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Research article

GIS-based methodology for tracking the grazing cattle site use

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ABSTRACT

Interest in tracking and monitoring animals in livestock farming using wearable sensors has been steadily increasing. The use of these devices is particularly crucial in extensive livestock systems where direct interaction between animals and farmers is infrequent, necessitating strenuous efforts in long-distance herd monitoring. Internet of Things (IoT) technologies offer a promising solution to address the challenges posed by vast distances, enabling real-time and remote animal monitoring. In this study, an experimental trial was conducted using a custom-designed device, located in a Polyvinyl Chloride (PVC) case, specifically tailored to fit onto a collar. This case incorporates an integrated SigFox communication system, i.e., a Low Power Global Positioning System (LP-GPS) omnidirectional system, and a power supply. The trial took place in two grazing areas located in different territorial zones, designated as *Case Study I* and *II*. A LP-GPS collar was provided for each selected animal, and the data were recorded at 20-min intervals for *Case Study I* and 10-min intervals for *Case Study II*. The acquired data were then imported and analysed using Geographical Information Systems (GIS) software. Information was collected through a purpose-built web application (AppWeb). The objective was to analyze those territorial areas mostly occupied by animals within the two considered grazing areas by developing a GIS-based methodology. Specifically, customized algorithms such as Heatmap and Kernel Density Estimation (KDE) plugins were employed to conduct spatial analyses. The maps obtained through Heatmap plugin, showed the temporal-spatial distribution of animals within their grazing areas. Additionally, the KDE tool was used to classify preferred territorial areas, generating tailored charts for each animal in the sample. The individual Core Areas, determined through KDE evaluation for each animal, were overlaid to provide a comprehensive analysis of the monitored animals.The results achieved applying the GIS-based methodology facilitated the identification of animal positions and could be adopted to provide insights into feeding behavior and soil erosion, thereby aiding in the prevention of environmental issues.

1. Introduction

Gradually, the attention of consumers for wellness and high quality of food is constantly increasing; in order to address these demands, farmers must attain high standards production while concurrently enhancing environmental sustainability and maintaining optimal animal welfare [1]. The growth of intensive livestock farms has exacerbated management issues related to the inability to

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provide individualized attention to animals concerning their welfare, health, and production efficiency. Conversely, extensive livestock farms face challenges in monitoring animals across vast open spaces, where tracking animal location and observing their health and grazing conditions are of paramount importance [2].

In light of these challenges, the importance of technology and innovations, such as Internet of Things (IoT) technologies, continues to grow [2]. Numerous studies worldwide have focused on validating wearable animal sensors to assist farmers in herd management [3–6]. Animal location monitoring yields critical information regarding animal movements across the landscape, the spatial variability of their field occupancy, pasture utilization, performance, behavior, and social interactions [7].

Moreno et al. [8], developed a conceptual framework for the classification of technologies in the agricultural sector, and introduced the "Agricultural Technology Navigator" (ATN), an iterative tool designed to identify and communicate technologies related to digital solutions, determining different dimensions or categories in which the different technologies applied to agriculture can be classified. They also evaluated the outcomes of the Horizon 2020 SmartAgriHubs (SAH) project, a European initiative aimed at enhancing Digital Innovation Hubs (DIHs) and Competence Centres (CCs) in the agricultural sector [8].

Recent advancements in IoT systems have enabled the deployment of sensor networks in extensive livestock systems, often situated in areas lacking electricity and internet connectivity [9]. Several studies worldwide have focussed on assessing Global Positioning Systems (GPS) for real-time animal monitoring, generating timely alerts to prevent animals from straying beyond grazing boundaries [10,11]. GPS-based technology is also suitable to implement anti-theft control systems, such as collar receivers, as livestock theft remains a significant concern for farmers, prompting substantial investments in insurance to mitigate economic losses resulting from theft [7].

Furthermore, landscape and ethologists planners strive to analyze the most heavily utilized territorial areas to understand the factors influencing animal movement and distribution within the landscape, with the aim of reducing soil erosion [12]. It is widely acknowledged that all livestock activities impact the ecosystem, altering water and air quality, microclimate, macroclimate, soil characteristics, biodiversity, and landscape [13,14]. While extensive breeding practices give rise to various environmental challenges, they are essential to meet the global demand for animal-derived food products [15,16]. However, the intensification of animal farming can exacerbate local environmental impacts [17], contributing to land degradation, a global environmental hazard causing environmental, social, and economic losses [18]. In this regard, to effectively study animal behavior, it is necessary to integrate location data with information derived from customized thematic maps, such as, heat maps, graduated symbol maps, and dot density maps [19]. GPS devices can also facilitate animal identification and territorial-level tracking through Geographical Information System (GIS)-based software. In order to obtain efficient studies of animal behavior, it is necessary to combine location data with information acquired from tailored thematic maps. This interaction can be carried out by adopting GIS software that allows easy management, analysis, and storage of large volumes of spatial data [12]. Barbari et al. [12] proved that the combination of using GPS and then GIS for tracking and locating animals in several grazing areas, is a key element in reaching important conclusions on the territory and on biological matters. Indeed, GIS-based models can integrate diverse data sources and conduct spatial analyses to both manage and analyze various types of georeferenced information using map layers. GIS software applications serve as decision-making tools across various disciplines, addressing location-allocation-related problems by minimizing transportation distances [20–23], or to produce dynamic temperature maps interpolating maps with the temperature records combining GIS and sensors [24]. In this context, an IoT-based solution could supply a significant dataset of geo-spatial information to be combined into GIS software for managing the environmental impacts of extensive livestock systems. Moreover, IoT tools enable rapid long-distance tracking of herd positions. Recently, several scientifics studies employing GPS to locate herds underscore the urgent need to address challenges related to the development of high-energy-density batteries and sensor miniaturization [25–27]. Many Low Power Wide Area Networks (LPWANs), such as Sigfox and LoRa, have emerged, offering long-distance wireless communication with low power consumption and low transmission rates [28]. Porto et al. and Castagnolo et al. demonstrated the feasibility of an automatic system for monitoring and detecting cows in extensive livestock systems using space-time data from a low-power global positioning system (LP-GPS) [7,9].

Several methods have been adopted worldwide for spatially analysing point distribution density and point pattern, including the nearest-neighbor distance method, Ripley's *K* function for point distributions, and ordinary Kriging method [29–31].

Among these methods, GIS-based methodology utilizing the Kernel Density Estimation (KDE) tool is the most widely used for evaluating the properties of point events, given its ease ofimplementation, comprehensibility, and suitability for identifying local spatial characteristics [32–36].

The main objective of this study was to demonstrate the suitability of the developed GIS model based on KDE analyses in order to track and locate cows, as an initial step towards enhancing farm productivity by reducing farmers' costs and time, especially in extensive livestock systems [37]. Grazing cattle site preference were detected and linked to vegetation and soil types. For the first time, this type of model is applied in a rural context, with the final aim of monitoring and preventing soil erosion, mitigating animal disease, and providing prompt assistance in emergencies.

2. Materials and methods

This paper proposes a methodology to achieve the stated objective, namely, the localization of cows in extensive livestock systems. The suggested methodology is GIS-based, utilizing base maps such as the Regional Technical Map (RTM 2008) to produce customized thematic maps. Data obtained from GPS wearable devices were collected and processed through trial experiments to develop tailored maps within a GIS framework. The trial experiments were conducted in two case studies situated in distinct territorial areas, referred to as *Case Study I* and *Case Study II*.For real-time monitoring of cow positions, a Low Power GPS-Based System (LP-GPS system) was employed, as established by Porto et al. [7]. This system utilizes wearable technologies capable of receiving position information from up to three global navigation satellites systems (i.e., navigation by satellites and ranging - NAVSTAR/GPS, Galileo, Global Navigation Satellite System - GLONASS), with this study focusing on the NAVSTAR/GPS system. The combination of a Low Power communication network and a low sampling rate contributes to an extended battery life compared to other systems documented in literature [4,38]. These wearable devices gather location data of cows, including latitude, longitude, distance moved, and time of detection by each animal, referred to EPSG:3004 Monte Mario/Italy zone 2 coordinate system. Subsequently, this data is transmitted via the SigFox telecommunication network to a cloud server for processing and visualization through a WebApp developed by *Trecastagni s.r.l. Company*.

The SigFox antenna located in the province of Syracuse, Italy, close to Monte Lauro, was used for both case study areas evaluated in this study. Each wearable device is equipped with an omnidirectional GPS antenna and receiver with - 167 dBm sensitivity and 72 channels, an ultra-low power microcontroller, a SigFox radio module operating at 868 MHz with 14dBm E.R.P., an omnidirectional SigFox antenna, and a powered by high-capacity Li-SOCL2 batteries. The accuracy of the wearable devices was tested at 4–5 m by suspending the collars on a perch and detecting their positions over a 24-h period.

