Madrid, the government of Castilla-La Mancha and SEO BirdLife (Life Cañadas, 2020).

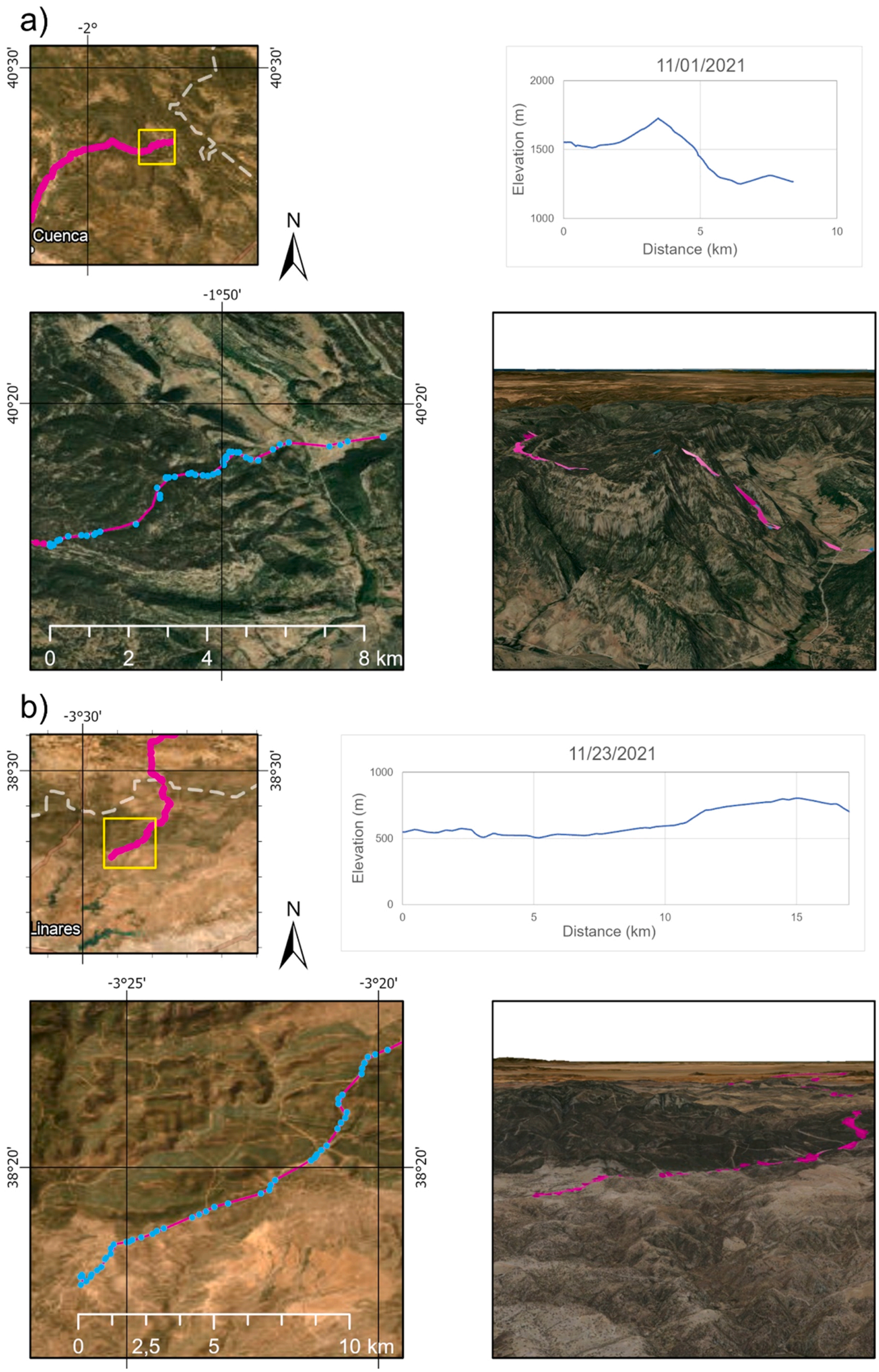

Fig. 4. Journey of the MMU sheep flock on the day 1 (a) and day 23 (b) of the *Conquense* route in central Spain, including the pathway, the terrain profile, and the 3D view.

