Kernel density estimation analyses based on a low power-global positioning system for monitoring environmental issues of grazing cattle

Simona M.C. Porto,[1] Giulia Castagnolo,[2] Francesca Valenti,[1] Giovanni Cascone[1]

[1]Department of Agriculture, Food and Environment; and [2]Department of Electrical, Electronics and Computer Engineering, University of Catania, Catania, Italy

Abstract

The use of wearable sensors that record animal activity in intensive livestock systems has become more and more frequent for both early detection of diseases and improving production quality. Their application may also be significant in extensive livestock systems, with infrequent farmer-to-animal contact. The present study aimed to prove the feasibility of a novel automatic system for locating and tracking cows in extensive livestock systems based on space-time data provided by a low-power global positioning system (LP-GPS). The information was used to study the pasture exploitation by the herd for modelling the environmental impacts of extensive livestock systems through geographical information systems (GIS). A customised device, placed within a rectangular PVC case compatible with the collar usually worn by animals, was equipped with an LP-GPS omnidirectional system, an integrated SigFox communication system, and a power supply. The experimental trial was conducted in an existing semi-natural pasture characterised by good pasture allowance and cultivated grazing areas. Ten cows were embedded with LP-GPS collars, and the data, *i.e.*, geographical coordinates and the time intervals related to each cow detection, were recorded every 20 minutes. Data were collected through a specifically developed AppWeb to be further imported and elaborated by using a GIS software tool. In the GIS environment, the daily distances travelled by each cow were linked with heatmaps obtained by applying Kernel density estimation models from the points obtained from the LP-GPS collars. The study results made it possible to obtain information on some relevant aspects of livestock's environmental issues. In detail, it was possible to acquire information on herd behaviour related to the use of the pasture, *e.g.*, the area of the pasture most frequently used during the day, individual use of the pasture, and possible animal interactions. These results represent the first step towards further insights and research activities because monitoring of animal locations could reduce several environmental issues such as soil degradation and greenhouse emissions.

Correspondence: Francesca Valenti, Department of Agriculture, Food and Environment (Di3A), University of Catania, via S. Sofia 100, 95123 Catania, Italy. E-mail: francesca.valenti@unict.it

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Introduction

For a long time, animal location and tracking have been topics of interest in several wild and bread animals research activities. For example, the monitoring of animal location allows researchers to evaluate some key aspects, such as the movements of animals around the landscape (Gordon and Foreword, 2001), the spatial heterogeneity of field occupancy by animals (Liu *et al*., 2012), the pasture utilisation, the animal performance and behaviour (Turner *et al*., 2000; Agouridis *et al*., 2003; 2004; Porto *et al*., 2015) or the social relations within a group of animals (Veissier *et al*., 1998; Senneke *et al*., 2004; Arcidiacono *et al*., 2020a).

An accurate location and monitoring of each herd animal could be helpful to analyse the environmental impacts (*e.g*., air and soil) of extensive farming systems. It is well known that livestock production interacts with the environment, both at local and global levels, affecting many aspects, including air and water quality, climate, soil characteristics, biodiversity, and landscape (Vanslembrouck and Van Huylenbroeck, 2004). These impacts are becoming increasingly important with the growth of worldwide demand for food of animal origin. Moreover, the intensification of animal husbandry is generally an advantage in terms of resource utilisation efficiency, but at the same time, it can embrace the environmental impact at the local level (Crovetto and Sandrucci, 2010).

Extensive breeding of dairy cows and cows in the cow-calf line generates various environmental issues, among which the most significant one concerns greenhouse gas emissions and soil degradation. In detail, extensive farming systems produce about 70% of livestock greenhouse gas emissions (Steinfeld *et al*., 2006; Crovetto and Sandrucci, 2010). The production of methane (CH_4), caused by the rumen and intestinal fermentation of the animals, represents about 35-40% of the methane of anthropogenic origin, and about 80% of these emissions would be linked to extensive farming systems (Steinfeld *et al*., 2006). As regards the issue of the impact of extensive livestock farming on soils, it should be stressed that the degradation processes can be triggered by incorrect agricultural practices for livestock food production or by the adoption of non-rational grazing systems, with consequent phenomena caused by the animal activity of both compaction, pathways, and erosion.

However, direct animal observation carried out by farmers is often time-consuming, includes observer fatigue and association errors, could suffer physical limitations (*e.g*., weather, light, and vegetation), and could affect animal behaviour (Turner *et al*., 2000).

In the last years, studies moved from very high frequency (VHF) tracking technologies, commercially available for gathering location data, to global navigation satellite systems (GNSS) by allowing the possibility of collecting large amounts of high-quality location data 24 h per day under all weather conditions, with accuracy ranging from 5-30 m depending on several factors, *e.g*., vegetation cover, topography, *etc*. (Rodgers *et al*., 1996; D'Eon *et al*., 2000; Frair *et al*., 2004). In literature, several research studies were carried out by adopting one of the providers of GNSS, *i.e*., global positioning systems (GPS) (Van Beest *et al*., 2010; Schieltz *et al*., 2017; Fogarty *et al*., 2018), to locate cattle and, almost all, demonstrated the necessity of miniaturising the sensor technologies and developing higher energy-dense batteries (Arcidiacono *et al*., 2020b). A critical problem in this kind of application is undoubtedly the telecommunication network used, since, for example, vast areas of the world, especially rural areas, are currently scarcely covered by efficient and reliable telecommunication networks, as highlighted by Rivero *et al*. (2021). Furthermore, cellular telecommunication networks (*i.e*., GSM, GPRS, 3G, 4G, LTE), if available, are not always the best choice as they are associated with high energy consumption. Having high energy consumption implies a reduced life of the batteries this, especially in the specific case of mobile tracking systems for livestock, represents a significant limit in the adoption by breeders of this kind of system for reasons of practicality, reliability, and associated costs (Tomkiewicz *et al*., 2010). In fact, despite the advances achieved in these recent years in tracking objects with GPS-based technology, several constraints limit the use of GPS-based systems in commercial farms for identifying, locating, and monitoring animals in large pastures (Evans *et al*., 2016; Nóbrega *et al*., 2018).

Over the years, to overcome the problems mentioned above, several Low Power Wide Area Network techniques have been proposed (Qadir *et al*., 2018), which are types of long-range wireless telecommunication networks characterised by low energy consumption and low bit rate.

Some of the most used LPWANs in IoT applications are SigFox and LoRa (Gomez *et al*., 2019; Mekki *et al*., 2019); they are also suitable in the field of IoT applications in PLF as, for example, they can allow continuous, real-time and low power monitoring and tracking of animals in extensive farms.

In this regard, the animal location retrieved by localisation devices (*i.e*., GPS) could also be used to develop anti-theft control systems. Livestock theft is a relevant issue in herd management, and farmers spend high economic resources on insurance to reduce the financial burden whenever livestock does get stolen. Moreover, since GPS devices could also retrieve animal identification, each identified animal position could be tracked during the monitored period and showed at the territorial level by geographical information system (GIS)-based software. This could allow the monitoring of animal walking activity a relevant parameter for a first remote screening of animal well-being. For example, in farms for dairy cows or in the cow-calf systems of beef production, the increment of cow walking activity could be an index of some physiological status such as heat calving.

On the contrary, an extended stationary time interval could alert the farmer of some disease activity or an accident. Barbari *et al*. (2006) who, in their study, by using GPS and subsequently through GIS, tracked and located animals in various grazing areas, proving a key element in reaching important conclusions on the territory and biological matters. In this context, an IoT-based solution that enables the location and tracking of cows in grazing fields could provide a large dataset of geospatial information to be integrated with GIS software to model, analyse, and manage the environmental impacts of extensive livestock systems and could be adopted by farmers for long-distance monitoring of herd position.