2.1. *GIS-based methodology*

In this study, a GIS-based model was developed using QGIS software (v3.26.2), an open source GIS software for collecting, organizing, analyzing, and visualizing geographical data [39-41].

Two plugins available in the QGIS software were utilized:the QGIS Heatmap Plugin and KDE tool, for generating heatmaps and calculating the Home Range (HR) (95 % fixed kernel analysis) and Core Area (CA) (50 % fixed kernel analysis). Firstly, the Heatmap plugin was applied to produce customized heatmaps. Heatmaps represent data graphically, with different intervals of values such as temperature, animal concentration, waste production, etc., each associated with a color. This facilitates the visualization and analysis of complex data, particularly dense point data, making them suitable for identifying clusters of high activity, such as animal presence, and conducting cluster or hotspot analysis [42]. In the Heatmap plugin application, the discrete-interpolation method was utilized, and the input feature was weighted by the attribute related to the system availability, in order to enhance its influence on the resultant heatmap.

Then, the KDE tool was applied to create a density raster of an input point vector layer. Kernel Density Visualization (KDV) has found wide application in various disciplines including geography, crime science, transportation science, and ecology, for analysing geospatial data [43].

Density calculation is based on the number of points in a location, with larger numbers of clustered points resulting in higher values, facilitating the identification of “hotspots” and point clustering.

The KDE algorithm is particularly suitable to calculate the home range of species, indicating the area in which a species lives and moves, providing an estimate of land use density. The result of a KDE analysis is a raster map showing the most frequently used part of land. Two density levels are considered: the 50 % CA, and the 95 %, HR. The CA represents the area in which the chance of detecting the species is 0.5, while the HR represents the area where this probability is 0.95. In this study, the KDE algorithm was adopted to generate tailored maps for each considered animal.

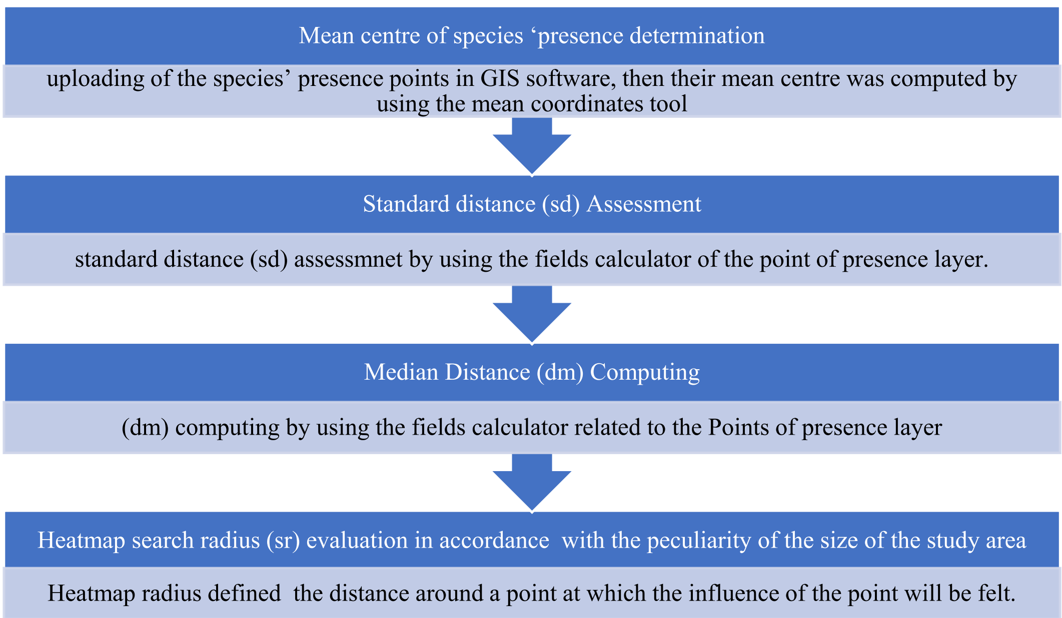


Fig. 1. Flow-chart of the KDE methodology.

In detail, Fig. 1 illustrates the KDE methodology flowchart.

In particular, the hetmap' radius specifies the distance around a point at which the influence of the point will be felt. Larger values result in greater smoothing, but smaller values may show finer details and variation in point density. This value mostly depends on the type of input data. To determine the search radius, the pixel size is chosen according to the specific requirements of the study, considering factors such as size of the study area, visualization needs, and the output raster's size [32,44]. For this study's specific requirements, the authors assumed a cow's influence radius up to 50 m from its location, thus selecting a pixel size of 50 m.

As a result, three areas most frequented by the species were distinguished. Two different KDE ranges (i.e., density levels) were calculated, the first one corresponding to the 50 % (CA), the second one evaluated by considering the 95 % (HR). These two computed threshold ranges were used to generate the heatmap.

2.1.1. *Case study I*

Case study I was conducted in the territorial area located within the municipality of Melilli, belonging to the province of Syracuse, Italy. Melilli covers an area of 13.608 ha, situated on a hilly area 3300 m above the sea level, with a population density of 90 inhabitants per square kilometre.

The experimental trial spanned 21 days, from January 1 to January 21, 2020. Unfortunately, due to the COVID pandemic, extending the trial period was not feasible. Nevertheless, the collected data were satisfactory for defining the functionality of the system and its possible applications.

The data acquisition-time interval was set to 20 min, as well as the time interval for sending messages to the cloud server. This acquisition-time interval is suitable for gathering long-term data to develop customized GIS analyses, such as applyng the KDE tool, while also enduring prolonged battery life.

The grazed area used for the experimental trial was delimited by an electric fence, to avoid cows oltrepassing, and extended over approximately 100 ha (Fig. 2). However, cows has access to the entire area. The floristic composition of the field was investigated through direct surveys and visual inspections conducted in the study area. The grazing area was uniform, with grasses and forage predominating, as reported by Porto et al. (2022) [7]. In areas close to the road network, various forage species including legumes, cruciferous, and composite grasses were observed.

For the experimental trial, as suggested by the farmer, 10 dairy cows were selected from among 90 animals, all belonging to the same mixed breed but differing in the number of births. 10 cows represented more than the 10 % of the total animal population, and to ensure a representative sample, cows were selected with ages ranging between 2 and 10 years. In detail, cows 1 to 10 ranged in age as follows: cow_{1_SR}, cow_{4_SR}, and cow_{10_SR} were 6 years old; cow_{2_SR}, and cow_{6_SR} were 2 years old; cow_{3_SR} was 10 years old; cow_{7_SR}, and cow_{8_SR} were 8 years old; cow_{5_SR}, and cow_{9_SR} were 4 years old; (ID cow = cow_{n_SR} where n is from 1 to 10).

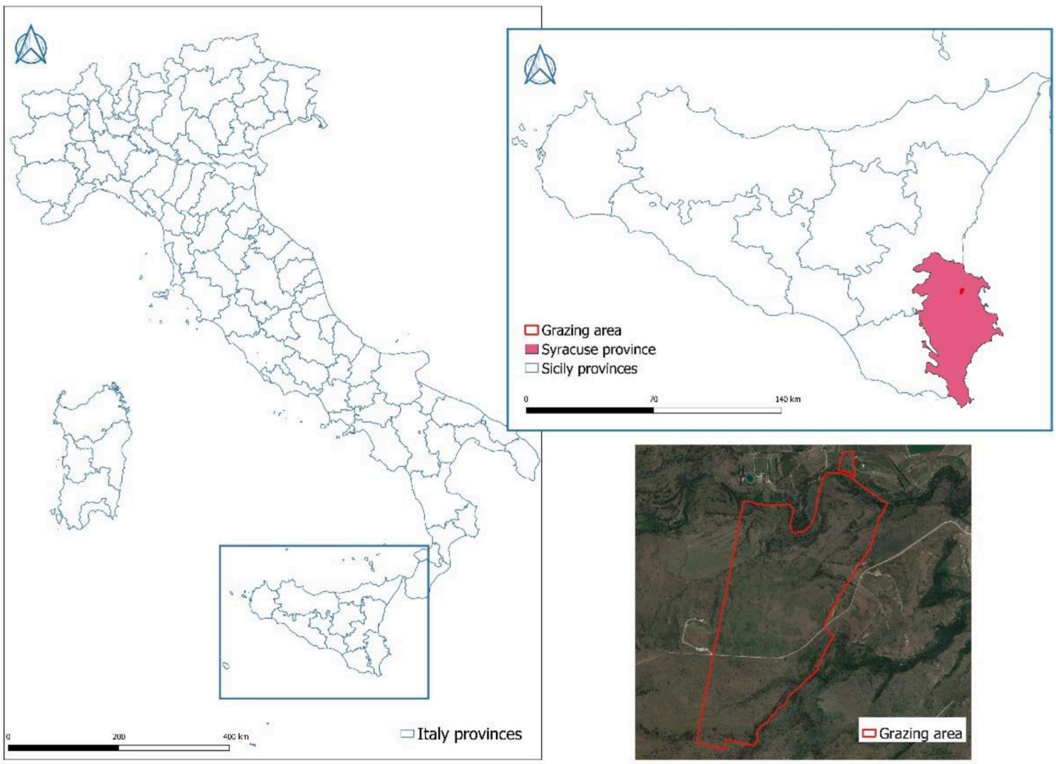


Fig. 2. The territorial area considered in CASE I by the localization of the grazing area.

