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Enhancing rangeland management through technology: a case study of sheep and goat grazing in Montesinho Natural Park

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Abstract

The advent of advanced technologies offers unprecedented opportunities to improve the sustainability and resilience of rangeland management. This study examines the application of Global Navigation Satellite Systems (GNSS) in monitoring and optimizing the shepherding journeys of sheep and goat pastoralists throughout the rangelands of Montesinho Natural Park, Portugal.

Two distinct flocks—sheep and goats—were each equipped with a GNSS collar to monitor their routes across seasons and landscapes from April 2022 to March 2023. The study yielded 186 grazing journeys for the sheep flock and 232 for the goats. The data collected were subsequently analyzed using Geographic Information Systems (GIS) and Principal Component Analysis (PCA). These analytical methods were employed to discern patterns and correlations between grazing journeys and environmental variables, including altitude, topographic wetness, and land use types. The land use types examined encompassed orchards, oak forests, and shrublands.

The study elucidates marked discrepancies in the shepherding landscapes of the two species under investigation. The flock of sheep exhibited a distinct preference for agroforestry zones, demonstrating heightened sensitivity to climatic fluctuations, particularly during extreme temperatures. In such conditions, the sheep sought refuge in oak woods, chestnut groves, and riparian forests. Conversely, the goats demonstrated a greater utilization of rangelands and forestlands, indicative of their superior adaptability to varying environmental conditions. Additionally, seasonal variations were pronounced, with both species modifying their grazing strategies in response to the dynamic environmental changes.

GNSS data integration with GIS facilitated the visualization and analysis of grazing dynamics, offering valuable insights for developing decision support tools for pastoralists and land managers. These tools enhance the ability to make informed decisions that promote sustainable rangeland use and contribute to achieving internationally harmonized definitions. Moreover, the research underscores the potential of technology to foster collaborative rangeland research and improve the precision of monitoring and management practices.

Introduction

Pastoral systems rely on the mobility of livestock herds and the extensive use of rangelands, often adapting to some of the planet's most challenging environments. These systems are particularly significant in arid and semi-arid regions, contributing to biodiversity preservation, carbon sequestration, and the sustainable use of natural resources. Despite their importance, silvopastoral systems face increasing threats from climate change, land-use changes, and intensifying pressures on limited resources, necessitating innovative approaches to their management and sustainability (Castro et al., 2021).

The advent of advanced monitoring technologies, such as Global Navigation Satellite Systems (GNSS) and Geographic Information Systems (GIS), has revolutionized the study and management of pastoral systems. These tools enable detailed tracking of livestock movements, analysis of grazing patterns, and insights into the interactions between herds and their environments. Such innovations are particularly valuable in regions like the Mediterranean, where the intricate interplay of seasonal dynamics, topography, and land use shapes pastoral practices.

This study examines the grazing behaviour of goats and sheep in Montesinho Natural Park, focusing on how these species adapt to diverse terrains and land-use types throughout the year. By employing GNSS tracking and advanced statistical techniques, the research explores the spatial and temporal dynamics of herd movements, offering insights into the ecological roles of these species. This research contributes to the broader understanding of pastoralism in Mediterranean ecosystems, emphasizing the potential of integrating modern technologies with traditional knowledge to support sustainable rangeland management in the face of global environmental change.

Methods

This study was conducted in Montesinho Natural Park (MNP) in Portugal. The MNP features varied topography, with significant differences in altitude and climate, which influence the pastoralists' decisions, the herding process, and the animals' behaviour.

Data collection spanned March 2022 to March 2023, using advanced technologies to monitor livestock movements and environmental interactions. GNSS collars tracked daily grazing routes, recording spatial-temporal data. Environmental variables included elevation (ALT), relative slope position (RSP), topographic wetness index (TWI), and land use/land cover (LULC) categories: orchards (ORCH), oak forests (OAKF), temporary crops (TRIC), and shrublands (SHRB). Seasonal variables captured proximity to solstices (WS, SS) and equinoxes (AE, VE). Behavioral metrics included start/end times (B-6AM, E-6PM), duration (DRT), distance (LGT), and the Shannon Diversity Index (H') for grazing environment heterogeneity.

The GNSS data were exported to Geographic Information System (GIS) software for detailed analysis. The GPS collars used in this study provide a high level of accuracy, with latitude and longitude records inherently accurate to within 2 to 3 metres. Erroneous or anomalous grazing points, such as those recorded before animals left or after they entered the corral, were identified and removed to ensure the reliability of

the dataset. One GNSS collar per flock was considered sufficient for accurate tracking, given the length of the grazing routes and validation from trials in previous studies.

