Characterization of Grazing Patterns: Analyzing Sheep Herd Dynamics in Montesinho Natural Park

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"In order to be an immaculate member of a flock of sheep, one must above all be a sheep oneself."

— Albert Einstein

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Abstract

The production of small ruminants in North-East Portugal is an extensive activity, mainly based on the exploitation of spontaneous resources, which is strongly conditioned by seasonality. Shepherds direct their herds on daily grazing routes through different types of resources, creating a mosaic of varied land uses within the same management unit. This practice integrates the exploitation of landscape by-products such as spontaneous native vegetation and agriculture leftovers.

This study, part of the PASTOpraxis project, focuses on characterizing the grazing patterns of a sheep herd breed, Churra Galega Bragançana Branca, in Montesinho Natural Park, Portugal. Using a GNSS collar, data for each day of grazing were monitored and captured over a year from March 2022 to March 2023. The data obtained from the GNSS collar were integrated into GIS and analyzed using RStudio to evaluate and characterize grazing patterns and sheep behaviour. Significant insights into the temporal and spatial dynamics of flock behaviour were obtained through descriptive and inferential statistical analyses, including Principal Component Analysis (PCA).

The research highlighted the influence of seasonal and climatic variations on grazing journey duration, the critical role of diverse land use types such as orchards, shrublands, and temporary crops, and the adaptive strategies shepherds employ to optimize grazing efficiency. Key findings revealed that grazing durations were more prolonged in spring and autumn, with significant correlations between grazing patterns and variables like elevation, relative slope position, and topographic wetness index.

The study underscores the importance of integrating traditional pastoral knowledge with modern monitoring techniques to sustain grazing practices amid changing environmental conditions and highlights the potential impacts of climate change on pastoral systems.

Keywords: Grazing patterns, Churra Galega Bragançana Branca, Montesinho Natural Park, GNSS collar, GIS, RStudio, Seasonality, Land use, Climatic variations, Pastoral systems, Climate change adaptation.

Resumo

A produção de pequenos ruminantes no Nordeste de Portugal é uma atividade extensiva, baseada essencialmente na exploração de recursos espontâneos, fortemente condicionada pela sazonalidade. Os pastores orientam os seus rebanhos em percursos diários de pastoreio através de diferentes tipos de recursos, criando um mosaico d'usos variados do solo dentro da mesma unidade de gestão. Esta prática integra a exploração de subprodutos da paisagem, como a vegetação autóctone espontânea e os restos de agricultura.

Este estudo, parte do projeto PASTOpraxis, centra-se na caraterização dos padrões de pastoreio de uma raça de rebanho ovino, Churra Galega Bragançana Branca, no Parque Natural de Montesinho, Portugal. Utilizando uma coleira GNSS, os dados de cada dia de pastoreio foram monitorizados e capturados ao longo de um ano, de março de 2022 a março de 2023. Os dados obtidos a partir do colar GNSS foram integrados no SIG e analisados usando o RStudio para avaliar e caraterizar os padrões de pastoreio e o comportamento das ovelhas. Foram obtidas informações significativas sobre a dinâmica temporal e espacial do comportamento do rebanho através de análises estatísticas descritivas e inferenciais, incluindo a Análise de Componentes Principais (PCA).

A investigação destacou a influência das variações sazonais e climáticas na duração da jornada de pastoreio, o papel crítico de diversos tipos de utilização da terra, tais como pomares, arbustos e culturas temporárias, e as estratégias adaptativas que os pastores empregam para otimizar a eficiência do pastoreio. As principais conclusões revelaram que a duração do pastoreio foi mais prolongada na primavera e no outono, com correlações significativas entre os padrões de pastoreio e variáveis como a elevação, a posição relativa do declive e o índice topográfico de humidade.

O estudo sublinha a importância de integrar o conhecimento pastoral tradicional com técnicas de monitorização modernas para sustentar as práticas de pastoreio no meio de condições ambientais em mudança e destaca os potenciais impactos das alterações climáticas nos sistemas pastoris.

Palavras-chave: Padrões de pastoreio, Churra Galega Bragançana Branca, Parque Natural de Montesinho, Coleira GNSS, SIG, RStudio, Sazonalidade, Uso da terra, Variações climáticas, Sistemas pastoris, Adaptação às alterações climáticas.

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List of Abbreviations

	LGT	Length
	DRT	Duration
PHYSICAL SYSTEM	**ALT**	Elevation
	RSP	Relative Slope Position
	TWI	Topography Wetness Index
LAND USE AND LAND COVER (LULC)	**ORCH**	Orchards
	OAKF	Forests of Other Oaks
	TRIC	Temporary Rainfed and irrigated crops
	SHRB	Shrublands
	H'	Shannon Diversity Index
ANNUAL CYCLE	**WS**	Proximity to Winter Solstice
	SS	Proximity to Summer Solstice
	AE	Proximity to Autumnal Equinox
	VE	Proximity to Vernal Equinox
DAILY CYCLE	**B-6AM**	Difference between the start grazing time (Begin) and 6AM (Minutes)
	E-6PM	Difference between end grazing time (Begin) and 6PM (Minutes)

1. Introduction

Pastoralism faces significant risks due to climate and landscape changes (Scoones, 2023), posing threats to the existence and sustainability of pastoral communities (Godde et al., 2020). As a result, these communities are actively modifying their pastoral practices to preserve their livelihoods and ensure the continuity of their traditions (Menghistu et al., 2020).

This research, part of the PASTOpraxis project, investigates the biophysical and socio-cultural adaptive responses of pastoral communities in the Montesinho Natural Park (PNM) to climate change impacts. By studying how herds interact with their landscape, we can develop strategies to mitigate climate change effects and maintain traditional grazing practices for sheep in the Montesinho Natural Park.

The study aims to analyze the grazing circuits of sheep flocks in Montesinho Natural Park from March 2022 to March 2023. Using GPS collars to track the movements and grazing patterns of the Churra Galega Bragançana Branca sheep, this detailed analysis seeks to optimize grazing practices to support environmental sustainability and the resilience of pastoral communities facing climate change.

This research examines the adaptive responses of pastoral communities to climate change using GNSS collars and GIS data. It investigates the influence of seasonal variations, land use, and topography on grazing efficiency and herd management, aiming to inform adaptive grazing strategies and support the sustainability of pastoral systems amidst environmental changes.

The production of small ruminants in North-East Portugal is extensive and strongly conditioned by seasonality. Shepherds direct their herds on daily grazing routes through various resources, creating a mosaic of varied land uses within the same management unit. Portugal's Northeast sheep production relies on exploiting landscape by-products such as spontaneous native vegetation and agricultural leftovers.

GNSS collars have proven to be an excellent tool for monitoring and capturing detailed data on grazing patterns. These collars allow precise tracking of sheep movements, providing valuable insights into how herds interact with their environment. By integrating GNSS data into Geographic Information Systems (GIS) and analyzing it with software like RStudio, researchers can evaluate and characterize grazing patterns and sheep behaviour more effectively.