2.1.2. Case study II

The second case study was conducted on an extensive farm situated in the municipality of Aidone, located in the province of Enna, Italy. Aidone spans an area of 20,986 ha, with a population density of 32 inhabitants per square kilometre. It upsurges over an internal hilly area, 800 m above the sea-level.

Aidone, located on the eponymous mountain, is renowned for its cultivation of walnuts, olives, wheat, grapes, almonds, and citrus fruits. The region also boats thriving cattle breeding and sheep farms, thanks to its vast pasturelands. The trial took place from July 2021 to August 2021, with temperature ranging between 22 °C and 42 °C, spanning a duration of 38 days.

The selected grazing area was enclosed by an electric fence to prevent herd trespassing (Fig. 3), encompassing approximately 300 ha. Similarly, cows in this study area had unrestricted access to the entire area. Visual inspections and direct surveys were conducted in this research area, which featured classified articficial pasturelands. The grazing areas was divided into three different territorial zones (i.e., 1, 2, and 3): the first characterized by olive trees and natural meadows; thesecond by *Trifolium alexandrinum,* and the third by

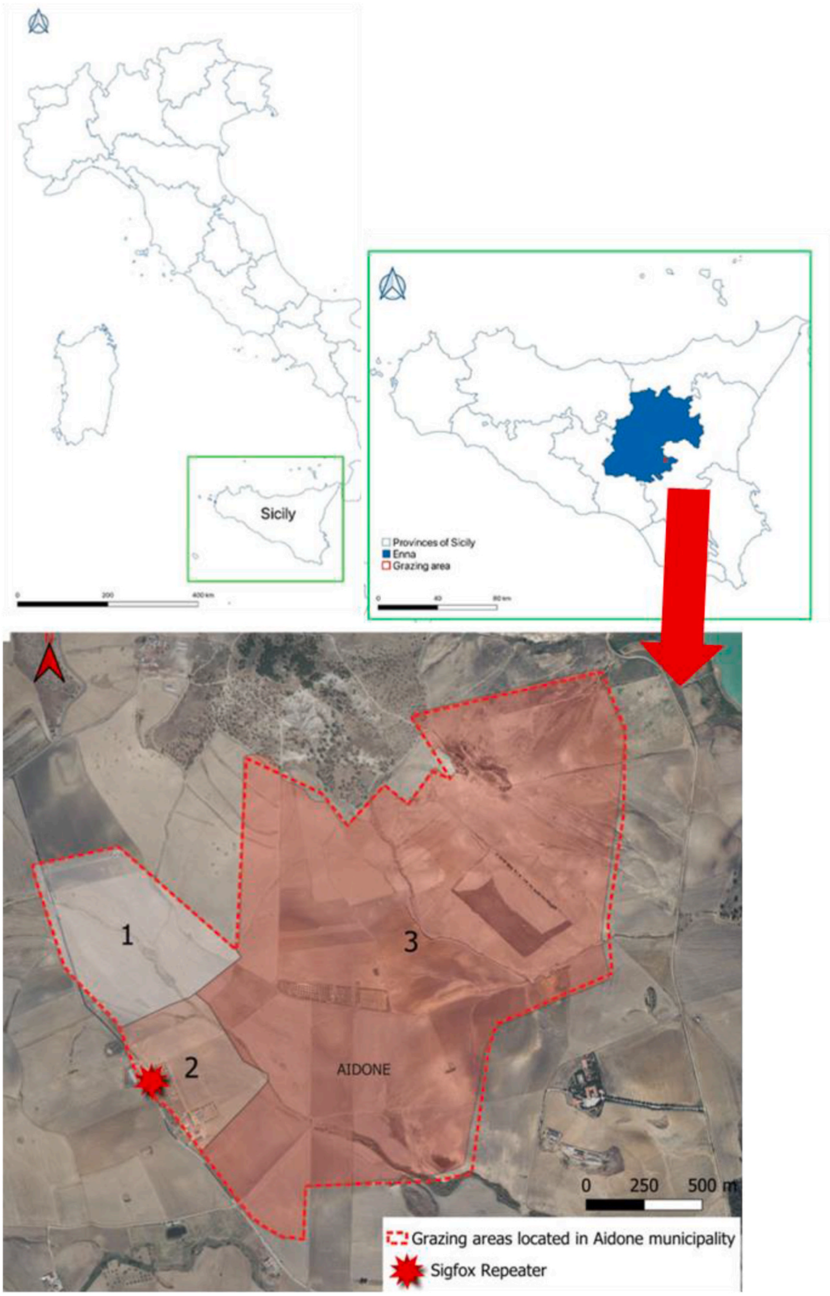
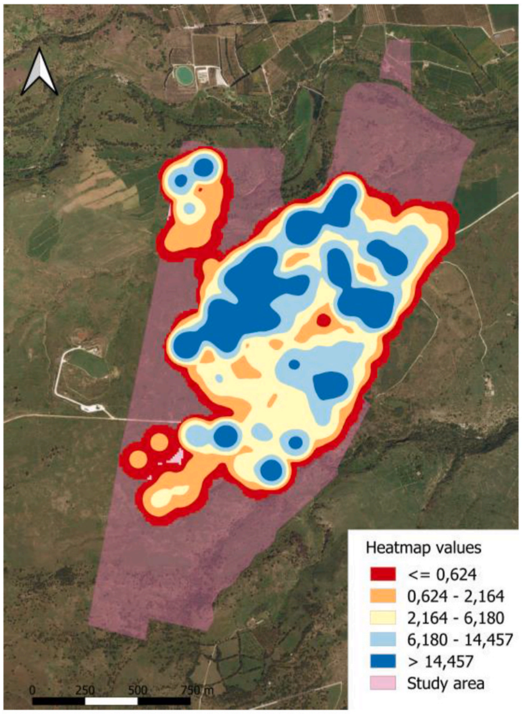
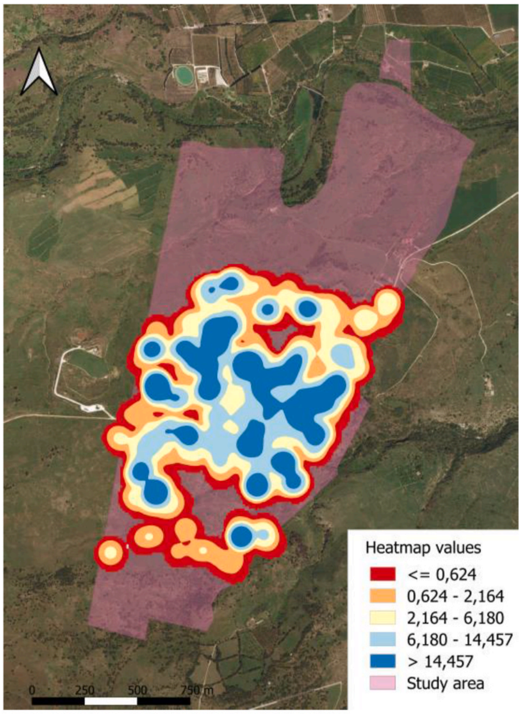


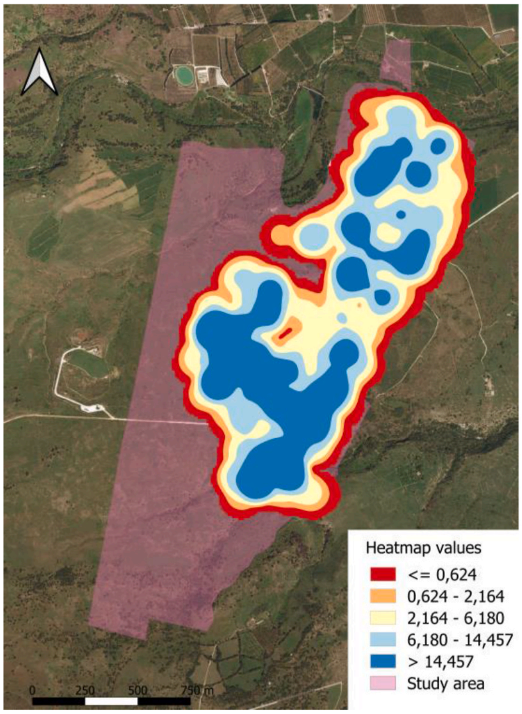
Fig. 3. Localization of grazing area belonging to Enna province. Zoom in to the three different territorial areas belonging to the grazing areas.