Therefore, the main objective of this paper was to accrue out Kernel density estimation (KDE) analyses (Seaman and Powell, 1996) based on space-time data provided by a low power global positioning system (LP-GPS) for locating and tracking cows in extensive livestock systems. Data acquired from the system were used to carry out KDE analyses to monitor the environmental issues of grazing cattle and improve the farm's efficiency by the costs and time reduction of farmer's work.

Materials and methods

The herd under study

Livestock transhumance represents a way of adapting breeds to the variable climatic conditions. In detail, summer transhumance to highland pastures is still highly widespread in Sicily, the largest island of the Mediterranean Sea, characterised by a continental climate in the inland areas, where winters become moderately cold and summers are still hot.

The breed considered in this study generally moves from the Nebrodi mountains, located in the province of Messina, to the Margilupo district belonging to the municipality of Melilli within the province of Syracuse at an altitude of 200 m a.s.l. (Figure 1).

The experimental activity was carried out in December 2019. The cows were grazed in an area of about 100 hectares, delimited by an electrified fence to avoid cattle trespassing. The breeding consists of 90 animals: 1 limousine breed bull, 70 suckler cows aged between 5 and 10 years, 13 heifers 1 to 4 years old, and 10 calves under 1 year of age.

The pasture is mainly made up of permanent natural fodder, typical of the Mediterranean climate since no processing is carried out. This type of vegetation origins from the interaction of climatic, pedological, and species adaptation factors. By visual analysis, through direct surveys and visual inspections carried out in the study area, it emerged that the vegetation cover of the soil is characterised by many thorny shrubs, several species of cruciferous and composite grasses which due to their morphological characteristics such as the presence of thorns on the stems, are not eaten by animals. These conditions, combined with the lack of water resources, contributed to defining the pasture's medium-low production potential (Figure 2). Furthermore, the main soil characteristics, *i.e.*, slope, exposure, and geomorphological, were deeply analysed through a GIS software tool. Copies of spatial data sets, or a part of them, were obtained from the National Geographic Portal through the Download Service. In this case study, data related to the slope, geomorphology, and exposure were downloaded by web feature service (WFS) and reported in GIS software. Then statical analyses were carried out to extract the mean, max, min, and standard deviation of basic parameters describing terrain morphology (*i.e.*, altitude, slope, and exposure) to relate these features with animal locations.

The cattle breeds considered in this study are rustic and not very used to wearing equipment. Therefore, to select a sample of cows for the experiment, the breeder chose 10 animals among the tamest generally wearing the collar with the cowbell. The breeder makes the collar using a very resistant plastic material but can mould itself based on the required shape. Each collar is provided with a bell that makes a sound when the animal is moving allowing the breeder to track the animal (Figure 3).

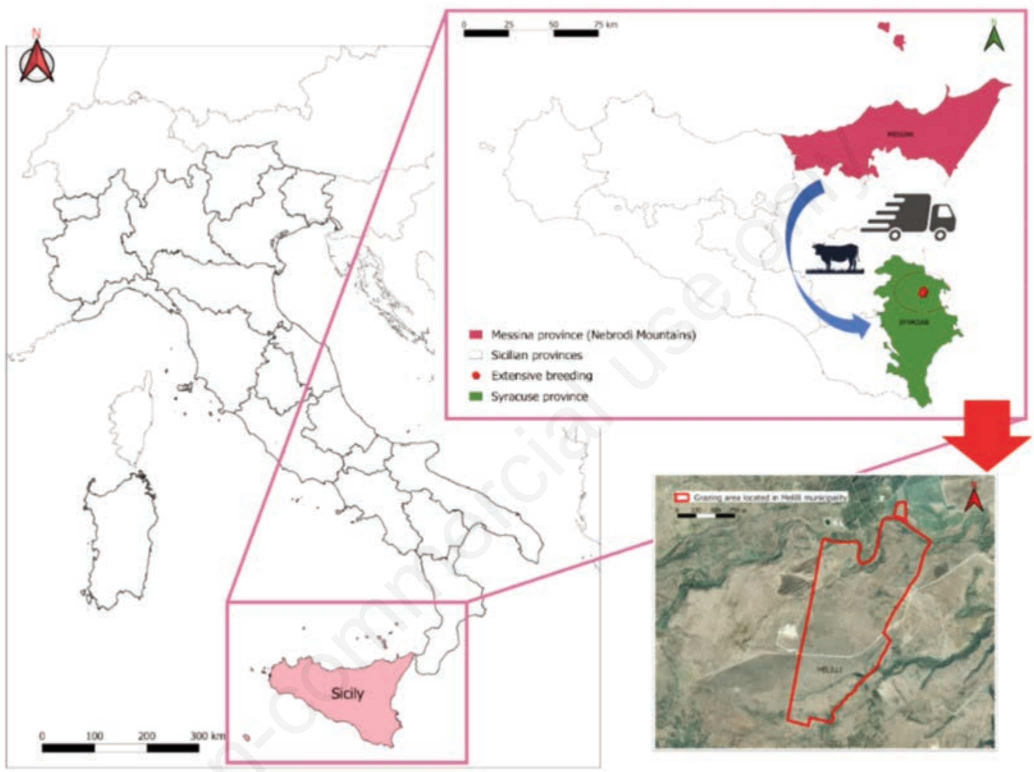

Figure 1. The territorial area by the localisation of the grazing area (red box).

Figure 2. A grazing survey carried out on 27th December 2019.

Each bell is produced with a specific shape and size to be adapted to animals by considering different ages, and furthermore, it could emit different sounds, which allow the breeder to identify and locate the animal. Even today, especially in the Nebrodi mountains area, this very ancient method of tracking animals is the most used by breeders to retrieve the animals.

Data collection and analysis based on the low power global positioning system-based system

The low power GPS-based system (LP-GPS system) developed in this research study comprises wearable devices that could receive position information from up to three global navigation satellites systems (NAVSTAR/GPS, Galileo, GLONASS) in this study only NAVSTAR/GPS was used. After receiving position information, the wearable devices send it to a cloud server by using the SigFox telecommunication network, as shown in the graphical scheme reported in Figure 4. In detail, the SigFox antenna was placed close to Monte Lauro, within the province of Syracuse, about 25-km distant from the study area.

This system, which ensures a long-term tracking of animals, allowed the collection of waypoints, *e.g.*, latitude and longitude, of the cows selected in this study, date, time of detection, and distance travelled by each animal. The time interval of the acquisition was 20 minutes and the time interval of sent messages to the cloud server. This time interval was adopted to acquire long-time data that allowed GIS analyses, *i.e.*, the application of KDE algorithms, by guaranteeing long-lasting battery life (Jiang *et al*., 2008; Stache *et al*., 2012). As reported in the literature, both trajectories and behaviours can be estimated with good accuracy with GPS sensors using a high sampling rate of <0.016 Hz (Frost *et al*., 1977; de Weerd *et al*., 2015). In this study, the LP-GPS collars were embedded only with GPS sensors that are energy-consuming devices, but

Figure 3. Low power-global positioning system device attached to the cow's collar.