This study explores the functioning and patterns of the sheep herding systems within the Montesinho Natural Park. Our specific objectives include:

- Analyzing how grazing paths vary over time and space within the year.
- Assessing the seasonal changes in land usage.
- Investigating how the use of the landscape correlates with the needs for shelter, water, and food.

This document is organized into five chapters:

- The first chapter overviews the study's background, significance, and objectives.
- The literature review examines existing documentation on the characterization of sheep grazing patterns and methods for monitoring and understanding the impact of grazing.
- The methods chapter describes the methodologies employed, including GNSS collars and data analysis techniques.
- The results and discussion chapter presents descriptive and inferential statistical analyses of the collected data, highlighting key findings and interpretations.
- The conclusion chapter summarizes the study's findings and discusses their implications for pastoral practices and climate change adaptation.

2. Literature Review

2.1 Sylvopastoralism and rangelands: Insights and Perspectives

Overview of Pastoralism:

Pastoralism, a livestock production system based on extensive land use and herd mobility, has been practised for centuries across many regions. Currently, it occurs on about 25% of the earth's land area, primarily in the developing world, including the drylands of Africa and the Arabian Peninsula, as well as the highlands of Asia and Latin America where intensive crop cultivation is not feasible. This system supports approximately 200 million households and nearly a billion head of livestock, contributing to around 10% of the world's meat production. Pastoralism is vital for the populations it sustains, its ecological services, its economic contributions to some of the world's poorest regions, and the civilizations it maintains. However, it faces significant challenges from human population growth, economic development, land use changes, and climate change, threatening its sustainability and protection (Dong et al., 2011).

Pastoralism often emerges due to the accumulation of surplus animals, necessitating year-round grazing around settlements. The Amorites are among the earliest pastoralists, herding cattle, sheep, goats, and donkeys in the Near East in the second millennium BC. This culture likely spread from the Nile Valley and North Africa through ancestors of today's Berber populations (Blench, 2001).

Pastoralism may decline where it competes with agriculture, but unsustainable rangeland development might lead to its resurgence. The future of pastoralism hinges on political decisions in grassland-rich countries. While enclosed pastures may not expand, land expropriation by farmers and conservationists will pose challenges. However, the literature on pastoralism is inconsistent, shaped by political and security issues as much as empirical needs (Blench, 2001).

These systems can be managed intensively or extensively. Intensive systems feature high-density cultivation of fodder shrubs, tropical grasses, and tree species, while semi-intensive systems use three levels of vegetation: pasture, shrubs, and trees, providing more edible plant material and animal products than pasture-only systems (El-Hage Scialabba, 2021). Silvopastoralism provides a method to use forested areas deemed unproductive by incorporating livestock grazing (Guerin, 2008).

Integrating woody vegetation with animal grazing in silvopastoral systems faces challenges from agricultural intensification and simplification trends, reducing their resilience (Plieninger & Huntsinger, 2018). However, when managed effectively, silvopastoral systems can benefit the forest and the livestock. By carefully managing the introduction of livestock in forest areas, these systems promote forest health and livestock productivity (Challot, 1990). Effective silvopastoral systems integrate trees with pasture and livestock management to boost carbon sequestration, enhance biodiversity, and increase productivity (Montagnini et al., 2013).

Silvopastoralism involves integrating traditional grazing into forested areas to provide benefits such as forage and shade. (Hamilton, 2008.) silvopasture is an agroforestry practice combining livestock, forage production, and forestry within a single land management unit (ONF, 2021). This ancient practice, mainly grazing sheep in forests, has been marginalized over the past fifty years due to modernization, specialization, and grazing prohibitions in Mediterranean forests. Managing forested spaces for multiple functions, and integrating pastoral use by livestock with forest production management, remains crucial (Étienne et al., 1994).

In temperate environments such as Europe, the integration of sheep within high-value tree systems, such as apple orchards, olive groves, chestnut woodlands, and walnut plantations, is increasingly practised (Fungo et al., 2021.). Based on rational resource management, these traditional systems, enhance productivity and sustainability, effectively combating land degradation, desertification, and desertion in the Mediterranean Basin (Le Houérou, 1990).

Rangelands, critical terrestrial natural resources with significant ecological, economic, and social value for many global regions (Castro & Fernández-Núñez, 2016), encompass grasslands, shrublands, woodlands, and deserts. These lands are typically marked by limited precipitation, sparse vegetation, extreme climatic variations, highly variable soils, frequent salinity, and diverse topography. Traditionally, rangelands have been primarily used to provide forage for livestock and wildlife, including sheep. They offer crucial habitats for sheep, and rangelands are vital for meat production, with range and pasture supplying 91% of nutrients for sheep nationwide (UIRC, 2012).

Pastoralism has a long tradition in the Mediterranean region, but its contribution to sustainable development is not well-documented. The intensification, specialization, and modernization of pastoral systems threaten ecosystem services and endanger the sustainability of traditional systems, including silvo-pastoralism and mobile pastoralism, leading to cultural erosion and abandonment of these practices (El Bilali et al., 2021). Grazing in forests was common in the past in most of the Iberian Peninsula, and this practice remains vital in some regions today (Mosquera-Losada et al., 2008).

Extensive livestock systems, characterized by the interaction between humans, herds, and their environment, rely heavily on the spatial and temporal diversity of the region and the availability of heterogeneous forage resources (Landais & Balent, 1993). These systems typically feature low stocking rates and minimal technology, with shepherds guiding flocks across various land cover patches (Castro et al., 2010; Georgoudis et al., 2023).

These systems utilize diverse vegetation types, such as natural grasslands, shrublands, woodlands, and forestlands, often integrating crop by-products (Castro, 2004; Papanastasis & Schnabel, 2004). Extensive livestock systems are flexible and opportunistic, adapting to marginal areas unsuitable for cropping due to topography, temperature, or rainfall (Steinfeld H. et al., 2006). Over 90% of the dry matter consumed by livestock in these systems comes from natural pastures, forages, and rangelands, with stocking rates below ten livestock units per hectare (Seré Rabé & Steinfeld, 1996).

In the Mediterranean region, extensive livestock systems have created resilient ecosystems with high species diversity, productivity, and utility to society by shaping a mosaic landscape of forests, shrubs, and herbaceous communities (Kizos et al., 2013). In the Trás-os-Montes region, daily livestock movements guided by shepherds utilize spontaneous vegetation influenced by environmental conditions, with long-established indigenous knowledge and practices guiding land use and grazing circuits (Castro, 2015; Georgoudis et al., 2023).

Sheep and goats are typically managed by landless farmers and smallholders, with shepherds playing a crucial role in selecting patches and land use based on environmental conditions and social relationships (Baumont et al., 2000). These systems rely on informal social rules and formal regulations established by local authorities to manage grazing circuits and interactions with landowners (Georgoudis et al., 2023).

2.2 An Integrated Review of Grazing Behaviour and Patterns in Sheep: Factors Influencing Herd Dynamics

Sheep exhibit a diurnal pattern in their diet, preferring clover in the morning and grass later in the day, influencing their foraging behaviour and pasture composition. Including clover in their diet increases their intake rate and production levels. Restricting sheep to mixed rations instead of allowing them to follow their natural preferences can lead to frustration and potentially affect their welfare (Rutter, 2010). Sheep exhibit a consistent daily grazing pattern with a significant peak in eating activity just before sunset (Champion et al., 1994).