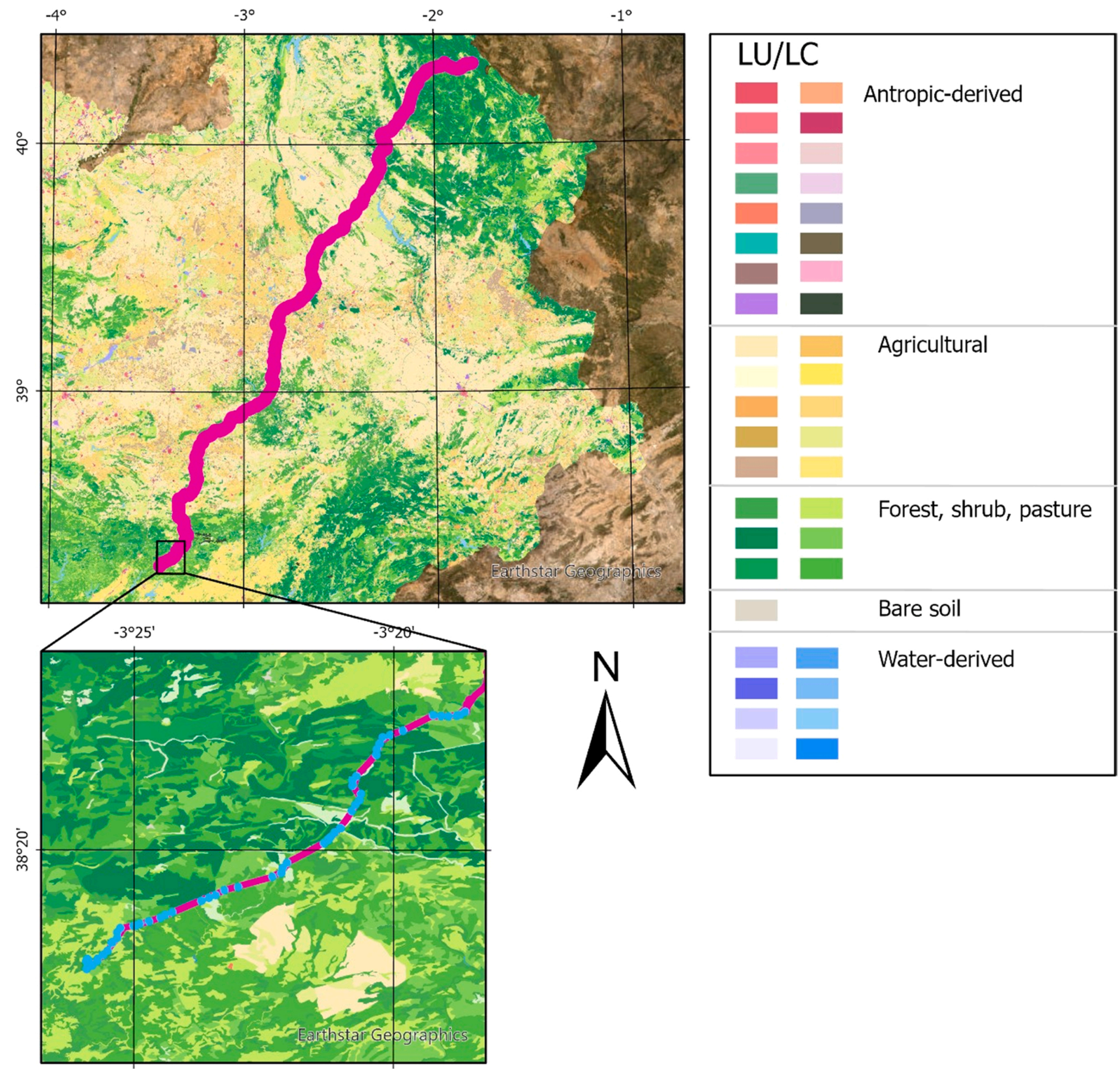

Fig. 5. LU/LC map with the detailed legend of categories, that were grouped into five simpler classes later, comprising "scrublands", "olive trees and vineyards", "rangelands", "woodlands" and "rainfed crops" on the *Conquense* route in central Spain.