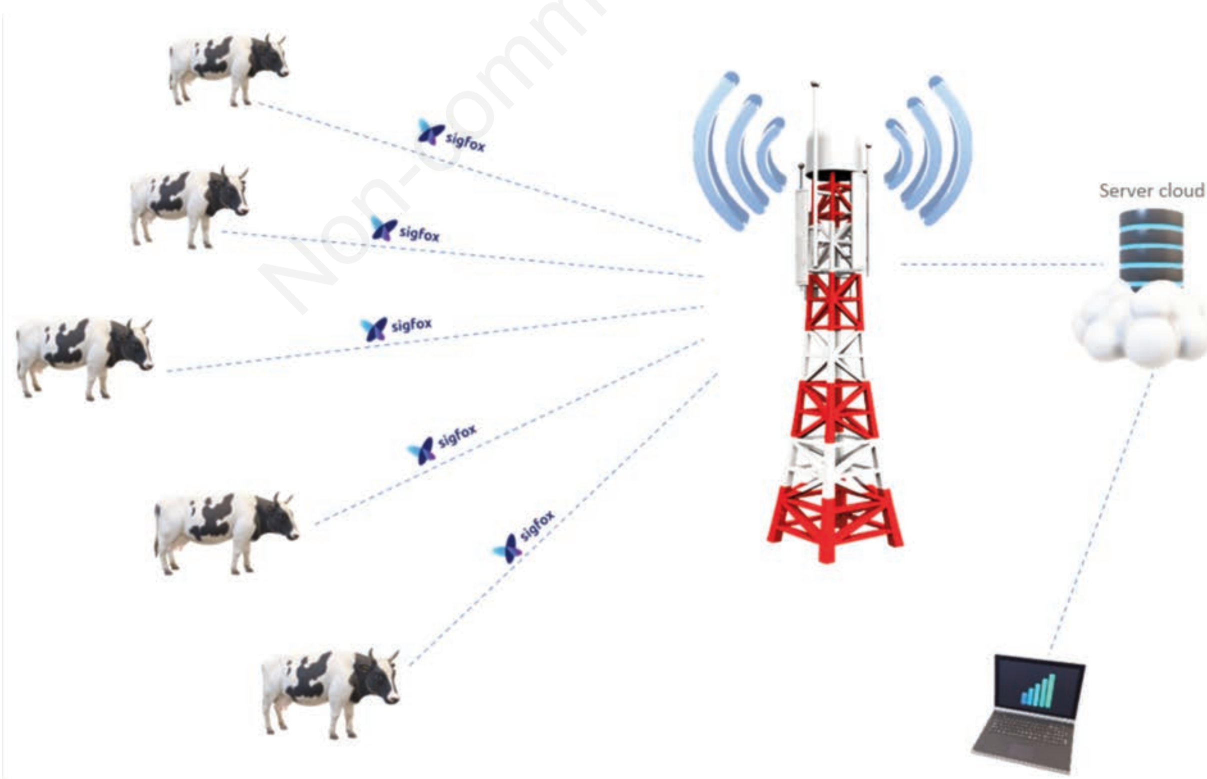

Figure 4. Scheme of the proposed low power GPS-based system (LPGPS).

in the next phase of this research project, which is in progress, the LP-GPS collars will be equipped with other sensors (*i.e.*, accelerometers at 4 Hz) to study cow behavioural activities in extensive systems by following the same methods adopted in previous studies (Arcidiacono *et al*., 2017a, 2017b, 2020b; Riaboff *et al*., 2020). In this regard, as reported by Raizman *et al*. (2013), due to the limited battery life of the devices, in some research studies, the animal's position was detected only one time per hour (or a little bit more) with the result that by reducing the number of detections it is impossible to achieve efficient monitoring of grazing animals. Therefore, the priority of this study is to investigate battery-life and Sigfox communication network suitability by demonstrating that the adopted low sampling rate and LP telecommunication network allowed to reach battery life longer than those investigated in literature (Raizman *et al*., 2013; Bailey *et al*., 2018; Tobin *et al*., 2021). All the information was sent to an AppWeb developed by Trecastagni s.r.l., which runs either on mobile devices or on personal computer (Figure 5). Data were then imported for further elaborations through both statistical and geospatial analyses.

In detail, geo-spatial analysis was carried out by using the Quantum GIS (QGIS) software tool (v.3.10.11), a free software provided by Open-Source Geo-Spatial Foundation (Chicago, USA), which allows the organisation, the analysis, and visualization of data at the territorial level to understand the link between livestock and environment deeply.

By applying the KDE tool available in QGIS, land use analyses were carried out by considering the positions of each animal equipped with the devices. In particular, the KDE analysis, frequently used in biology studies, allows the calculation of the species' home range (the area of the agricultural land in which a species lives) and provides a density estimation of the use of the territory. The result of the KDE analysis consists of a map (*i.e.*, a raster or a vector image) that represents the area of the territory most frequently used by animals in terms of density. The density levels are 95% (home range) and 50% (core home range); the home range (HR) represents the area in which the probability of finding the monitored items is 95%; while the core home range (CHR) represents the area in which the probability is 50%.

These maps were obtained for each animal of the sample and for all the selected cows to classify the preferred areas.

The device developed in this study was equipped with an omnidirectional GPS antenna and receiver with –167 dBm sensitivity and 72 channels, an ultra-low-power microcontroller, a SigFox radio module 868 MHz, 14dBm E.R.P., an omnidirectional SigFox antenna, a powered by high-capacity Li-SOCL2 batteries (ExtraCell 3.6 V C ER - 2 × 6500 mA). The device can operate at a temperature range between –20 and 50°C and be put into a commercial case of a small dimension 119×66×43 mm with an IP degree equal to 68 (Figure 6). The accuracy of the location of the LP-GPS devices in static position was about 4-5 m, and it was tested by hanging the collars on a perch and recording the positions within 24 hours.

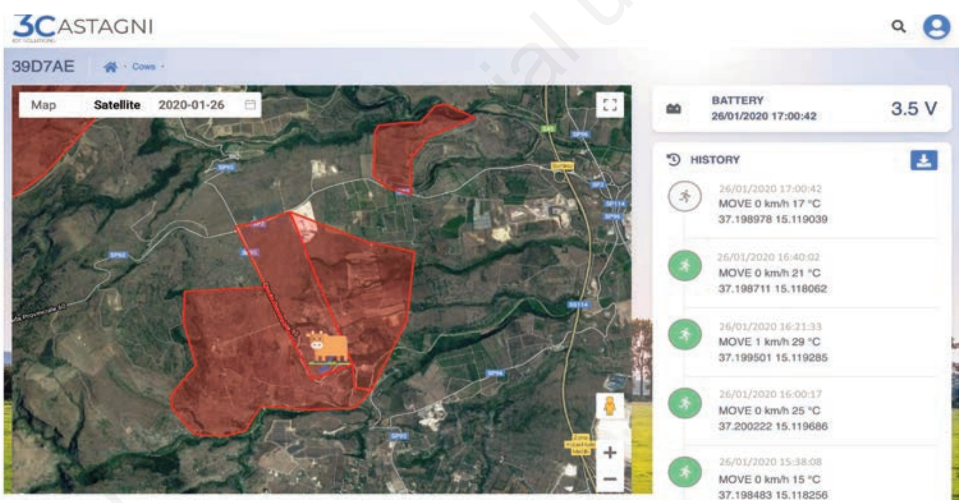

Figure 5. AppWeb interface developed by Trecastagni s.r.l. Company.

Figure 6. Low-power global positioning system device and the IP case.

Ten of these devices were put to the collars (Figure 3) of ten female cows, differing in age and number of births, selected as a sample because they were easily approachable by the breeder. Since the weight of the device (0.3 kg) represented <0.1% of the animal's weight (Feldt and Schlecht, 2016) a period of habituation to the devices of the cows was not necessary.

In Table 1, details related to the selected ten cows and their associated devices were reported. Moreover, a column was added to highlight specific physiological and pathological events during the trial.