Sheep grazing patterns are more evenly distributed when flocks include different sheep classes. When dominant individuals are removed, lower-ranked sheep intensify their use of preferred grazing areas and avoid less preferred ones (Di Virgilio & Morales, 2016). The spatial distribution of small groups of grazing sheep is influenced by breed, flock size, and density. Individual and social distances determine the spacing between sheep, which varies with activities and environmental conditions like food dispersion and animal density (Dudziński & Arnold, 1979). Social interactions within the flock heavily influence grazing patterns, with strong social bonds affecting foraging behaviour and pasture use. Social behaviour plays a more prominent role in grazing behaviour at low stocking rates, where animals spend more time together (Parnell et al., 2022).

Sheep grazing behaviour is influenced by factors such as sward height, tiller density, and biomass per unit area. Sheep intake rates are higher in tall, sparse pastures compared to short, dense ones, especially when herbage availability is below 1 t/ha. The amount of biomass consumed per bite decreases with sward height and density reductions, and sheep prefer pastures that allow for faster consumption when given a choice (Black & Kenney, 1984). The structure of the pasture significantly influences the feeding behaviour of grazing animals. Factors such as the number of meals, swallowing duration and speed, grazing time, bite rate, bite weight, and forage quality all affect the amount of feed consumed within a given period (Dias-Silva & Filho, 2020). Reintroducing sheep grazing in abandoned grasslands significantly increased forage biomass production and utilization. Extended spring grazing resulted in higher weight gain than traditional practices, with sheep preferring previously grazed areas (Steinshamn et al., 2018). Various factors influence their grazing behaviour, including the timing of dawn and dusk, temperature, humidity, and prior grazing activity. Temperature impacts daytime grazing times, while humidity affects midday and afternoon grazing. Afternoon grazing is more influenced by prior grazing activity than morning grazing (Dudziński & Arnold, 1979).

Sheep grazing behaviour is influenced by a conflict between feeding and social motivations, with increased vigilance and reluctance to graze away from the group unless accompanied by peers. Group size is crucial; smaller groups increase vigilance and reduce grazing at preferred sites, while larger groups provide social support, reducing vigilance and allowing freer grazing. Familiar peers influence foraging location, as sheep prefer to graze near familiar ewes, balancing social contact and feeding preferences (Dumont & Boissy, 2000). Sheep use spatial memory to improve foraging efficiency, frequently revisiting nutrient-rich sites. Their cognitive abilities, like spatial memory, are crucial for making informed grazing decisions (Bailey et al., 1996).

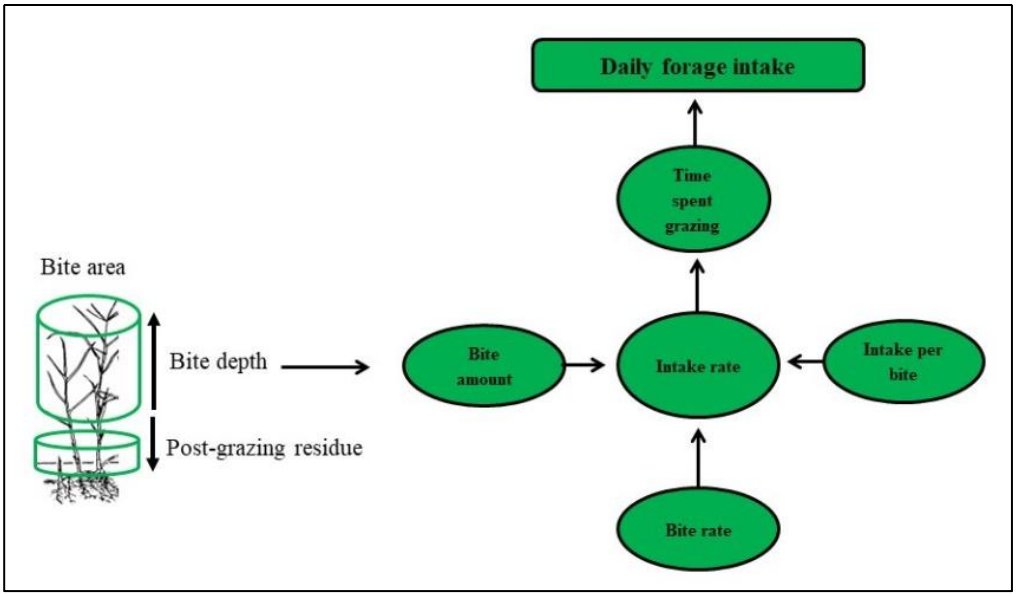


Figure 1. Components of ingestive behaviour. (Dias-Silva & Filho, 2020)

Sheep at higher stocking levels spend more time grazing, adjusting their behaviour based on pasture availability. Fatigue appears to set in at different times for different sheep, with those grazing the longest experiencing the most minor weight loss or the highest weight gain. The variability in grazing times among sheep indicates differences in their resilience and adaptability to changing pasture conditions (Arnold, 1960). Sheep can meet their nutritional needs by browsing various woody species (Papachristou et al., 2005). In pastoral systems based on grazing itineraries, sheep consume natural pastures, forages, fodder legumes, woody species, and crop residues (Castro & Fernández-Núñez, 2016). Sheep grazing patterns are shaped by a mix of environmental factors, such as terrain slope and water proximity, along with biological factors, such as the quality and availability of forage (Bailey et al., 1996).

Various environmental and biological factors influence sheep breeds' behaviours. For instance, the daily activity of Churra sheep in northwestern Spain follows a circadian rhythm, affecting processes like sleep and digestion. Flock activity, measured by movement patterns, shows significant circadian rhythmicity. In summer, particularly July and August, peak activity shifts earlier due to longer days and higher temperatures. Activity is highest during the day and lowest at night across all seasons, with increased dawn activity in summer. Grazing direction is non-random, influenced by terrain and grazing area boundaries (Plaza, Palacios, et al., 2022). Sheep prefer green legumes due to their higher nutritional value, increasing residency time in these areas. Understanding how pasture type influences grazing behaviours and how these behaviours affect pasture performance is crucial for sustainable management strategies (Parnell et al., 2022).

The grazing patterns of Churra sheep were found to be non-random, as they displayed common behavioural patterns influenced by vegetation height, land use/land cover (LU/LC) class, and terrain attributes such as slope and aspect (Castro & Fernández-Núñez, 2016). The Churra breed sheep consistently preferred for areas with lower vegetation cover and gentle slopes for grazing (Plaza, Sánchez, et al., 2022). In Northeast Portugal, sheep and goat production systems rely heavily on the extensive use of spontaneous plant resources, with shepherds guiding their flocks on daily grazing itineraries across various land use patches (Castro et al., 2010). The Montesinho Natural Park (PNM) offers a unique environment in which to study grazing patterns due to its diverse bioclimatological zones and traditional pastoral systems (Castro et al., 2021). Environmental variability, such as rainfall and snowfall, shapes grazing patterns. Non-equilibrium environments, characteristic of many pastoral areas, require flexible and opportunistic management strategies rather than fixed carrying capacities (Scoones, 2020).