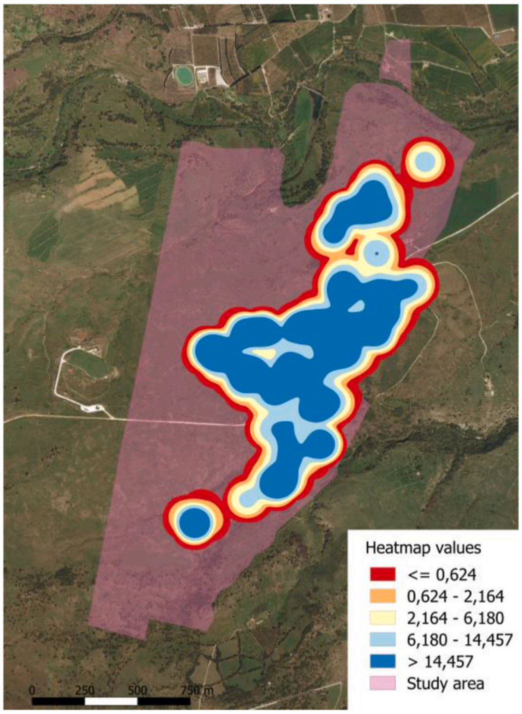
a) Cow 1



b) Cow 2

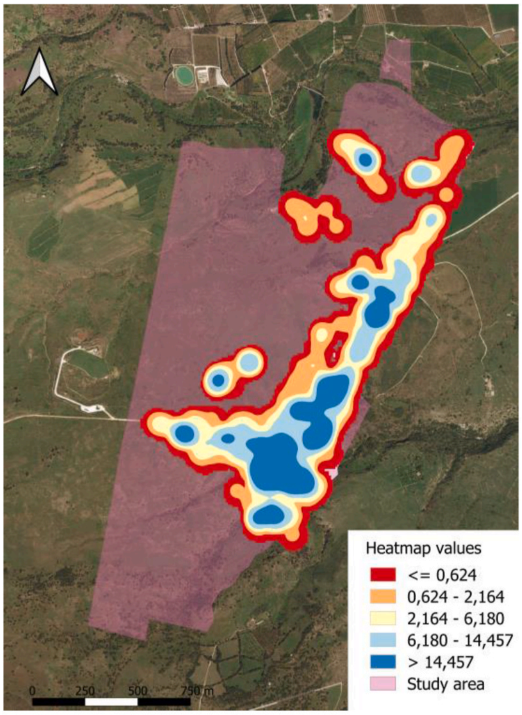


c) Cow 3

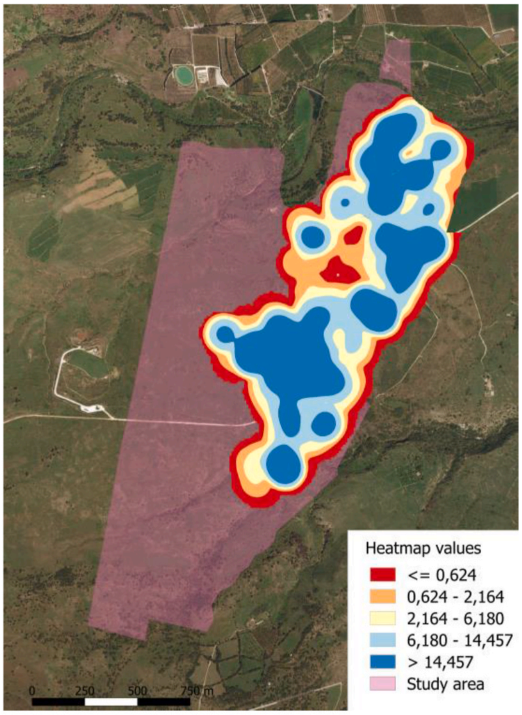


d) Cow 4

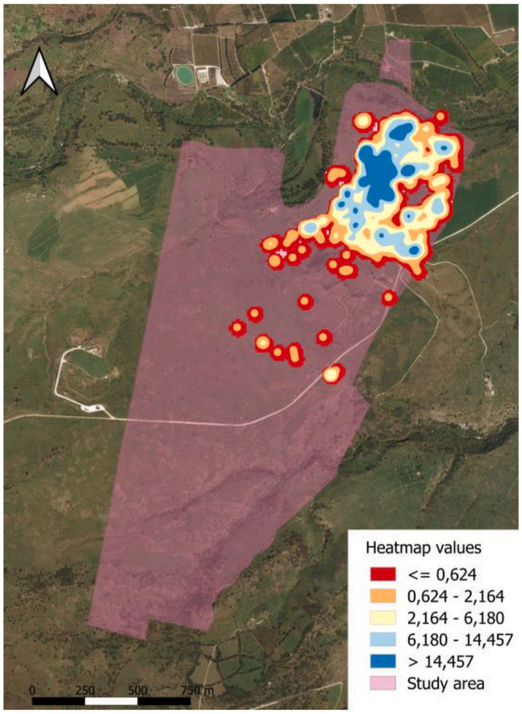
Fig. 4. Heatmap analysis on the most occupied territorial areas by animals during the whole data collection period in Syracuse grazing area. a) cow1; b) cow2; c) cow3; d) cow4; e) cow6; f) cow7; g) cow8; h) cow9; i) cow10.



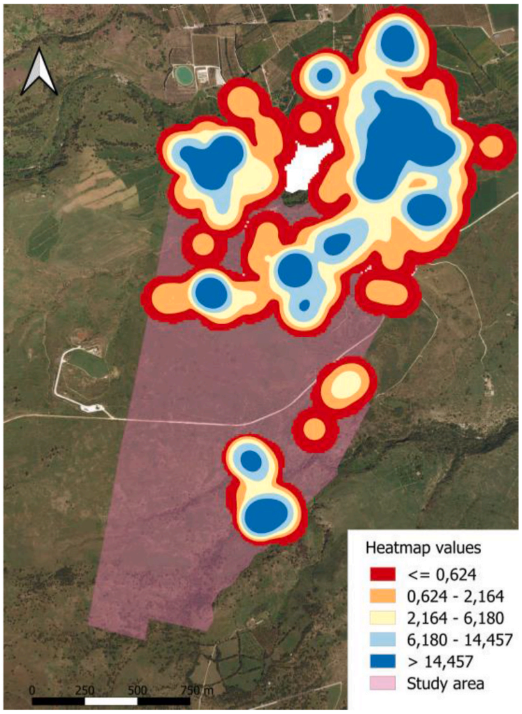
e) Cow 6



f) Cow 7

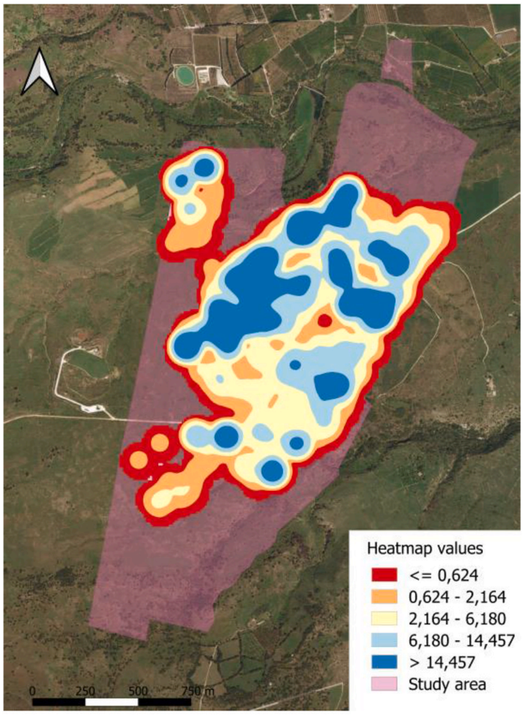


g) Cow 8



h) Cow 9

Fig. 4. (*continued*).



i) Cow 10

Fig. 4. (*continued*).