The analysis began on 27th December 2019, with the collars and device installation. However, the data recording took place from 1st January 2020, due to the Christmas holidays, and continued until 21st January 2020, when, for technical reasons, the GPS devices were removed from the collars, even if the batteries still had a residual charge. In detail, due to the weakness of the anchor points, some devices began to come off and fall to the ground. Therefore, in order not to damage the instrumentation, it was decided to remove the devices from the collars and reattach them with a safer system. Unfortunately, due to the lockdown, it was no longer possible to return to the company to complete animal observation in time before they were moved to the Nebrodi mountains in June 2020. However, it is believed that the data collected are, in any case, sufficient to describe the functionality of the system and its potential applications both for the management of the herd and in a broader context, that concerns analysis, monitoring, and management of land use. Therefore, data were recorded for 21 days at time intervals of 20 minutes. The whole observation period was subdivided into three 7-day time intervals: first-time interval between 1st and 7th January 2020; second-time interval between 8th and 14th January 2020; third-time interval between 15th and 21st January 2020. Data from Cow 5 were not available because of a problem with the collar attachment.

Results and discussion

Vegetation cover detection and geomorphological analyses of the study area

Through direct surveys and visual inspections carried out in the study area, it was possible to investigate the floristic composition of the field, which appears to be homogeneous in all areas of the pasture since there are no excessive deviations in the general characteristic of the soil regarding morphology (slope and exposure analysis), geology and hydrology (geomorphological analysis) and climatic condition. These activities took place between the end of December and the first ten days of January, a well-known period of medium-low production due to the climate conditions. After this first in-field analysis, the pasture was subdivided into ten different areas (*i.e.*, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10) (Figure 7).

The grazing areas, *i.e.*, 3, 4, 5, 6 (Figure 7), were considered as polyphote pasture close to the road network and characterised by not excessively thick soil coverage, with different pabulary species of legumes, cruciferous and composite grasses but also species that due to their morphological characteristics such as the presence of thorns on the stems are not eaten by the animals. The scarce vegetation cover recorded for these areas was due to the land exploitation by animals which inhibited the growth of pabulary species and

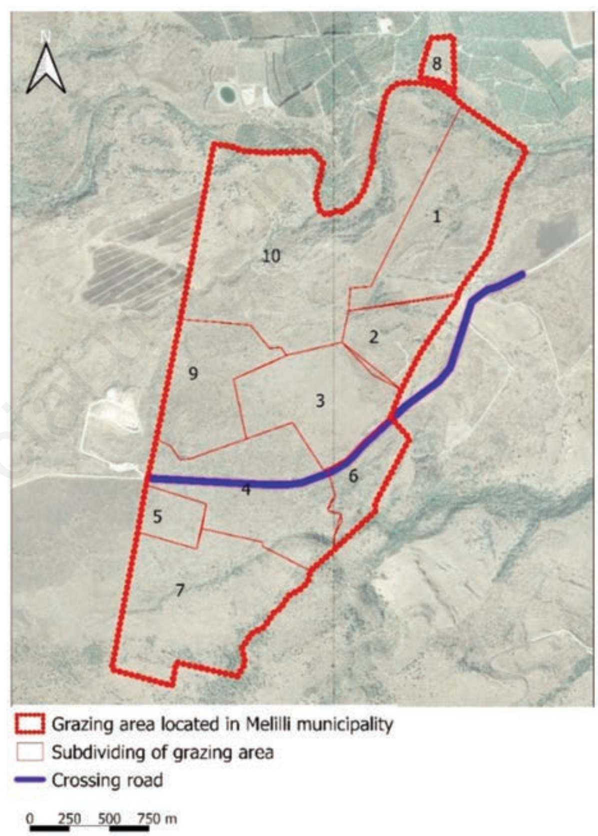

Figure 7. Grazing area subdivided into ten different areas.

Table 1. Main characteristics of the ten cows.

ID cow	Device	Age (year)	Birth	Gender	Calf age	Note
1	0039D0AA	6	3	F	-	-
2	0039D1D9	2	0	F	-	-
3	0039D4B8	10	6	F	30 days	-
4	0039D7AE	6	2	F	-	-
5	0039D35F	4	1	F	-	-
6	0039D56D	2	0	F	-	Oestrus
7	0039D883	8	5	F	-	-
8	003911EC	8	5	F	-	Oestrus
9	003913A1	4	1	F	-	Lameness
10	0036718F	6	3	F	30 days	-

implemented the development of spinescent shrubs.

The grazing areas 1, 8, 9, and 10 that are placed far from the road network are much richer in forage due to their proximity to a dam (Figure 8), a drinking source for the animals. These areas and area 7 are quite homogeneous, characterised by grasses and pabulary legumes (*i.e.*, *composites, 16 asteraceae, umbelliferae, and chenopodiacee*). Among the grasses predominate *Bromus sp., Avena sp., Hordeum sp.* Among the legumes predominate *Trifolium subterraneum, Trifolium campestre, and Medicago arabica and hispida*.

The Mediterranean scrub dominates almost all the vegetation, with carob, olive, and citrus trees. Dwarf shrubs and herbaceous plants, including *calicotome villosa, sarcopoterium spinosum,* and *cynara cardunculus altilis* are the main species characterising the pasture. The excessive presence of these species highlighted high exploitation by animals as the pabulary species become more and more sparse and the non-pabulary species take over.

Through the QGIS software tool, slope and exposure data of the study area were analysed, as reported in Figure 9. As shown in Figure 9A, the slope of the land within the different areas of the considered extensive breeding ranged from 0% to a maximum value of 12%. In detail, the land had a slope of about 0% within areas 1, 2, 3, 5, ranged between 6% and about 12% within areas 4,

Figure 8. Grazing areas in the proximity of the dam.