Human influences, such as herding practices and land management strategies, are critical determinants of grazing patterns. Traditional herding practices, informed by generations of local knowledge, guide the movement of sheep flocks and their use of different grazing areas (Castro et al., 2021)The shepherd plays a crucial role in determining grazing itineraries, including the length of the journey, resources exploited, and feeding patterns, although environmental conditions significantly influence these decisions (Castro et al., 2010). Sheep management varies depending on the products being harvested and whether these products are for home consumption or sale in local or export markets (Ferguson, 2017). Pastoralists utilize strategic mobility to adapt to variable grazing opportunities, optimizing nutrient availability for their livestock (Krätli et al., 2022). Pastoralists have demonstrated their ability to best adapt to the ramifications of climate change by employing localized coping strategies (Arjjumend, 2018).

2.3 Livestock Monitoring Methods and Technologies

There is no universally superior measurement technique; the most suitable method depends on the specific research objectives and the conditions under which the measurements are taken, including factors such as the study's time scale, the degree of environmental heterogeneity, the availability of tame animals, logistical considerations, and funding. Grazing ecologists have devised various methods to assess foraging strategies (Gordon, 1995).

In his 1995 study, Gordon utilized a combination of cameras, direct observation, and telemetry to investigate sheep grazing behaviours. Cameras continuously recorded the animals' behaviour and movements, providing a comprehensive dataset. Direct observation allowed researchers to manually record detailed activities and interactions in the field, capturing nuances that automated methods might miss. Using GPS collars, telemetry enabled remote monitoring of the sheep's location and movements, facilitating the tracking of grazing routes and spatial use of the pasture. These methods collectively offered a thorough understanding of grazing patterns and the environmental factors influencing them (Gordon, 1995).

❖ **Traditional Methods and Evolution of the Practices:**

- **Direct Observation in Animal Behaviour Studies**

Direct flock observations individually record sheep locations and behaviour activities during sighting, with locations estimated to the nearest grid square. The behaviour activity categories used were based on those defined by (Hester et al., 1999), including grazing, moving, standing, lying, interacting, and other activities (Williams, 2010).

It has evolved to provide detailed estimates of diet composition, daily intake, and diet selection throughout grazing periods (Meuret et al., 2013). This method allows for the real-time recording of observed and heard behaviours, offering valuable insights into animal ecology and behaviour (Scheibe et al., 2008).

- **Integration of Modern Techniques**

Traditional practices are essential, but integrating modern techniques can enhance the accuracy and efficiency of grazing monitoring. (Arjjumend, 2018) highlights that pastoralists now use mobile phones to obtain information about conditions for moving herds: weather, pasture and water availability, disease, and conflict along trekking routes. Zinsstag et al., 2016 highlight that the future of monitoring sheep grazing will benefit from incorporating modern technologies such as communication systems, GPS, and drones to enhance data collection and management practices.

Scientists are now employing technologies like Global Positioning System (GPS) data to track and monitor the behavioural ecology of free-ranging animals, allowing for the detection of subtle changes in livestock behaviour (Barwick, 2016.; Tomkins & O'Reagain, 2007; Ungar et al., 2005).

By combining traditional methods with modern technologies, researchers can achieve a more comprehensive understanding of grazing patterns and behaviours, thereby improving the management and sustainability of grazing systems.

Group 1: Technological Advances in Grazing Monitoring

Electronic Tracking Devices

- **GNSS (Global Navigation Satellite System) Technology**

GNSS and GPS technologies have improved the precision of tracking herd movements. These tools provide detailed spatial data for understanding grazing patterns and their interaction with landscape features (Castro et al., 2021). Global Navigation Satellite Systems (GNSS) are essential geospatial positioning tools that estimate specific locations on the earth's surface through the triangulation of signals from at least three orbiting satellites (Fogarty et al., 2015).

Recent advancements in GNSS technology have enabled its application in the remote monitoring of animal movements, providing valuable insights into complex behaviour patterns. This capability is advantageous in extensive sheep grazing systems (Fogarty et al., 2015). Implementing buffer zones and rolling averages significantly improves the accuracy of GNSS collars by reducing the impact of standard GNSS errors, thereby enhancing the accuracy of real-time location tracking for grazing sheep (Kodam, Duthie, & Waterhouse, 2017).

The positional accuracy of GNSS data has been validated through comparative studies, showing that GNSS estimates of each animal's location are highly reliable when compared with direct visual observations. One study estimated positional accuracy at 90-94% for a 4-meter and 6-meter buffer radius, respectively. This high accuracy demonstrates GNSS technology's potential for effectively monitoring sheep movements and behaviour (Fogarty et al., 2015).

The GNSS equipment tested in the study successfully differentiated various activities of the sheep, such as grazing, resting, and transit. It also accurately determined their locations and characterized their movement patterns, routes, and preferred grazing areas (Sales-Baptista et al., 2019). According to Castro et al. (2020), GNSS receivers are effectively used to monitor the movement of sheep flocks, estimating grazing time across different land use areas and providing detailed information on the spatial distribution and movements of the animals. For instance, in the Serra de Montemuro, central Portugal, GNSS collars monitored the spatiotemporal distribution of two goat herds and one sheep herd, capturing data on their grazing patterns and locations (Castro et al., 2023). The GNSS collars enabled the collection of positional data to analyze grazing patterns and the spatial use of the landscape (Castro et al., 2022). The study on GNSS technology and its application for improved reproductive management in extensive sheep systems demonstrated the potential for precise monitoring and management of grazing patterns (Castro et al., 2023).

GNSS technology is often integrated with other sensors and data sources to provide comprehensive monitoring solutions. For example, combining GNSS data with accelerometers, weather data, and machine learning algorithms can enhance the detecting of specific events such as parturition in sheep. This integration allows for more accurate and timely management interventions (Fogarty et al., 2021).

The costs associated with this monitoring included the purchase price of the equipment and web platform services, emphasizing the importance of balancing cost and precision in monitoring efforts (Castro et al., 2022). Recent advances in Global Navigation Satellite System (GNSS) technology have made portable devices more accessible and affordable. Although basic tracking units are relatively costly, their use in livestock research has significantly increased, enabling detailed studies of animal behaviour and resource interactions (Trotter et al., 2010).

- **SheepIT project:**

The SheepIT project is designed to control sheep posture and monitor their behaviour, actions, and location using a Wireless Sensor Network (WSN). This system uses cloud computing and an application layer to wirelessly transfer data collected by sensors. The nodes in the network handle relative location using the Received Signal Strength Indication (RSSI) value, which helps reduce power consumption. The project aims to implement a virtual fencing mechanism and ensure efficient sheep posture and movement monitoring (Nóbrega et al., 2017).

Received Signal Strength Indicator (RSSI) has gained attention due to the increasing number of IoT devices utilizing this method for localization. RSSI measurements are commonly used for target detection and can be employed for localization without additional sensor functionalities. RSSI utilizes signal propagation models, either theoretical or empirical, to translate signal strength into distance. However, RSSI is highly sensitive to interference and can experience significant deviations between measurements (Ojo et al., 2021).