The collars recorded data every 5 minutes, synchronized with the communications satellite, providing consistent and detailed location information. Key characteristics of grazing trips, including trip length, duration and proximity to environmental features, were calculated to provide insight into herd behaviour. Descriptive statistics were used to summarise seasonal variations in the herding process, ensuring a comprehensive understanding of the interaction between the herds and their environment.

Principal Component Analysis (PCA) was employed to assess the impact of environmental factors on grazing patterns. Simultaneously, correlation and inferential tests were utilized to identify significant relationships between grazing metrics and environmental variables. Spatial maps were created to superimpose the grazing route locations over the terrain, incorporating various land use types. A visual representation comparing seasonal grazing behaviours was developed to highlight patterns across winter, spring, summer, and autumn.

Results

GNSS locations database

A total of 16,389 GNSS location records were collected for the goat herd during the monitoring period. These records represent the goat herd's detailed movements and grazing patterns across different terrains and times. After the data cleaning process, which is essential to remove errors, inconsistencies, and irrelevant data points (such as outliers or points recorded during non-grazing activities), the dataset was reduced to 14,929 valid records, meaning 1,460 records were excluded for better accuracy and reliability of the analysis. This refined dataset ensured that only meaningful and relevant data were used to examine grazing behaviours and environmental interactions.

In the sheep herd, the dataset began with 13,510 GNSS records. After a similar data-cleaning procedure to ensure analytical integrity and precision, the dataset was reduced to 5,646 records, with 7,864 records excluded. This higher exclusion rate may reflect stricter criteria or more noise in the original data, such as points outside grazing periods or inaccuracies due to technical limitations.

Figure 1 provides a representation of the distribution of these GNSS locations over time and by date. It is critical for understanding the temporal patterns of movement and identifying any gaps or irregularities in the data collection process. By reviewing Figure 1, it can be seen that the data points were spread across the monitoring period, illustrating trends like seasonal variations or specific periods of intense activity.

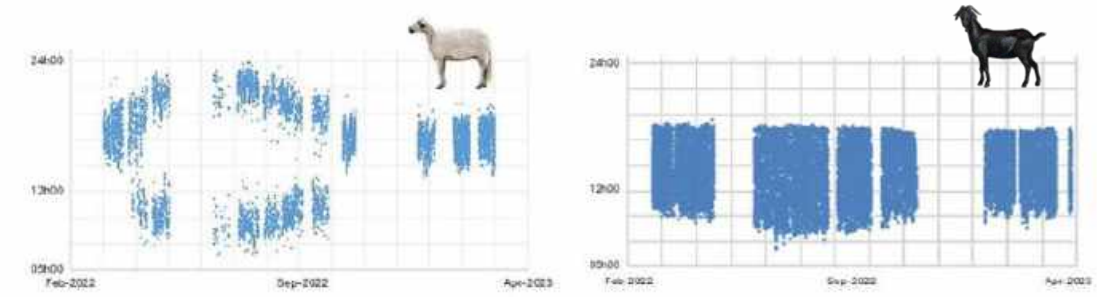

Figure 1 - Distribution of GNSS location records over time and dates for sheep and goat herds in Montesinho Natural Park.

These findings highlight the importance of data cleaning in GNSS-based studies to enhance the reliability of results and ensure that conclusions are drawn from accurate and meaningful data. The difference in the numbers before and after cleaning underscores the challenges in livestock movement tracking and the necessity of rigorous preprocessing.

The goat herd's first principal component (Dim1) is primarily influenced by physical, land use, temporal, and seasonal variables. These include the length of grazing paths (LGT), altitude (ALT), and diverse land use types like chestnut forests, oak forests, and orchards. Additionally, the Shannon Diversity Index (H') and grazing duration (DRT) contribute significantly, alongside seasonal markers such as proximity to the autumnal equinox (AE). The second principal component (Dim2) is shaped mainly by grazing duration and timing, particularly the differences in start and end times relative to 6 AM and 6 PM, which reflect temporal patterns of grazing behaviour. The third component (Dim3) highlights the influence of specific land uses like shrublands and temporary rainfed and irrigated crops. These variables are visually represented in Figure 2, where these grazing variables' spatial and temporal patterns can be observed across the goat herd's movement paths.