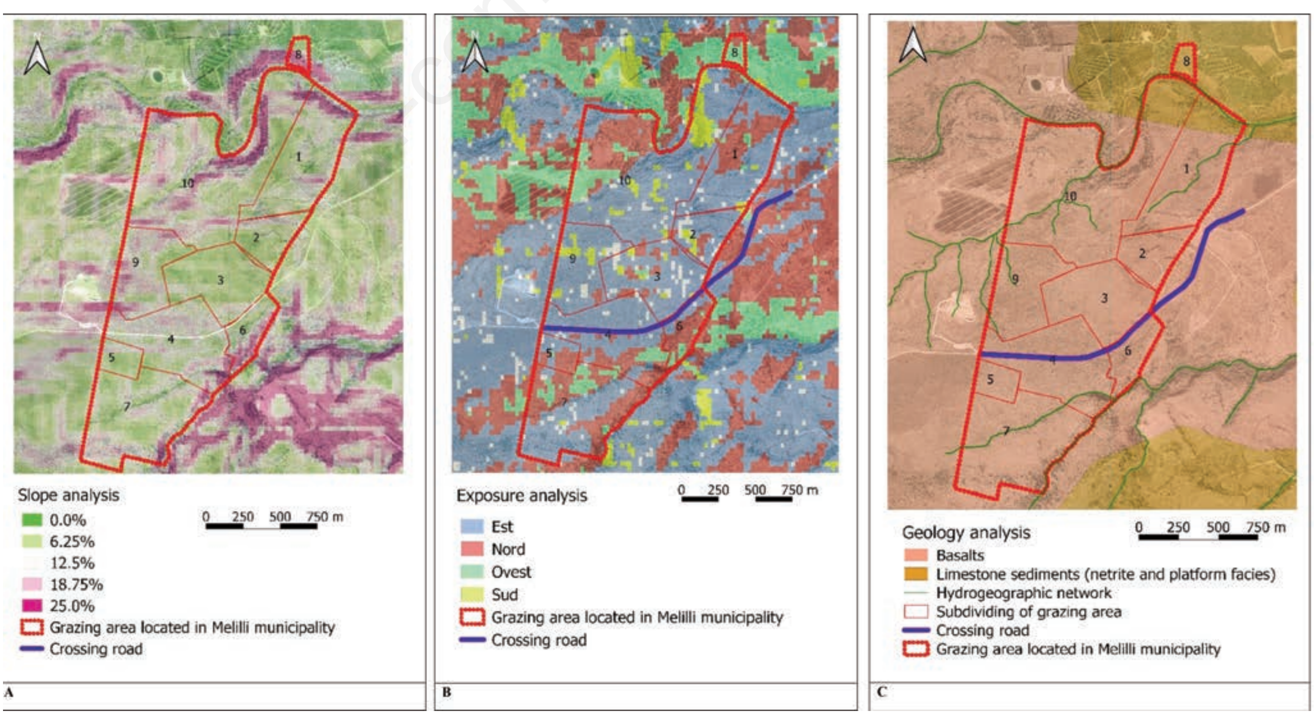

Figure 9. Exposure and slope terrain analyses: A) slope; B) exposure; C) geomorphology.

7, 9, and was about 20% in area 10 due to the presence of an artificial dam located in the North side of the pasture.

The whole grazing area had an Eastern exposure that generates a good experience for animals to solar radiation (Figure 9B), especially during the winter seasons. Furthermore, by analysing the geomorphological characteristics, as reported in Figure 9C, it is possible to observe that the considered area is almost hilly and is crossed by several little waterways, which contribute to increasing the animal well-being, especially during hot climate conditions that occasionally could occur in springer seasons before animals were moved to the mountains.

Analyses of data acquired by the low-power global positioning system-based system

Data collected during the 22 day-monitoring periods were used to locate and track the ten cows equipped with the LP-GPS collars. By applying the KDE algorithm to the dataset acquired by the LP-GPS collars, 9 thematic maps were obtained by using QGIS software tools, one for each monitored cow (Figure 10). Each map reports the perimeter of the whole grazing area, a dirt road that crosses the grazing area and divides it into two parts, the home range and core range areas obtained by the KDE algorithm, the subdivision of the whole pasture into the ten classes previously described.

Firstly, heat maps made it possible to highlight the grazing areas used mainly by animals during the whole data collection period. Table 2 reports the results obtained by these analyses for each animal. Generally, animals preferred flattened areas, as the mean of the slope value was about 4.7% with a maximum of 6.5%, having North-Est exposure, and located at an altitude of about 260 m a.s.l. on average. By analysing Figure 10, it is possible to observe that HR areas (green areas) are higher than CHR ones (red areas) and, as reported in Table 2, they are on average 84% higher than CHR ones, 56.00 ha, and 8.70 ha, respectively. In detail, for Cow 1, Cow 3, and Cow 10, respectively reported in Figure 10A, C, and I, the areas in which the probability of finding the monitored items is 95%, *i.e.*, HR, were similar, about 76.00 ha on average, which is higher than the HR areas recorded for the other cows, especially if compared to Cow 8 (*i.e.*, 19.95 ha).

Instead, by considering the areas in which the probability of finding the monitored items is 50%, *i.e.*, CHR, the lowest areas were recorded for Cow 8 (Figure 10G), about 3.00 ha, and the highest for Cow 3 (Figure 10C) with about 14.00 ha.

By elaborating data recorded from the developed AppWeb, it was possible to define a behavioural profile for each animal

Table 2. Statistical analyses.

39D0AA						39D1D9					
ID Cow 1	GPS-altitude	Slope (%)	Exposure (degree)	HR (ha)	CHR (ha)	ID Cow 2	GPS-altitude	Slope (%)	Exposure (degree)	HR (ha)	CHR (ha)
Mean	232.0	4.2	109.1	76.71	11.18	Mean	260.7	4.9	121.6	59.69	10.05
Max	284.0	10.4	348.8			Max	318.0	15.4	353.3		
Min	176.0	0.8	5.1			Min	215.0	0.9	0.9		
Dev.	20.9	1.9	102.6			Dev.	22.9	2.7	107.3		
39D4B8				39D7AE							
ID Cow 3	GPS-altitude	Slope (%)	Exposure (degree)	HR (ha)	CHR (ha)	ID Cow 4	GPS-altitude	Slope (%)	Exposure (degree)	HR (ha)	CHR (ha)
Mean	239.2	4.4	115.9	74.49	14.34	Mean	238.3	3.4	101.1	49.32	7.03
Max	295.0	18.9	354.8			Max	309.0	9.5	348.8		
Min	167.0	0.6	0.9			Min	168.0	0.8	0.9		
Dev.	29.7	2.4	104.6			Dev.	24.8	1.6	85.8		
39D56D						39D883					
ID Cow 6	GPS-altitude	Slope (%)	Exposure (degree)	HR (ha)	CHR (ha)	ID Cow 7	GPS-altitude	Slope (%)	Exposure (degree)	HR (ha)	CHR (ha)
Mean	260.4	5.9	104.0	35.77	4.93	Mean	225.2	3.7	114.7	55.41	8.94
Max	296.0	19.9	348.8			Max	288.0	12.9	352.0		
Min	166.0	1.3	3.0			Min	168.0	0.9	0.9		
Dev.	25.2	3.0	90.7			Dev.	27.4	2.0	95.3		
3911EC						3913A1					
ID Cow 8	GPS-altitude	Slope (%)	Exposure (degree)	HR (ha)	CHR (ha)	ID Cow 9	GPS-altitude	Slope (%)	Exposure (degree)	HR (ha)	CHR (ha)
Mean	194.1	3.9	129.4	19.95	3.27	Mean	200.0	6.5	112.8	61.66	7.43
Max	246.0	13.6	353.2			Max	290.0	21.0	353.3		
Min	144.0	0.8	7.0			Min	151.0	0.8	6.7		
Dev.	9.6	2.3	95.6			Dev.	29.4	3.8	93.8		
36718F											
ID Cow 10	GPS-altitude	Slope (%)	Exposure (degree)	HR (ha)	CHR (ha)	ALL Cows	GPS-altitude	Slope (%)	Exposure (degree)		
Mean	230.2	5.2	158.9	76.71	11.48	Mean	231.1	4.7	118.6		
Max	314.0	13.2	354.8			Max	171.4	0.9	2.9		
Min	188.0	0.9	0.9			Min	293.3	15.0	352.0		
Dev.	22.6	2.4	125.5			Dev.st	23.6	2.5	100.1		

GPS, global positioning system; HR, home range; CHR, core home range.

through the device, as reported in detail below.

Cow 1, during the whole observation period, travelled about 43 km, with an average of 2 km per day (Table 3) and a maximum and minimum covered distance of about 3.5 km and 1.3 km, respectively. During the first 7-day time interval of monitoring, about 12 km- distance was travelled, and an increase of about 4 km was recorded in the second-time interval because of the necessity confirmed by the farmer of moving for looking better forage mainly located in the areas 2, 9 and 10.

Cow 2, during the whole observation period travelled about 50 km with an average of 2.4 km per day and a maximum and minimum covered distance of about 3.6 km and 1.6 km, respectively (Table 3). During the first 7-day time interval of monitoring, about 18.5 km-distance was travelled, and a decrease of about 3 km was recorded in the next time interval. By comparing heatmaps (Figure 10A and B) and travelled distance of Cow 1 and Cow 2, it emerged that Cow 2 covered areas 1 and 10 more than Cow 1 that, conversely, preferred to stay for longer in those areas close to the crossing road (*i.e.*, areas 4, 6, 3). This difference could be explained by the fact that Cow 2 is younger than Cow 1 and preferred group life.