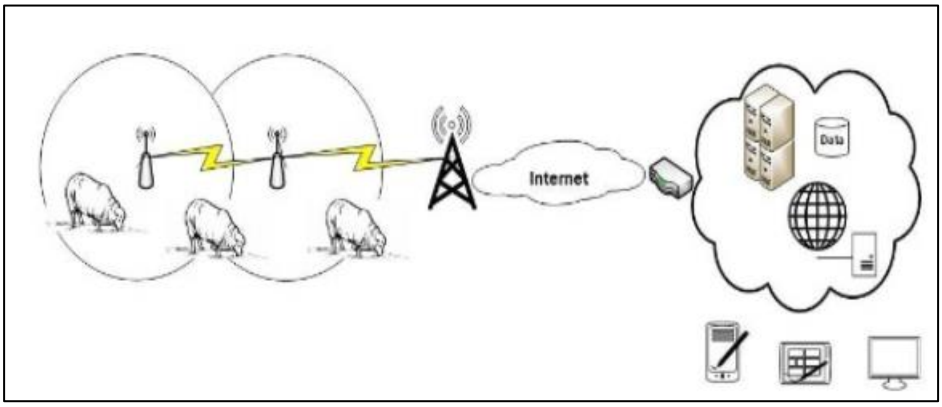


Figure 2. Architecture of the Sheep IT project. Source: (Nóbrega et al., 2017).

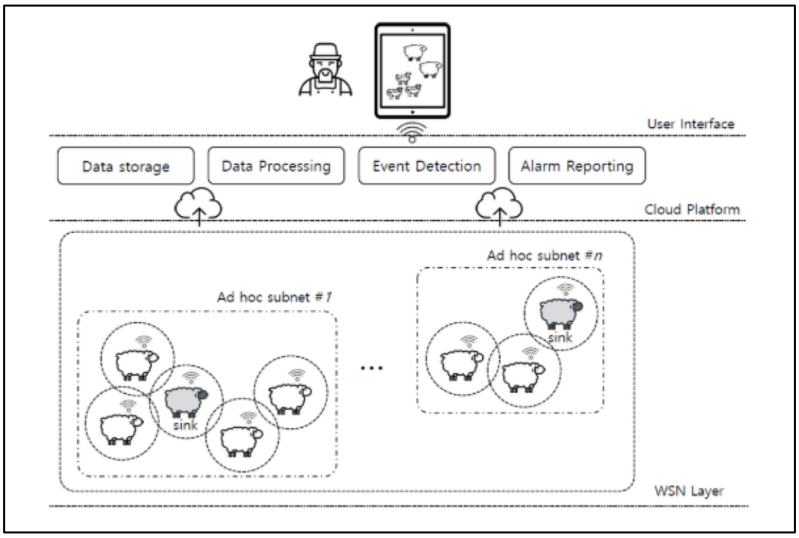


Figure 3. WSN layer Cloud-based Architecture for sheep monitoring (Park & Park, 2020).

- **Arduino-Based Tracking Systems**

Ramesh et al. (2021) developed a system to track the location of farm animals using Arduino and a GPS module. The system is designed as a collar worn on the neck of the animals, featuring an Arduino Uno (ATmega328p), a Wi-Fi module (ESP8266), and a GPS module, all powered by a battery. This setup provides real-time positional data.

- **Low-Cost IoT-Based System**

Maroto-Molina et al. (2019) proposed a low-cost solution to monitor sheep's location in a herd. The system is composed of Global Positioning System (GPS) collars connected to a Low Power Wide Area network and low-cost Bluetooth Low Energy (BLE) tags connected to the collars. GPS collars provide precise location data using satellites, while BLE tags offer approximate positioning through low-power radio communication technology. Some sheep wear GPS collars, while others wear BLE tags. Data collected by the GPS collars and nearby BLE tags is sent to a cloud service, enabling real-time alerts via an app. The GPS collars have more than 365 days of autonomy, whereas the BLE tags last up to 280 days.

Figure 4. Devices used to track sheep location: (A) GPS device; (B) BLE Tag. Source: (Maroto-Molina et al., 2019)

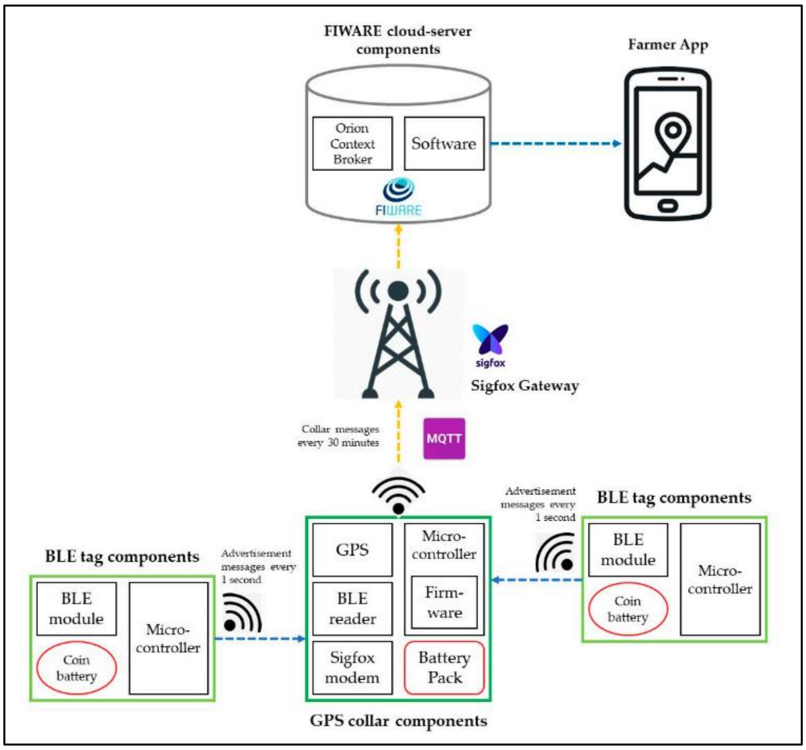


Figure 5. Architecture diagram of the project (Maroto-Molina et al., 2019)