Triticum stubble, Vicia faba, Vicia sativa, and various weeds including *Lolium* L*, Hedysarum coronarium* L*, Avena fatua* L*, Sinapis arvensis,* and *Papaver rhoeas,* respectively. For this trial, 6 cows were selected from a herd of 130 cows of the cow-calf line. These cows were choseen based on their age, type of breed, good physical condition and docility. The remaining cows in the herd exhibited a more rugged temperament and were unsuitable for wearable devices. All selected cows were in the fertile period. Area 1 was equipped with trees to shield the herd from solar radiation. Typically, from 6 a.m. to 5 p.m., the animals remained in Area 1, where they had access to water and feeding racks. Subsequently, during cooler hours, from 5 p.m. to 6 a.m., the herd was relocated by the farmer to Areas 2 and 3 for feeding (Fig. 3).

For this trial, the 6 selected cows, with ages ranging from 2 to 9 years, varying in number of births, belonged to the Limousine breed [9]. However, two cows differed in breed, namely cow_{1_EN}, and cow_{4_EN} which were of the Italian "Pezzata Rossa" breed, aged 2 and 6 years respectively. Cow_{2_EN} was 6 years old; cow_{5_EN} was 3 years old, and cow_{6_EN} was 2 years old (ID cow = cow_{n_EN} where n is from 1 to 6).

To extend battery life, lasting four months, the data acquisition interval was set to 10 min. The acquired data, sent to the cloud for subsequent processing and visualized through a WebApp, developed by *Trecastagni s.r.l. Company*, were analysed using QGIS software to obtain spatial analyses. Specifically, the KDE tool was used to generate six thematic maps, one for each observed cow. Through the KDE tool, all locations occupied by the cows during the observation period were assessed, along with the density of landscape utilization.

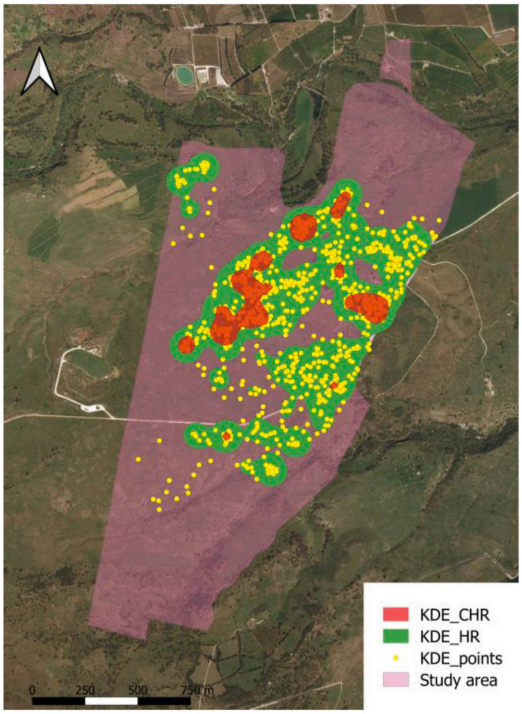
3. Results

3.1. Case I

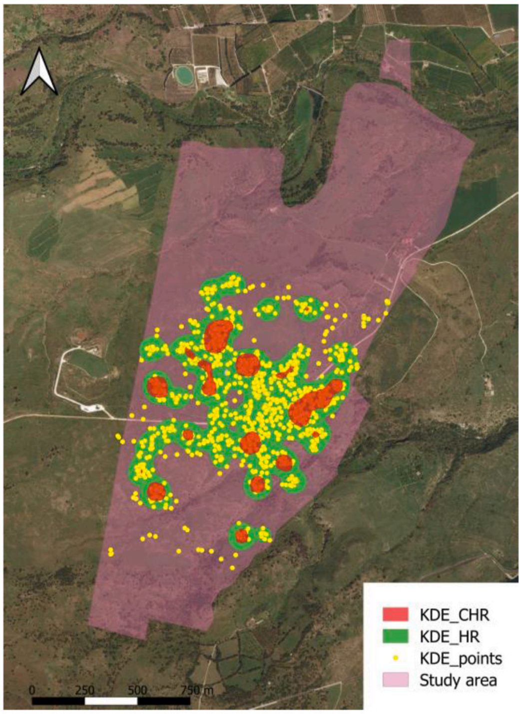
In Case study I, data collected from the LP-GPS device, visual inspections, and direct surveys were integrated, merged, and processed to track and locate the 10 selected animals. Through QGIS software, the grazing areas frequently utilized the animals throughout the trial period were identified. For each animal, GPS-altitude, Home Range (HR) (in hectares), Core Area (CA) (in hectares), and daily travelled distance were calculated.

Specific heatmaps and KDE maps were generated for each cow, with the exception of cow_{5_SR}. Unfortunately, due issues with fitting the collar, data related to this cow could not be analysed, resulting in the assessment of data only 9 wearable devices.

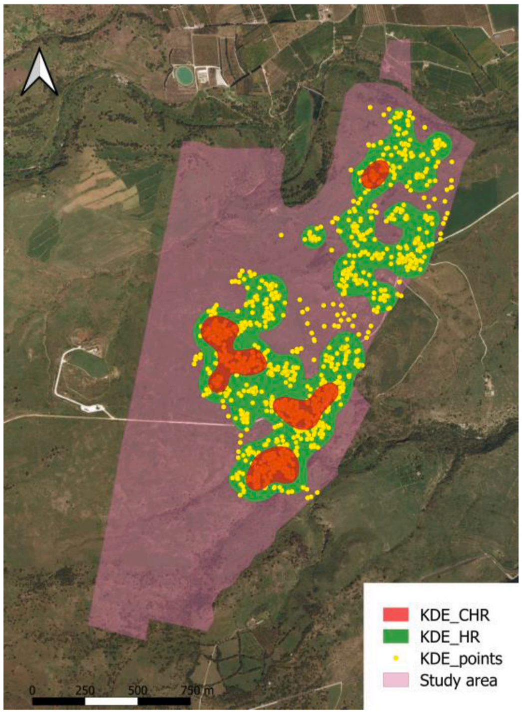
Initially, 9 heatmaps were created, displaying five ranges of cows 'concentration areas: the first ranging from 0.624 units or less, the second between 0.624 and 2.168 units, the third between 2.168 and 6.180 units, the fourth between 6.180 and 14.457 units, and the last one above 14.457 units. These units correspond to the Heatmap used to generate a raster from a point layer.