Concerning Cow 3, as Cow 2, it covered about 50 km with an average of 2.4 km per day and a maximum and minimum covered distance of about 3.2 km and 1.3 km, respectively. As shown in Figure 10C, the behaviour profile of Cow 3 obtained through the heatmap was like that of Cow 2 and highlighted an HR area, which was far from the central grazing area due to the possible necessity to move to areas richer in forage and closer to the natural drinking source (*i.e.*, area 1 and areas 10). This movement occurred mainly in the second-time interval of observation when the distance travelled was higher than in the other two periods (18.77 km) (Table 3). Cow 4, during the whole observation period, travelled about 48 km, with an average of 2.3 km per day and a maximum and minimum covered distance of about 3.0 km and 1.7 km, respectively (Table 3). During the first 7-day time interval of monitoring, about 14 km - distance was travelled, and an increase of about 3 km was

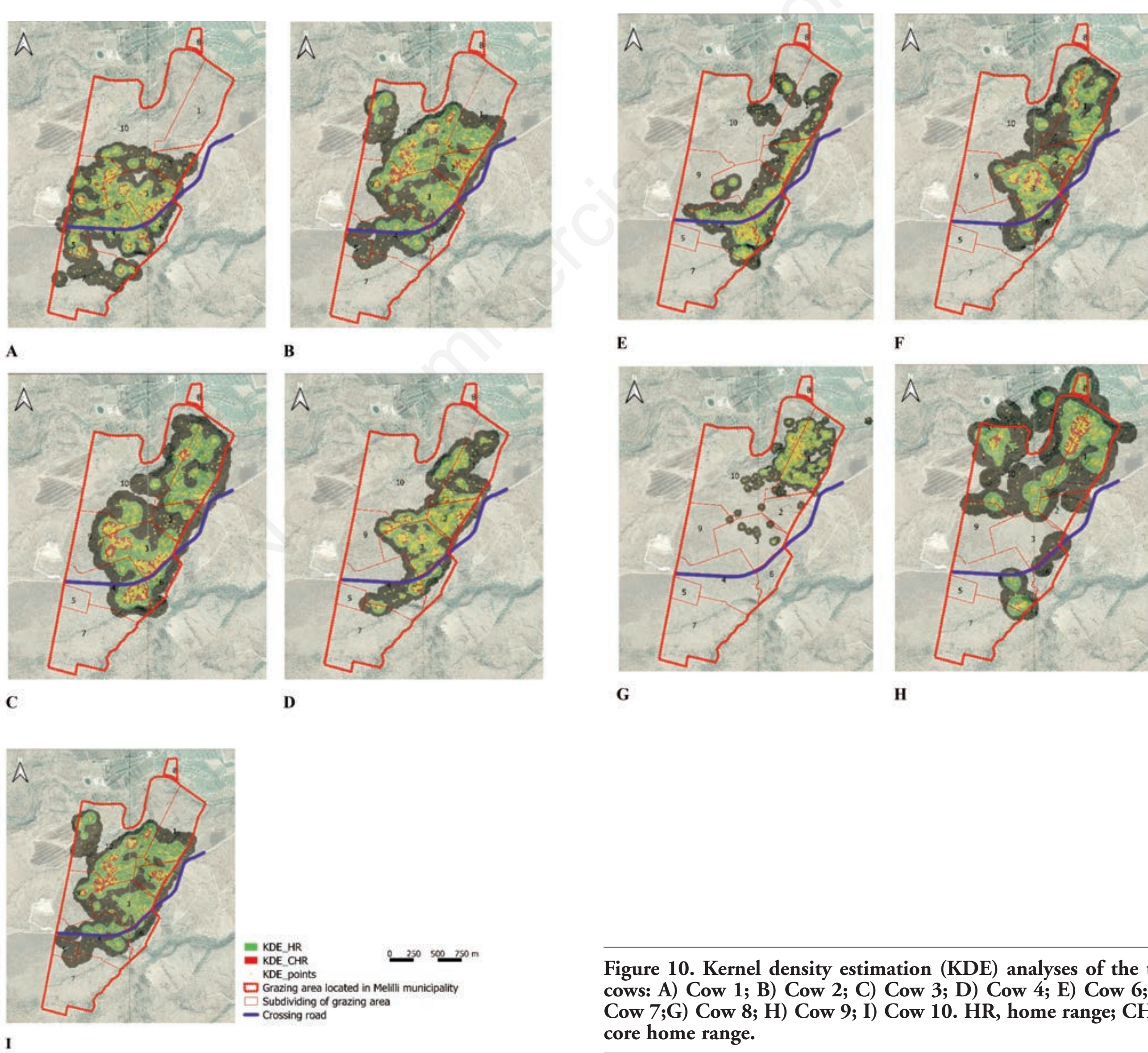

Figure 10. Kernel density estimation (KDE) analyses of the ten cows: A) Cow 1; B) Cow 2; C) Cow 3; D) Cow 4; E) Cow 6; F) Cow 7;G) Cow 8; H) Cow 9; I) Cow 10. HR, home range; CHR, core home range.

registered in the second-time interval. The Heatmap reported in Figure 10D shows only a few HR areas close to the road network (*i.e.*, areas 2, 3, 4, 6), which could be explained due to the Cow 4 rustic attitude that prompted the preferences for those areas placed in North-Est side of the grazing area further away from the road and human presence.

A similar behaviour profile was observed for Cow 8 that travelled about 45 km within the 21-days of the experiment. In detail, similar travelled daily distances were recorded during the first-time interval of observation, while during the second one, an increase of about 4-km was recorded, on 10th January, due to the heat state during the oestrus cycle, as then confirmed by the farmer. The Heatmap reported in Figure 10G shows that CHR and HR areas are both far from the crossing road, placed within the inner part of the grazing area 10, because of the cow's solitary and rustic attitude.

With regard to Cow 6, the whole travelled distance was about 47 km, with an average per day of 2.2 km and a maximum and minimum of 4.0 km and 1.1 km, respectively. Figure 10E shows HR areas along the road and mainly located within areas 4. As reported by the farmer, the cow has an oestrus cycle during the second time interval. Data revealed an increase in the travelled daily distance on 12th January (4.02 km).

Cow 7 recorded data, in comparison with the others, show different travelled distances during the three-time intervals considered. It travelled about 54 km, with an average of 2.6 km per day (Table 3) and a maximum and minimum covered distance of about 4.4 km and 0.86 km, respectively (Table 3). An increase of about 2 km of the travelled distance was registered in the third-time interval. The CHR and the HR areas show (Figure 10F) that cow preferred to stay mainly in areas 1, 2, and 3. In the latter is located most of the HR areas as for Cow 1 and Cow 4.

The overall travelled distance of Cow 9 was the smallest observed, equal to about 36 km, with an average per day of less than 2 km (1.7 km). In the first-time interval of observation, Cow 9 travelled about 14 km, similarly to other cows (*i.e.*, Cow 4, Cow 8, Cow 10), however both in the second- and third-time intervals, the travelled distance drastically decreased to about 11 km and 10 km, respectively. From observing this sudden reduction in the travelled distance, the breeder promptly recognised a lameness in the right anterior limb of the Cow 9, which was therefore transferred for medical treatments. The heatmap reported in Figure 10H shows that the CHR areas are widely distributed throughout the entire grazing area; instead, as related to the HR areas, the largest one shows that the animal remained there for longer and represents the equipped shelter area where the animal was transferred for medical treatments due to the limb lameness (between areas 1 and 10).