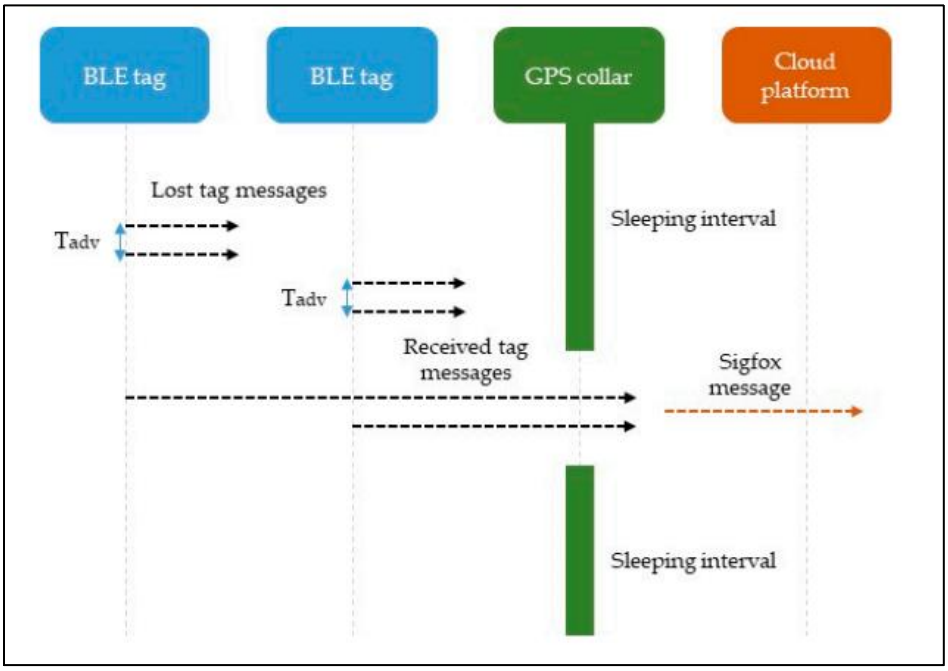


Figure 6. Communication protocol of the system (Maroto-Molina et al., 2019)

Internet of Things (IoT) and UAV (Unmanned Aerial Vehicle) Technologies

- **Integrated IoT Systems**

According to the Internet Society (ISOC), the Internet of Things (IoT) refers to scenarios where network connectivity and computing capability extend to objects, sensors, and everyday items not usually considered computers. These devices generate, exchange, and consume data with minimal human intervention. There is, however, no single, universal definition (Rose et al., 2015).

Recent advancements in high-resolution remote sensing and Internet of Things (IoT) technologies have significantly improved the monitoring of pastured vegetation. UAVs equipped with high-performance sensors can now accurately survey the vegetation structure and composition over time and space using multi- and hyperspectral sensors, radar, and thermal technology. Geolocation and data transmission devices, such as new GNSS systems, GSM, LoRa, and satellite networks, are widely available for tracing the activities and movements of herds. Integrating IoT technologies with traditional herding knowledge has shown to be highly complementary, linking herders' decisions to the distribution of grazing records and animal preferences (Castro et al., 2023).

- **Smartsheep project**

The Smartsheep project exemplifies an IoT-based system for real-time livestock location monitoring. It integrates ad hoc IoT devices with inertial sensors, GPS receivers, and LoRaWAN transceivers. These devices collect location and activity data, transmitting it via LoRaWAN gateways to a cloud-based platform for processing and management. This system balances performance, cost, and energy consumption and is suitable for remote and mountainous grazing areas (Ojo et al., 2021).

- **UAV (Drone) Technology**

An Unmanned Aerial Vehicle (UAV), commonly known as a drone, is an aircraft that operates without a human pilot onboard. These vehicles are components of an unmanned aircraft system (UAS), including a ground-based controller and a communication system between the UAV and the controller (Austin, 2010).

Unmanned Aerial Vehicles (UAVs), play a significant role in sheep herd monitoring by providing aerial surveillance and data collection. UAVs with advanced sensors can capture high-resolution images and videos to assess the flock's health, monitor grazing patterns, and detect potential threats such as predators or poachers. These drones can operate autonomously or be remotely controlled, offering a comprehensive view of large grazing areas that would be challenging to monitor manually. Integrating UAVs in herd management enhances the ability to oversee extensive pastures, ensuring better animal care and optimizing resource use (Dunsun, 2023).

Using drones equipped with multispectral sensors, such as Parrot Sequoia or Micasense, provides significant advantages in grazing management. These drones offer superior temporal, spatial, and spectral data for monitoring purposes (Castro et al., 2020).

- **LoRaWAN Technology and Abeeway Project:**

LoRaWAN, a low-power wide-area network (LPWAN) technology, is also used for livestock monitoring. It provides long-range communication with low energy requirements, making it suitable for extensive grazing areas with limited infrastructure. LoRaWAN networks utilize techniques like Received Signal Strength Indicator (RSSI) for coarse positioning and Time-Difference-of-Arrival (TDoA) for finer accuracy, achieving location accuracies between 20–200 meters depending on conditions (Ojo et al., 2021).

Abeeway has developed a device to provide real-time location tracking of sheep in remote agricultural areas where cellular-based GPS trackers are ineffective. The device utilizes the LoRaWAN network for connectivity, a low-power technology significantly extends battery life. Additionally, Abeeway employs LoRa TDoA (Time Difference of Arrival) technology, which offers approximate location tracking with lower power consumption than GPS. The system also supports geofencing, allowing farmers to define a virtual boundary for the grazing area and receive alerts if a sheep exits this area. Abeeway, in collaboration with Actility, developed a modular Location Engine called ThingPark X. This system processes, analyzes, and manages geolocation data, storing it securely and providing the best possible location information through multiple geolocation technologies (Abeeway, 2023).

Time-Difference-of-Arrival (TDoA) measures the difference in propagation time between signals, such as RF, acoustic, or ultrasonic signals, to calculate the distance by determining the differences in arrival time of the packet to different receivers. This method is affected by delays that can be experienced by the transmitted signal, with different distances calculated based on propagation times. TDoA sometimes mitigates synchronization issues and reduces system complexity (Ojo et al., 2021).

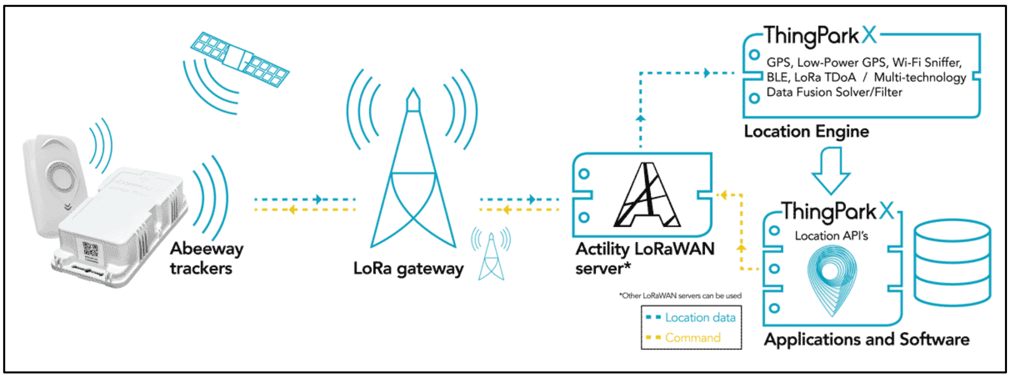


Figure 7. Architecture of the Abeeway project. Source: (Abeeway, 2023)