The diet of the flock was not supplemented with concentrate or forage during the transhumance and, based on traditional knowledge, the transhumance does not affect the body condition of the ewes (Ramo et al., 2018). Zanon et al. (2022) estimated the maintenance energy requirements of ewes in the mountain pasturing period (transhumance) in the Italian Alps based on the animals' movements as recorded by satellite-based GPS tracking devices and found that, especially in the first months of transhumance (May-Jun), pregnant and lactating ewes experienced a severe negative energy balance, which was probably mainly caused by the longer walking distances and large changes in elevation. Although our study occurred in Nov, ewes were pregnant and, given the topography they encountered, it is likely that they experienced a negative energy balance at some point.

We presented GPS and new tools to expand the knowledge of transhumance routes, as a first stage to activate their potential. However, other levers to dynamize transhumance should be considered after this first step, and particularly socioeconomic and cultural ones.

The first package of measures taken by the Spanish government focus on the development of a new regulatory and institutional framework, in order to protect the drove roads, to guarantee animal health and to create a coordinating entity capable of promoting communication between the transhumance stakeholders and the public administration. Furthermore, following the guidelines of section 9.2.2 of the Spanish White Book on Transhumance (MAPA, 2012), activities aimed at studying the identification of transhumance areas, including the description of the main drovers' roads, should be promoted.

The social and economic integration of transhumance could start with the creation of a professional qualification for shepherds, in order to improve training and encourage generational replacement. Shepherding educational programs may also attract and recruit newcomers

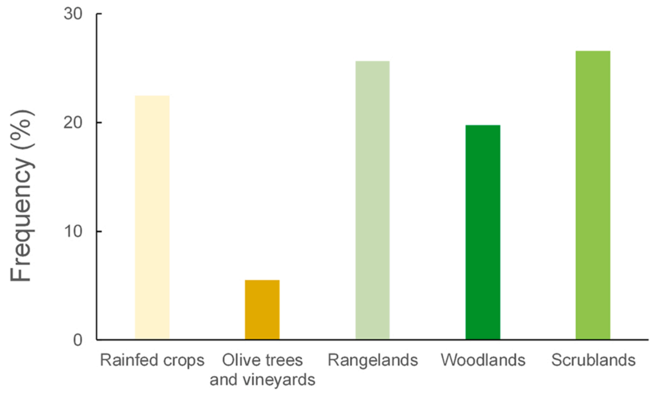

Fig. 6. Frequency of LU/LC on the *Conquense* transhumance route in central Spain.

and immigrants to address labor needs and therefore settle them in these sparsely populated rural areas. In addition, access to subsidies for the promotion of production systems of native livestock breeds in extensive regimes could also be promoted, as well as the encouragement of transhumance producer groups.

Alternatively, transhumance could be revalued through innovative local development projects that integrate the economic, cultural, environmental and tourism values associated with it. Indeed, in Europe, a connection between transhumance and tourism has been established, paving the way for a new pastoral tourism, integrating activities and traditions into cultural and educational tourism packages (Sauer et al., 2022). In this vein, educational in situ training activities with scholars would be very beneficial to disseminate the transhumance activity, both in urban and rural schools. All these initiatives aim to change society's perception of this activity, giving back the shepherd and transhumance the prestige they deserve and increasing social recognition and appreciation of their environmental role.

5. Conclusion

Geotechnologies can provide important information that might help in restoring old sustainable livestock farming practices that form part of the cultural heritage of society, which might mark a turning point in the use of extensive productive systems. Transhumance is an old pastoral practice that plays an essential role in maintaining environmental sustainability and in the optimization of resources. These remote technologies have revealed specific topographic (e.g., distance, slope, elevation) and biotic (vegetation cover) features of the *Conquense* transhumant route, the traditional knowledge of which has been lost over time. The study has revealed the harsh conditions (350 km over 23 d, walking 9–10 h per day, with slopes > 60 % and > 500 m in elevation increments per day) to which the MMU sheep were subjected to in the transhumance and, therefore, indirectly showed the outstanding physiological aptitudes of the *Merino de los Montes Universales* breed to withstand the long journey, even when pregnant.

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.

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