The overall travelled distance of Cow 10 was among the great-

Table 3. Daily distance walked by the monitored cows.

Monitoring (day)	Cow 1 0039D0AA Distance (km)	Cow 2 039D1D9 Distance (km)	Cow 3 0039B4D8 Distance (km)	Cow 4 0039D7AE Distance (km)	Cow 6 0039D56D Distance (km)	Cow 7 0039D883 Distance (km)	Cow 8 003911EC Distance (km)	Cow 9 003913A1 Distance (km)	Cow 10 0036718F Distance (km)
1	1.94	2.25	2.12	1.66	2.43	2.13	1.55	1.98	2.32
2	1.51	2.83	2.11	2.06	2.34	2.05	2.1	2.32	2.77
3	2.09	1.63	3.21	2.23	2.43	2.81	2.07	1.89	3.18
4	2.01	3.01	2.5	1.9	2.36	2.26	1.92	2.06	2.83
5	1.27	3.6	2.13	2.11	1.97	3.22	2.63	2.44	1.87
6	1.47	2.68	1.77	2.25	1.93	2.42	1.87	2.14	0.91
7	1.93	2.50	2.75	2.20	1.92	2.60	1.86	1.63	1.05
1st time -interval	**12.22**	**18.5**	**16.59**	**14.41**	**15.38**	**17.49**	**14.00**	**14.46**	**14.93**
8	2.53	2.50	2.43	2.0	2.49	3.42	2.36	1.32	3.37
9	1.86	2.16	1.92	2.18	1.85	2.41	2.11	1.55	2.29
10	3.46	2.56	3.17	2.61	2.04	3.26	4.32	3.01	3.19
11	1.66	1.65	2.56	2.09	1.72	2.59	1.91	1.98	2.14
12	2.08	2.18	3.13	2.53	4.02	2.27	2.45	1.20	3.06
13	2.34	2.100	2.95	2.9	1.69	1.69	1.68	1.03	2.22
14	2.11	2.20	2.61	2.36	2.07	1.72	2.11	1.51	2.13
2st time -interval	**16.04**	**15.35**	**18.77**	**17.07**	**15.88**	**17.36**	**16.94**	**11.60**	**18.4**
15	1.41	2.27	2.66	1.77	2.13	2.36	2.48	1.00	2.16
16	1.94	2.69	2.61	2.76	2.00	2.75	1.67	1.50	2.96
17	1.83	2.46	2.58	2.2	1.82	2.79	1.54	1.75	2.07
18	2.68	2.05	1.8	2.55	3.26	3.96	2.83	0.59	4.67
19	2.19	1.74	1.3	1.92	1.11	2.31	1.45	0.97	1.98
20	2.39	2.39	2.34	1.98	3.26	0.86	2.16	2.89	1.60
21	2.38	2.69	2.16	3.07	2.01	4.41	1.97	1.69	3.25
3rd time -interval	**14.82**	**16.29**	**15.45**	**16.25**	**15.59**	**19.44**	**14.10**	**10.39**	**18.69**
Total	43.08	50.14	50.81	47.73	46.85	54.29	45.04	36.45	52.02

est, equal to about 52 km, with an average per day of about 2.5 km and a maximum and minimum of 4.7 km and 0.9 km, respectively. Through the heat maps, it was possible to identify the widest HR area (Figure 10I) located in area 2 where the cow stayed from 6th to 7th January 2020, when a drastic decrease of the travelled daily distances was registered, about less than 1 km per day as also observed for Cow 9. However, during the second- and the third-time intervals, the travelled distances increased again because of the necessity of finding new grazing areas richer in forage. Therefore, cow 10 stayed more time in area 10, located near the dam.

The monitoring of animal behaviour profiles could be useful for understanding and analysing the interaction between animals and the environment. In this regard, through the Kernel Density Estimation, it was possible to create heat maps aimed at evaluating the most preferred territorial areas from all the considered cows. The analysis was carried out by profoundly analysing the time intervals within the daytime observation period in which the cows moved from the occupied territorial area to another one. In detail, the analysis was carried out by observing four-time intervals considered as most representative of these cows' activities, *i.e.*, from 08:00 a.m. to 10:00 a.m., from 10:00 a.m. to 00:00 p.m., from 00:00 p.m. to 02:00 p.m., from 02:00 p.m. to 04:00 p.m., from 04:00 p.m. to 06:00 p.m. A heatmap was carried out for each of the selected time intervals, as reported in Figure 11.

By analysing Figure 11A and E, obtained by carrying out KDE analyses at 8:00 a.m. and 4:00 p.m., respectively, it is possible to observe similar HR areas (*i.e.*, 96.97 ha and 118.31 ha, respectively), larger than that obtained for Figure 11B, C, and Figure D (*i.e.*, 68.30 ha, 61.68 ha, 86.28 ha), carried out at 10:00 a.m., 00:00 p.m., and 02:00 p.m., respectively. The similarity in these two HR areas could be explained because at 8:00 a.m.; the animals are still scattered within the grazing area since, as it is well known, they prefer to stay alone and not assembled during the night hours. Then after the sunrise, the cows started their daily activities (*e.g.*, walking, feeding, ruminating, drinking) before beginning again to disperse throughout the territory to spend the night (4:00 p.m.).

As it is possible to observe from Figure 11B, C, and D that show KDE analyses carried out at 10:00 a.m., 00:00 p.m., and 02:00 p.m., respectively, the reported HR areas are smaller than the previous ones cited above and similar to each other, since the cows grouped together and carried out the same daily activities.

In order to evaluate the territorial areas most visited by all the cows during the whole observation period, the heatmap reported in Figure 11 was developed. It was built by merging all the HR areas obtained by the previous KDE analyses (Figure 10). From Figure 12, it is possible to see that, among the obtained six areas (*i.e.*, A, B, C, D, E, F), 'area D' was frequented mainly by the animals, about 63.00 ha. Furthermore, 'area D' registered an HR area higher more than 80% than other ones, *i.e.*, 3.90 ha, 0.78 ha, 0.23 ha, 6.90 ha, and 2.40 ha, recorded for 'area A', 'area B', 'area C', 'area E', and 'area F', respectively.

'Area D' was preferred because it was the flattest, near the dam, far from the road network, and far from the humans' presence, and had a great supply of forage, as observed during the visual inspection.