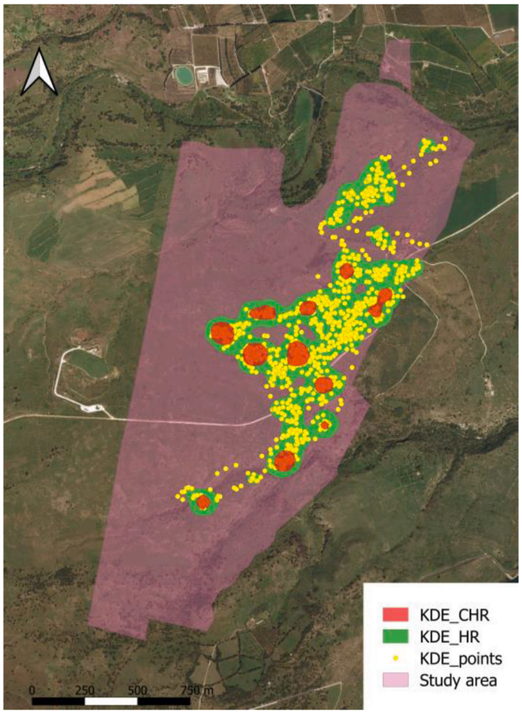
a) Cow 1



b) Cow 2

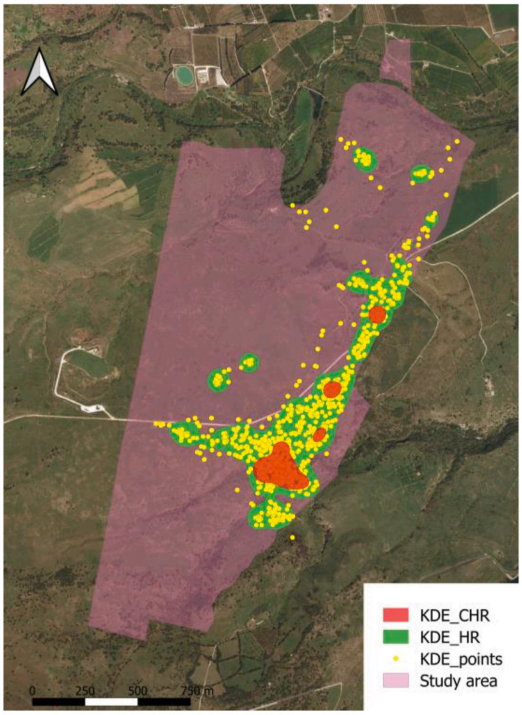


c) Cow 3

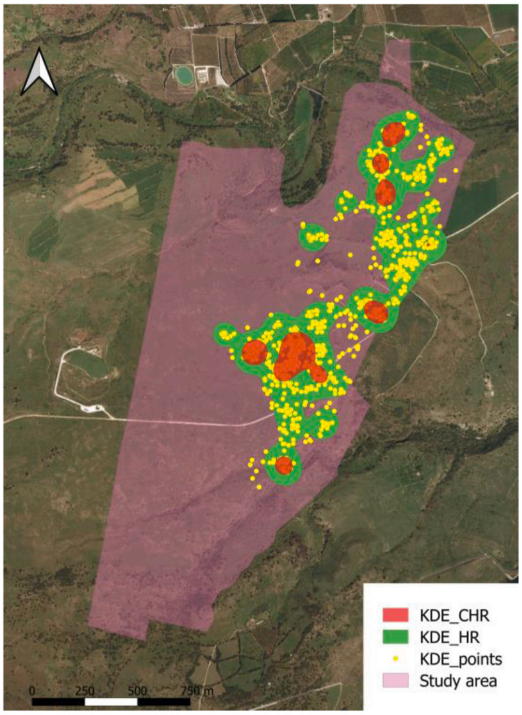


d) Cow 4

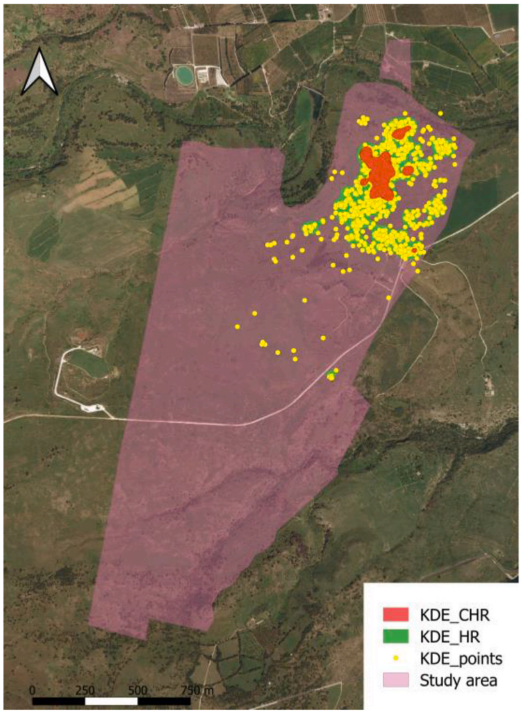
Fig. 5. KDE analyses results. a) cow 1; b) cow 2; c) cow 3; d) cow 4; e) cow 6; f) cow 7; g) cow 8; h) cow 9; i) cow 10.



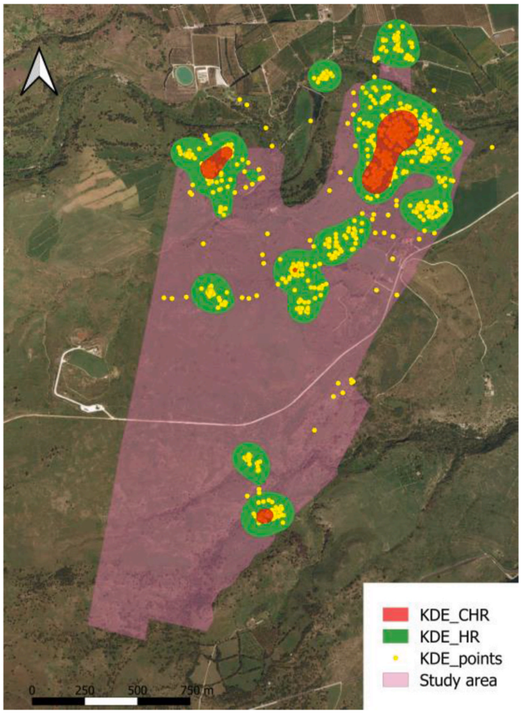
e) Cow 6



f) Cow 7

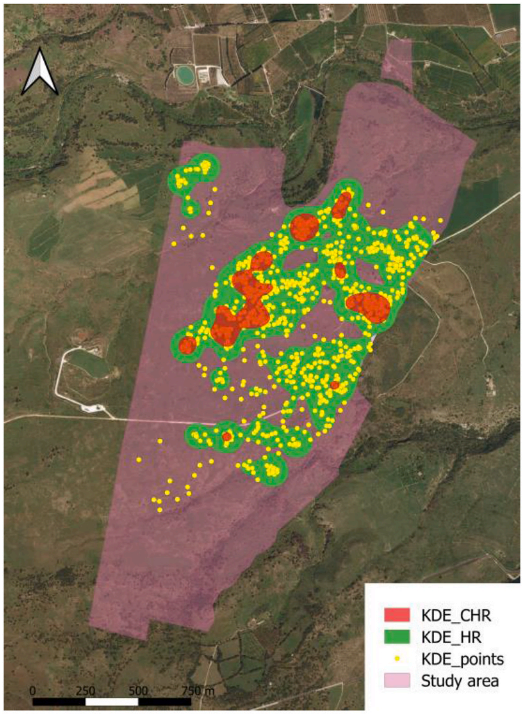


g) Cow 8



h) Cow 9

Fig. 5. (*continued*).



i) Cow 10

Fig. 5. (*continued*).

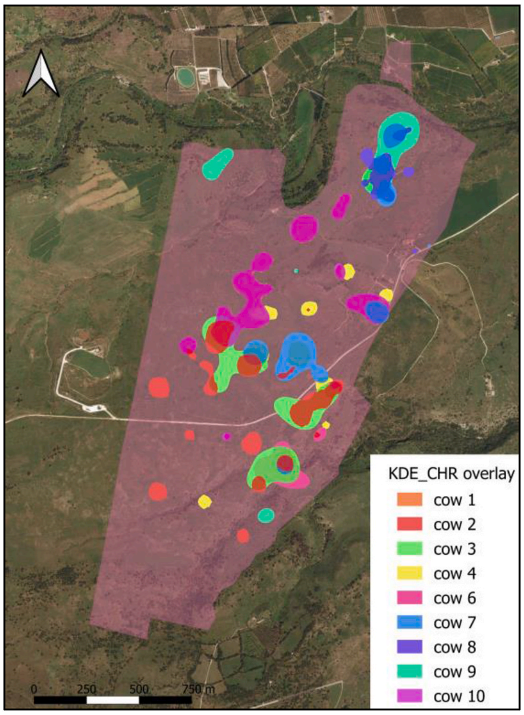
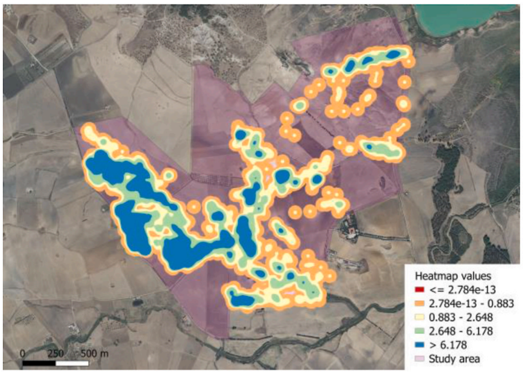
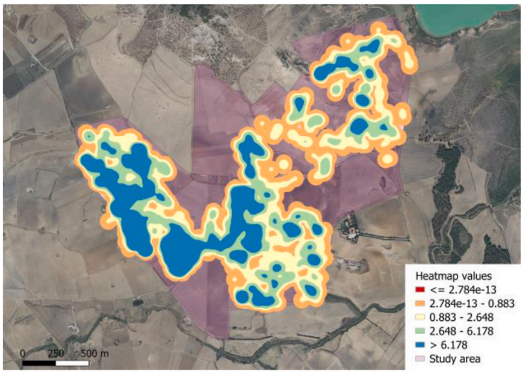


Fig. 6. Overlay of CA areas obtained by KDE analyses carried out for each animal of the herd located in Syracuse province.