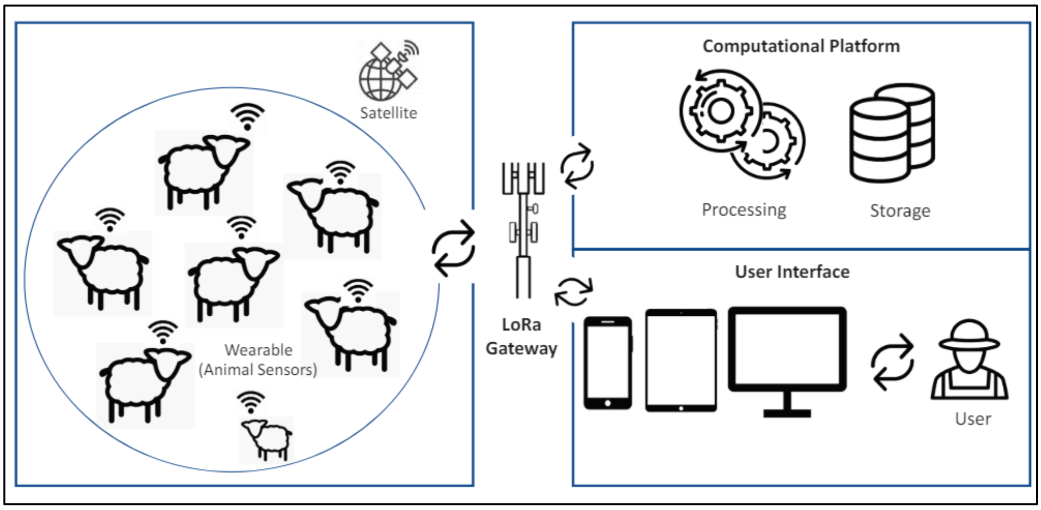


Figure 8. LoRaWAN-based livestock monitoring system (Ojo et al., 2021)

Camera and Video Monitoring

- **Combined Audio, Video, and Sound Descriptor Analysis**

In monitoring the foraging behaviour of free-ranging sheep, a small video camera is attached to a halter and a wireless microphone is used to capture acoustic data, distinguishing between resting, feeding, and non-foraging chewing activities. This data is analyzed using SoundAnalysis Pro 2011 software, which examines globally recognized sound descriptors such as frequency modulation, amplitude modulation, pitch, goodness of pitch, and Wiener entropy. The combined audio and video data allow for accurate categorization and calibration of foraging behaviours based on the sounds associated with biting and mastication (Sneddon & Mason, 2014).

(a)

(b)

Figure 9. (a) Small video camera with 120° wide-angle lens (b) Attachment of the video camera to a Texel ewe via a halter (Sneddon & Mason, 2014)

Group 2: Advanced Sensing and Analysis Techniques

Passive Acoustic Monitoring (PAM)

Karmiris et al. (2021) demonstrated using Passive Acoustic Monitoring (PAM) to track sheep grazing activities in the Rhodope mountain range, Greece. Combining autonomous recording units with detection algorithms effectively captured and analyzed sounds such as sheep bleats and livestock bells. This method provided high-resolution spatiotemporal data on grazing patterns and highlighted the potential of PAM as a cost-efficient, non-invasive tool for sheep grazing management. Their findings suggest that PAM can significantly enhance the monitoring of sheep grazing activities in remote areas.

Wearable Sensors

Wearable sensors such as tri-axial accelerometers and GPS systems provide data on sheep's movement, behaviour, and physiological conditions (Giovanna Ciliberti et al., 2023).

Barwick et al. (2020) evaluated a 'clean state' moving window behaviour classification algorithm on accelerometer data from the collars, legs, and ears of five Merino ewes. The algorithm, applied to 3, 5, and 10-second data segments, successfully categorized grazing, standing, walking, and lying behaviours. The highest accuracy was with ear-mounted sensors (86%–95%), followed by collar-mounted (67%–88%) and leg-mounted sensors (48%–94%), with no significant difference in accuracy across the different window lengths.

In a study, ActiGraph wGT3X-BT accelerometers were used to measure the amplitude and frequency of movement across three axes (X, Y, Z), with these sensors attached to different body positions such as neck collars, head halters, and body harnesses to collect continuous acceleration data. It highlights the importance of sensor placement for accurate behaviour classification in sheep (Ikurior et al., 2021).

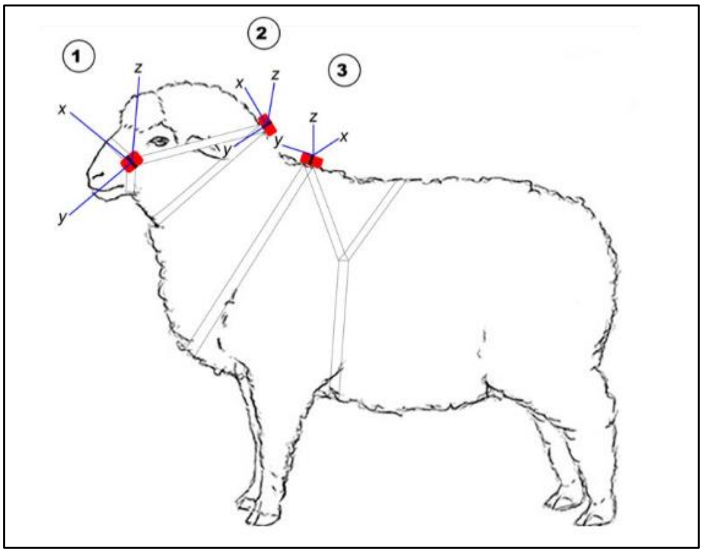


Figure 10. Positions and Axis Orientations of ActiGraph Tri-Axial Accelerometers: 1 (Head Halter), 2 (Neck Collar), and 3 (Body Harness) in Relation to the Sheep's Body (Ikurior et al., 2021)

Geographic Information Systems (GIS) and Remote Sensing

GIS and remote sensing tools are integral in analyzing grazing patterns. These technologies enable the visualization and spatial analysis of grazing data, identifying key grazing areas and assessing the impact of environmental changes on grazing behaviour (J. Castro et al., 2021).

Castro et al., 2020 describe using GIS combined with remote sensing data to analyze and map the spatial distribution of grazing activities, offering a detailed view of grazing patterns.

A geographic information system (GIS) was employed to analyze the GPS data, considering vegetation characteristics, altitude, and proximity to fences, water sources, and a sheep shed (Putfarken et al., 2008).

Sentinel-2 Satellite Imagery

Sentinel-2 multispectral data is utilized for high-accuracy land use and cover classifications. The use of supervised classification algorithms, such as Maximum Likelihood (ML), enhances the accuracy of these classifications (Castro et al., 2020).

Group 3: Other Methods:

Stocking Density and Grazing Pressure Modelling

Castro et al. (2020) explain that the calculation and spatial interpolation of Stocking Density (SD) allows for the creation of detailed maps of grazing pressure (GP), integrating land use and cover preferences.

Management and Mitigation Strategies

Grazing pressure modelling and mapping are instrumental in developing herding programs to reduce wildfire risks by managing fuel loads at both parish and regional levels (Castro et al., 2020).

Index Methods

Ivlev’s selectivity index is used to quantify sheep preferences for different land use and land cover (LULC) classes. This index helps determine the proportion of time herds spend in various grazing areas relative to their availability in the landscape (Lechowicz, 1982).