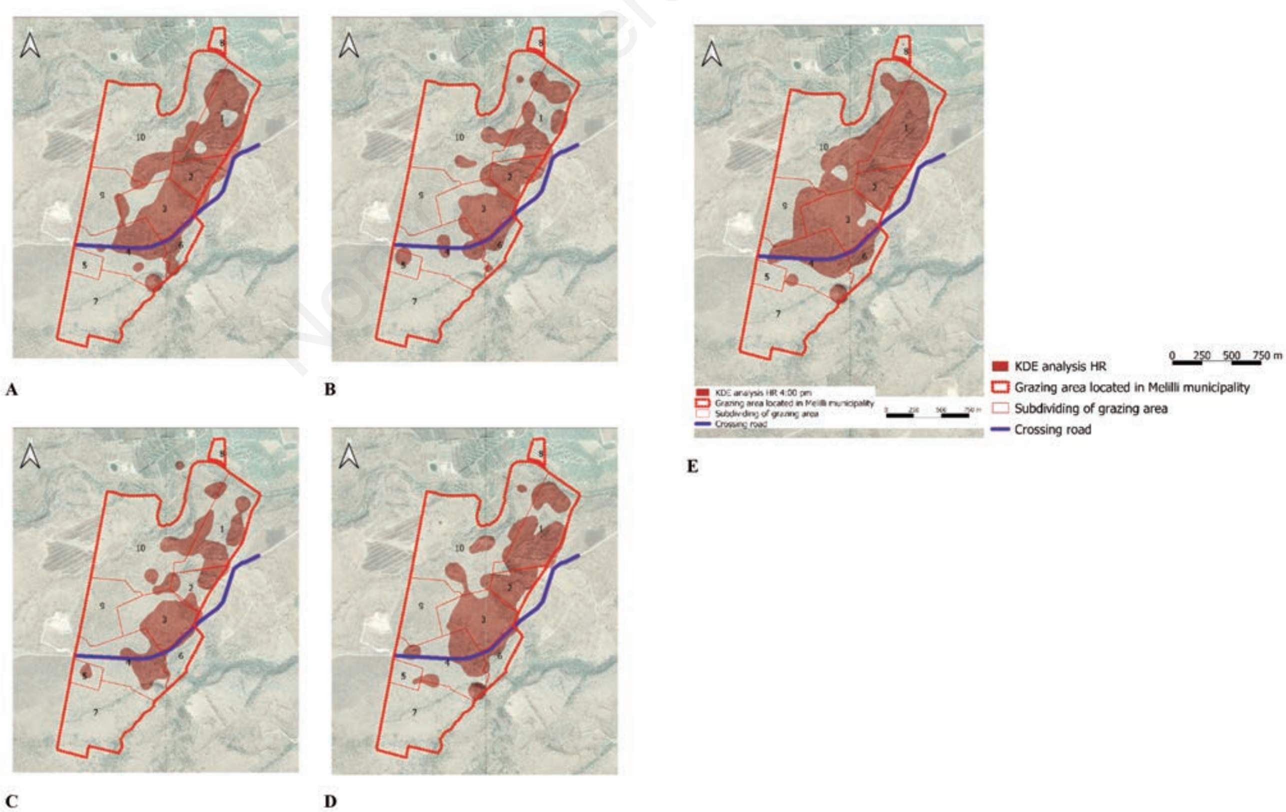

Figure 11. Kernel density estimation (KDE) analyses: home range (HR) of all considered cows during the whole observation period: A) time 08:00 a.m.; B) time 10:00 a.m.; C) time 00:00 p.m.; D) time 02:00 p.m.; E) time 04:00 p.m.

Cow's activities influenced the soil cover of this area by taking plants and seeds and the restitution through the manure. Furthermore, animal trampling modifies the natural form of the soil; in fact, it was possible to observe the presence of well-established paths in the direction of the few watering points.

Data obtained by LP-GPS collars could allow farmers to assess feeding areas and grazing conditions and, if required, make it possible to improve herd management by evaluating possible nutritional supplements or looking for other pastures.

The behavioural profiles obtained using data acquired by the LP-GPS collars (Figure 10) could represent a crucial aspect of livestock management since it could allow prompt actions for preserving animal welfare (Figure 12). In fact, by observing the reduction of the daily distance travelled by Cow 9, the breeder immediately discovered a right limb lameness and quickly transferred the cow for medical treatment by preventing other diseases. As stated by Frost *et al*. (1977) since animal behavioural activities are clear indicators of cow physiological and physical status, particular attention will be paid to further improvement of the developed automated locating system by implementing other sensors able to monitor the daily activities of grazing cows.

In this regard, data coming from LP-GPS collars combined with data coming from land use in the GIS environment could allow the monitoring of any important variations within the structure of the vegetation and in the composition and variety of plant species that may arise due to food selection of essences, trampling, and release of manure. Through these actions, the animals modify the habitats and the populations of invertebrates and other organisms (Crovetto and Sandrucci, 2010). Changes in the intensity of grazing or the animal species involved can have significant consequences on biodiversity (Batalla *et al*., 2015). Furthermore, from the social, economic, and cultural point of view, the identification of the most exploited grazing areas can be useful in the context of the assessment procedures of the landscape characteristics (relationship of the areas subject to grazing and the characteristics of the landscape of the area) (Crovetto and Sandrucci, 2010; Meier *et al*., 2015). In general, the relationship between animal husbandry and landscape quality can be positively configured, as it can happen in the case of rationally conducted grazing farming systems where the maintenance of the grass in good clean conditions, together with the presence of grazing animals, contribute to landscape amenities (Leinonen *et al*., 2012). On the other hand, the presence of marginal areas, which from the analyses may not be used by animals, could reduce the aesthetic value of the landscape because of abandonment that could result (Rivero *et al*., 2021).

This kind of automated monitoring systems could be significant for transhumance, a practice relevant for breeders as it integrates the normal annual forage and allows access to public economic aids (Zendri *et al*., 2013). Moreover, transhumance has significant economic externalities because it increases the cultural values of a territory, by improving landscape quality, promoting local products, such as milk and cheese (Sturaro *et al*. 2013), maintaining local tradition (Baudry and Thenail 2004; Eriksson 2011), supporting the biodiversity through the conservation of native species of high values (Zendri *et al*., 2016).

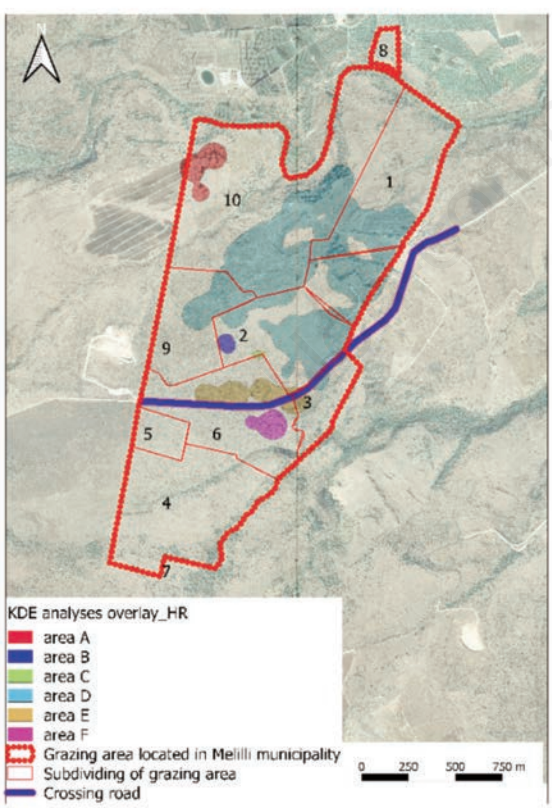

Figure 12. Overlay of home range (HR) areas obtained by Kernel density estimation (KDE) analyses carried out for each herd animal.

Conclusions

Real-time monitoring of the herd in extensive livestock systems represents a challenging task to measure those variables that can provide farmers with timely alerts. Prompt reactions to any change in health, welfare, and production status are the key factors helpful for reducing management difficulties and improving animal welfare.

The results achieved in this study demonstrate the feasibility of the system based on GIS analyses and LP-GPS devices for locating grazing cattle, as this system could ensure a long-term tracking of the animal. They could help farmers monitor cows within the grazing areas and therefore observe relevant modifications to their habits and/or avoid or partially solve problems related to animals' theft. In this context, this study represents the first step towards new research aiming at a reliable classification of grazing cow behaviour based on data collected from other sensors and validated by breeder observations.

Potential applications of the proposed monitoring system may be of interest to local authorities or regional environmental protection agencies. In fact, the system in addition, could help stakeholders to estimate the impacts of extensive dairy cattle and cows of cow-calf line farms on soil quality.

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