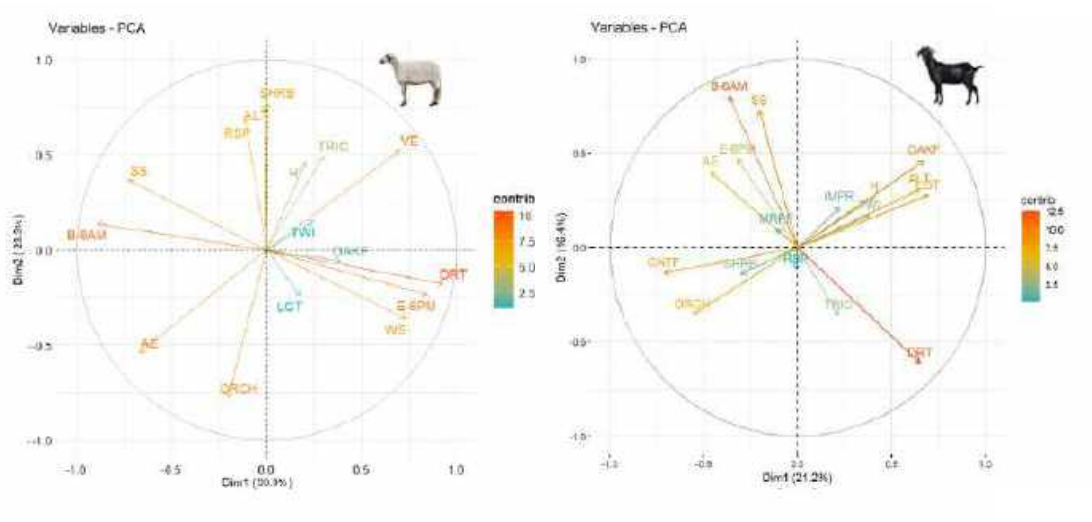

Figure 2 - Spatial and temporal patterns of grazing variables for sheep and goat herds in the Montesinho Natural Park along the first two PCA components for both herds.

In the sheep herd, the first principal component (PC1) is dominated by temporal variables, including grazing duration, the difference in grazing start times relative to 6 AM, and seasonal markers like proximity to the winter and summer solstice (WS and SS). The second principal component (PC2) emphasizes land use and topographical features such as orchards, shrublands, altitude, and relative slope position. These variables illustrate how sheep movements are influenced by terrain and land cover types. The third principal component (PC3) reflects topographical features like elevation and slope, diversity indices such as H', and seasonal proximity to the vernal equinox (VE). Figure 2 illustrates these dynamics by showing the distribution of grazing locations over different terrains and seasons, providing a comprehensive view of how these variables interact to shape grazing patterns in the sheep study.

Discussion and Conclusion

Both the goat and sheep GNSS locations reveal detailed insights into how these herds interact with their environments, highlighting differences in their behavior concerning terrain and land use throughout the year. Goats tended to explore diverse terrains, particularly for elevated areas and extended grazing paths. They relied heavily on land use types such as chestnut forests, oak forests, and shrublands, indicating their adaptability to rugged terrains and varied vegetation. This behavior was particularly evident in summer and autumn, when goats utilized high-altitude areas for longer grazing routes, reflecting their inherent ability to browse shrubs and foliage in challenging environments. In contrast, the sheep herd demonstrated more concentrated grazing patterns, favoring gentler slopes and areas with consistent vegetation. Their preference for orchards and temporary crops suggests a reliance on structured agricultural landscapes where nutrient-rich forage is readily available. Seasonal variation was marked in the sheep study, with grazing patterns closely tied to vegetation availability, particularly in spring and fall when conditions were favorable. Sheep showed reduced activity during harsher seasons, such as summer and winter, emphasizing their dependency on predictable resources and more accessible terrains than goats.

The comparative analysis highlights significant behavioral differences, as previously reported by several authors (e.g. Castro, 2004; Castro and Fernández-Núñez, 2016). Goats displayed greater adaptability to rugged terrains, utilizing steeper slopes and higher elevations, consistent with their physiological traits and foraging behavior. They were also more versatile in their land use, exploiting a broader range of vegetation types, including shrublands and forested areas. On the other hand, sheep concentrated their grazing in more controlled and accessible areas, thriving in environments with dense vegetation and less topographical challenge.

Both herds exhibited seasonal variations in grazing behavior; however, sheep were more directly influenced by climatic conditions and vegetation cycles, whereas goats maintained consistent foraging patterns across seasons. This adaptability of goats makes them particularly suited for managing vegetation in rugged and heterogeneous terrains, whereas sheep are better suited to structured landscapes like agricultural zones.

In conclusion, the results emphasize the ecological roles of each species in pastoral systems. Goats effectively manage vegetation in challenging and underutilized terrains, while sheep excel in agricultural settings where forage is predictable and abundant. These findings provide valuable insights for sustainable land management and adaptive strategies to address changing environmental conditions, ensuring the resilience and productivity of pastoral practices.

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Decision support tools for pastoralists and grazing systems