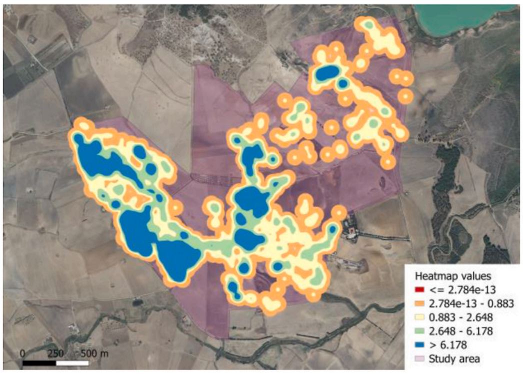
Upon analysing the results, it was observed that Cow 1, Cow 3, and Cow 10 exhibited similar behaviour by not favouring any specific area over others (Fig. 4a, c, 4i). As shown in Fig. 4b, Cow 2 preferred the central and the southern zones of the study area, characterized by moderately dense soil coverage and various species of legumes, cruciferous palnts, and composite grasses. Cow 4 and Cow 7 (Fig. 4d and 4f) predominantely stayed in the eastern zone of the study area, which was rich in grasses and leguminous plants such as composites *Asteraceae* and *chenopodiacee*. Cow 6, as depicted in Fig. 4e, favored the eastern zone with a smaller portion in the middle and the northern areas of the study area. Cow 9 predominantely stayed in the northern zone of the study area (Fig. 4h) eith a small portion in the middle eastern area.



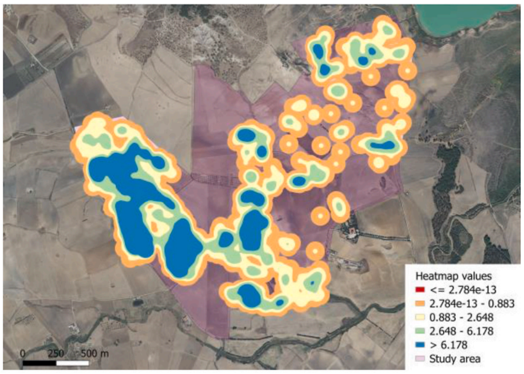
a) Cow 1



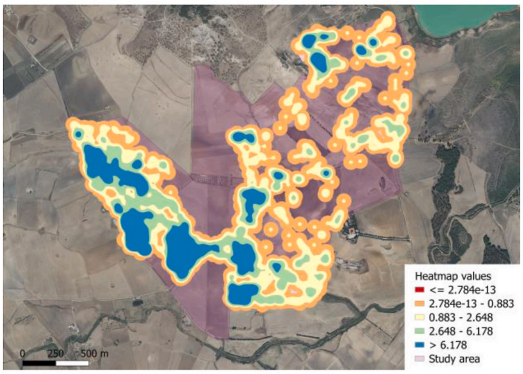
b) Cow 2



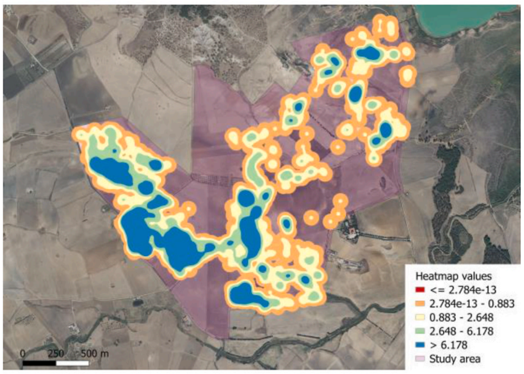
c) Cow 3



d) Cow 4



e) Cow 5



f) Cow 6

Fig. 7. Heatmap analysis on the most occupied territorial areas by animals during the whole data collection period in Enna grazing area. a) cow 1; b) cow 2; c) cow 3; d) cow 4; e) cow 5; f) cow 6 Subsequently, KDE analyses were carried out for each of the selected 6 cows, computing both the 50 % CA and 95 % HR density levels.

Overall, during the experimental period, all monitored cows did not exhibit a concentrated preference for a specific zone within the grazing area, except for Cow 8. As illustrated in Fig. 4g, Cow 8 consistently stayed in a small portion located in the northern part of the study area. These areas were situated away from the road network and resulted higher in forage density due to their proximity to the dam located in the norther part of the study area.

By utilizing the KDE tool, customized maps were generated for each cow, indicating their most preferred territorial zones. As shown in Fig. 5a-i, there is no clear predominance of the red zone, corresponding to CA, while the green areas (HR) are widespread throughout the grazing area. Fig. 5e, g, and 5h, are the only KDE maps showing a distint presence of CA related to Cow6, Cow8, and Cow9.

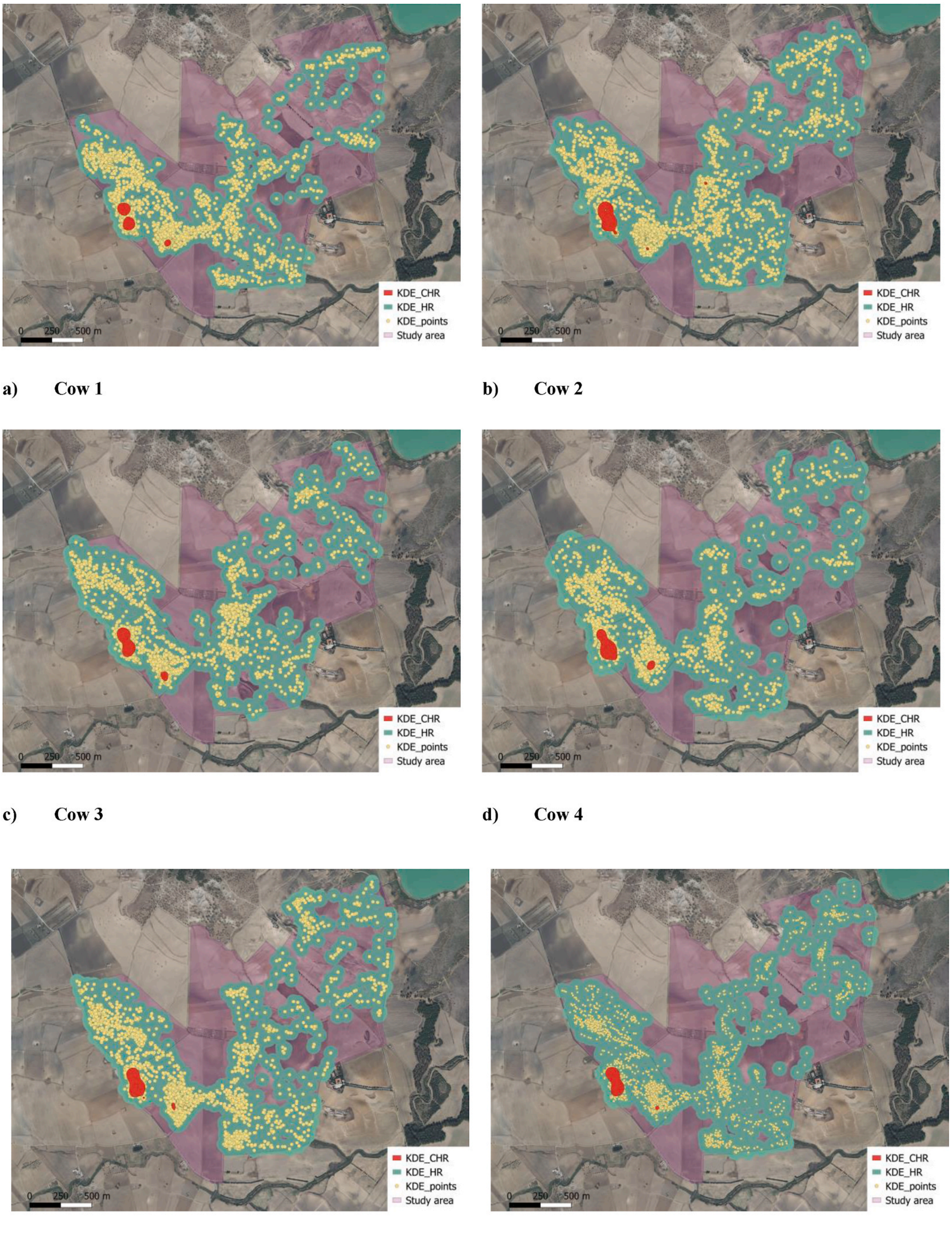


Fig. 8. KDE analyses results. a) cow 1; b) cow 2; c) cow 3; d) cow 4; e) cow 5; f) cow 6.

After computing both the 50 % CA and 95 % HR density levels from the KDE analysis condicted for each selected cows, the resulting KDE maps were overlaid in terms of CA areas (Fig. 6). By observing Fig. 6 a prevalence of cow presence appears in the west-central area, as preferred by 6 cows (i.e., Cow $_1$_SR, Cow $_2$_SR, Cow $_3$_SR, Cow $_4$_SR, Cow $_7$_SR, and Cow $_{10}$_SR).

In general, upon analysing the obtained data, the animal's most preferred area was the one richest in feed and distant from the road.

3.2. Case II

Similar to Case I, in the Case II study area, 6 tailored maps were developed, one for each observed cow. Heatmaps and KDE maps were adopted to assess their preferred territorial areas.

Initially, heatmaps were created, depicting 5 ranges of cows 'concentration areas: the first ranging from 0.02784 or less, the second between 0.02784 and 0.883 units, the third between 0.883 and 2.648 units, the fourth between 2.648 and 6.170 units, the last one above 6.170 units.

As illustrated in Fig. 7a-f, all the 6 selected cows exhibited a simliar behaviour. The highest concentration of the 6 cows was observed on the middle-east side of the study area, rich in *Trifolium alexandrinum* forage.

a-f shows the resulting maps from the adopted KDE analysis. In this case study, all obtained KDE maps exhibited a clear predominance of the CA areas (i.e., the red one showed in Fig. 8a-f).

Following the KDE analysis, the resulting maps were further analysed by overlapping the CA areas. As demonstrated in Fig. 9, it was evident that all considered cows spent a longer time in Area 2. This area corresponds to the location chosen by the breeder for feeding the animals, thus the most frequented area. This information validates the entire experimental trial and the resulting outcomes.

This area was chosen by the cows due to itsabundance in forage, especially *Trifolium alexandrinum,* which is highly palatable to cows. The CA calculated for each animal ranged approximately from 18.5 to 28.05 ha, with an average of about 24.39 ha.

4. Discussions

In the intensive farming sector, the demand for analyzing a large number of animals simultaneously is ensured through the use of automated systems, such as Information and Communication Technologies (ICT) applications, sensors, and sensing techniques. Improving animal productivity while concurrently fostering farm development is intricately linked to animal well-being. The use of wearable devices capable of tracking and remotely monitoring herds is crucial in reducing illness, injuries, reproductive problems, and stunted growth rates. Monitoring animal walking activity is a significant parameter for an initial remote assessment of animal well-being. For instance, an increase in cow walking activity could indicate physiological states such as heat or calving, while prolonged stationary could alert the farmer to potential disease activity or accidents.

Continuous data acquisition related to livestock animals, along with the assessment and modeling of this data to extract valuable information, plays a pivotal role in addressing various diseases, such as lameness. Real-time monitoring of changes in cows' behaviors serves as a vital indicator for detecting health issues or specific physiological statuses that can impact well-being and reproductive cycle management.

By evaluating data in GIS, it is possible to obtain information about the actions of animals throughout grazing areas and the spatial heterogeneity of the areas occupied by the animals.

In this study, tailored heatmaps and KDE analysis were conducted by processing the data acquired by the LP-GPS protype. This marks the first application of such analyses within a rural context. The results, particularly the preferences of animals regarding grazing areas, are crucial for livestock management as they provide feedback on the type of forage ingested, as demonstrated by the results achieved in Case II, where animals chose a specific area (i.e., area 2) particularly rich in *Trifolim alexandrinum*. Additionally, it is essential to consider the ability to monitor soil conditions in grazing areas to prevent issues related to soil degradation, such as soil erosion. Changes in grazing intensity or the animal species involved can have significant consequences on biodiversity.

To further enhance the system's capabilities and gather more information about the well-being of cows during the grazing period, integrating the LP-GPS prototype hardware with an accelerometer could be beneficial. Analysing the behavioural activities of cows by combining motion sensors and GPS data allows for the most accurate measurement of animal activity on extensive farms. However, in literature only a few research studies combining GPS data with accelerometers were found compared to studies using single types of data [45,46]. Most of these studies focused on using GPS collars combined with accelerometers in small pastures and over short time periods [46]. Therefore, as demonstrated by the results obtained, testing this technology in larger pastures and, more importantly, for longer observation periods is urgently needed.

Indeed, applying these wearable sensors to the bodies of dairy cows provides valuable information about their posture and motion. For example, it is known from the literature that the estimation of estrus duration is based on increased walking activity, but further refinement in accuracy and precision is needed to determine the optimal time range for artificial insemination in cows.

5. Conclusions

Real-time monitoring of animals in extensive livestock systems is a challenging task, crucial for evaluating variables that can provide farmers with timely alerts. A prompt reaction to such alerts could significantly improve management efficiency by reducing issues and enhancing animal welfare. Furthermore, knowledge of animal positions can provide valuable insights into feeding behaviour and soil erosion. In this study, animal tracking and monitoring were examined within two case studies. This was accomplished firstly by utilizing the heatmap plugin and subsequently by applying the KDE tool. The generated tailored maps enabled the

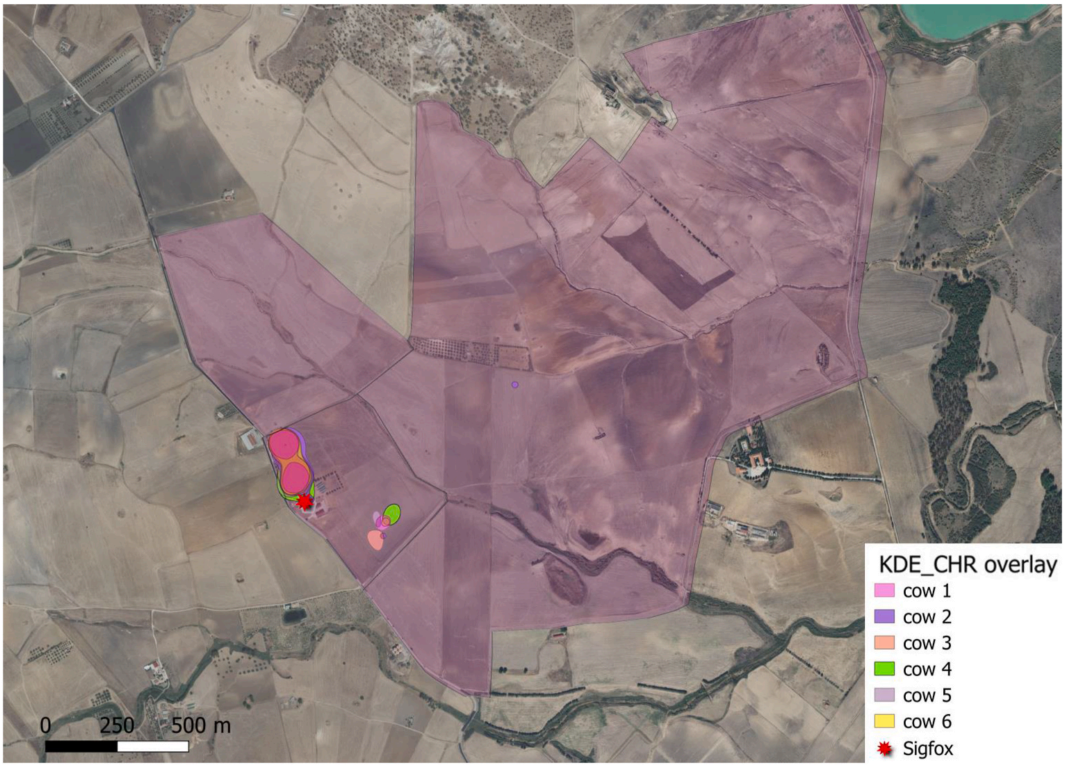


Fig. 9. Overlay of CA areas obtained by KDE analyses carried out for each animal of the herd located in Enna province.

classification of animals' preferred territorial areas, providing essential information for livestock management, allowing farmers to understand the type of forage ingested based on the spatial and temporal preferences, as well as the soil conditions of grazing areas, thus helping to prevent or reduce phenomena such as compaction, pathways, and erosion.

Additionally, monitoring animal walking activity can serve as indicator of physiological states such as heat or calving. Indeed, comparing daily distances travelled by each animal could be useful for the farmers to promptly detect anomalies in their trends, which may signal potential diseases, i.e., a drastic reduction in the daily travelled distance could indicate limb lameness.

The achieved results, when compared with breeder information, confirm the validity of both, the developed and applied methodology and the entire experimental trial. Furthermore, potential applications of the proposed GIS analyses may also be of interest to local authorities and regional environmental protection agencies. The GPS-retrived animal locations, coupled with GIS heatmaps, could be used to develop anti-theft control systems. Livestock theft is a significant concern in herd management, and farmers invest substantial economic resources in insurances to mitigate the financial burden in case of theft.

Data availability statement

Data will be made available on request.

CRediT authorship contribution statement

Monica C.M. Parlato: Writing – review & editing, Writing – original draft, Data curation, Conceptualization. **Francesca Valenti:** Writing – review & editing, Writing – original draft, Supervision, Methodology, Data curation, Conceptualization. **Simona M.C. Porto:** Visualization, Funding acquisition.

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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