2.4 Implications of Grazing Patterns on Rangeland Health and Environmental Sustainability: Contributions to Climate Change

Environmental and Climatic Influences:

Sheep grazing can reduce shrub vegetation and promote the growth of mixed vegetation, especially in areas where sheep frequently rest (Oom et al., 2008). Grazing shapes plant populations and communities through recurrent disturbances such as plant defoliation, trampling, urine, feces, and saliva deposits. Extensive grazing enhances plant diversity by creating spatial heterogeneity. Differences in grazing intensity, particularly with distance from the sheepfold, influence vegetation, fodder, litter, and soil in varying ways (Vidaller et al., 2022). Sheep grazing and trampling significantly impacted vegetation in grass-dominated and heather-dominated habitats, increasing the likelihood of moderate to severe vegetation impacts (Albon et al., 2007). Additionally, grazing is critical in mediating soil carbon levels, often omitted in Life Cycle Analyses (LCAs) (Houzer & Scoones, 2021).

Sheep grazing is crucial in maintaining the balance and quality of Mediterranean rangelands. Traditional heavy grazing in the Mediterranean region prevents shrub encroachment, maintains open landscapes, and enhances species diversity and ecosystem resilience. Long-term grazing by sheep shapes the structure and composition of rangeland vegetation, and even heavy grazing can boost resilience and productivity by preventing the dominance of woody species (Perevolotsky & Seligman, 1998).

Sheep grazing on rangelands offers significant economic and ecological benefits, reducing feed costs and enhancing rangeland health and ecosystem diversity. Sheep graze on different forages than cattle, including woody and forb species, leading to more uniform forage utilization and promoting rangeland diversity. They can navigate rough terrain and graze areas that cattle often miss, ensuring more even grazing distribution. Multispecies grazing with sheep improves forage utilization, supports rangeland biodiversity, and maximizes the productivity of grazing operations (Whaley, 2022). Extensive livestock systems, including pastoralism, are low-impact and play a vital role in climate justice (Houzer & Scoones, 2021).

Livestock, including sheep, consume underbrush, which is hazardous for spreading fires, thus contributing to forest fire prevention (Castro & Fernández-Núñez, 2016; Challot, 1990). Sheep grazing can improve the soil environment by boosting biodiversity, soil carbon, and nutrient levels (Scott & Robertson, 2008). Properly managed grazing supports biodiversity and soil health, contributing to carbon sequestration, whereas overgrazing can lead to land degradation and reduced biodiversity. Sustainable grazing practices are essential to maintain ecosystem health and support pastoral livelihoods (Næss, 2013; Scoones, 2020; Zinsstag et al., 2016). Depending on grazing patterns, rangelands contain substantial soil carbon reservoirs and have high sequestration potential (Houzer & Scoones, 2021).

Livestock grazing on extensively managed grazing lands impacts plant community diversity, soil properties, and nutrient cycling within the plant-soil-water continuum, significantly influencing ecosystem functions like nutrient retention, primary production, and resilience (Schacht & Reece, 2008). Reducing sheep grazing increases dwarf shrub abundance and vegetation height but decreases the structural heterogeneity of vegetation mosaics, affecting biodiversity, wildfire risk, soil erosion, water retention, and landscape utility (Pollock et al., 2013).

Climate change significantly impacts pastoral systems, affecting herbage growth and livestock productivity (Dong et al., 2011; Nassef et al., 2009). Increased CO2 concentrations and precipitation may boost rangeland net primary production, but rising temperatures could alter this effect (Herrero et al., 2016). Adaptive management strategies, informed by traditional practices and modern technologies, are crucial for enhancing the resilience and sustainability of pastoral communities (Arjjumend, 2018; Scoones, 2020; Zinsstag et al., 2016).

Shepherding practices in Montesinho Natural Park provide essential regulating services, including fire risk control, maintaining landscape heritage, and supporting biodiversity and nutrient cycling. These services are vital for confronting the threats posed by climate change (Castro et al., 2021; Hartel et al., 2018; Marsoner et al., 2018; Múgica et al., 2021; Tenerelli et al., 2016). Grazing in Montesinho Natural Park is crucial in maintaining biodiversity by influencing vegetation patterns and ecosystem dynamics (Torres-Manso et al., 2017; Velado-Alonso et al., 2020).

Additionally, low-impact, extensive livestock systems, including pastoralism, can show a way to the future, ensuring that pastoralists' and smallholder livestock keepers' voices are heard, a matter of climate justice. It is also essential to explore how light, mobile grazing impacts carbon balances, as this could help reduce emissions and enhance carbon and nitrogen sequestration. Extensive livestock systems are crucial in managing soil carbon levels, a factor often overlooked in Life Cycle Analyses (LCAs) (Houzer & Scoones, 2021).

Landscape decision-makers and managers are encouraged to implement a landscape monitoring system to optimize grazing for ecological balance. This system will help inform policies and strategies to protect and safeguard mountain pastoralism and its vital ecosystem services, particularly in a warming climate scenario (Dolton-Thornton, 2021; Lasanta et al., 2017; Torres-Manso et al., 2017). Effective management practices, informed by modern technologies, can optimize grazing to maintain ecological balance and sustainability (Torres-Manso et al., 2017).

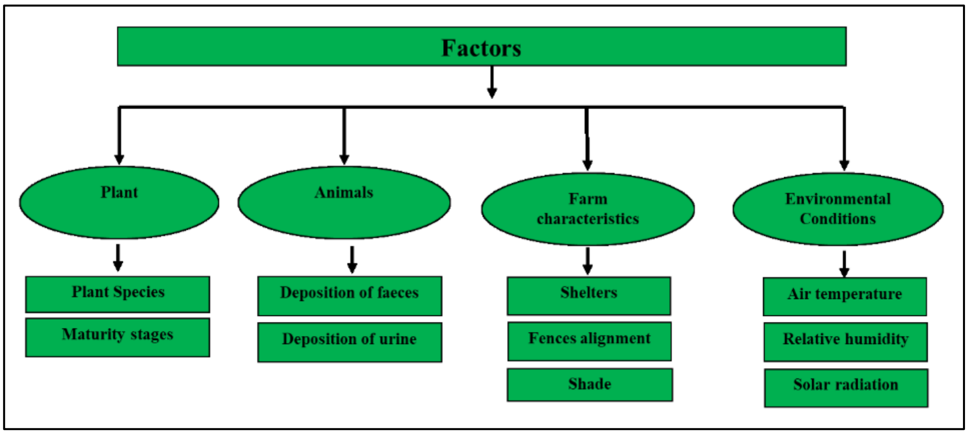


Figure 11. Factors influencing the feeding site selection. (Dias-Silva & Filho, 2020)

3. Material and Methods

3.1 Study Area

3.1.1 Description of Montesinho Natural Park

Montesinho Natural Park (PNM), located in northeastern Portugal, within the municipalities of Vinhais and Bragança, covers roughly 748 square kilometres, making it one of the largest protected areas in the country. Established in 1979, the PNM features a diverse landscape that includes mountains, valleys, and forests, with elevations ranging from 438 meters to 1,486 meters. The PNM supports about 9,000 residents living in 92 traditional villages, preserving a solid cultural heritage (Matos-Silva et al., 2022).

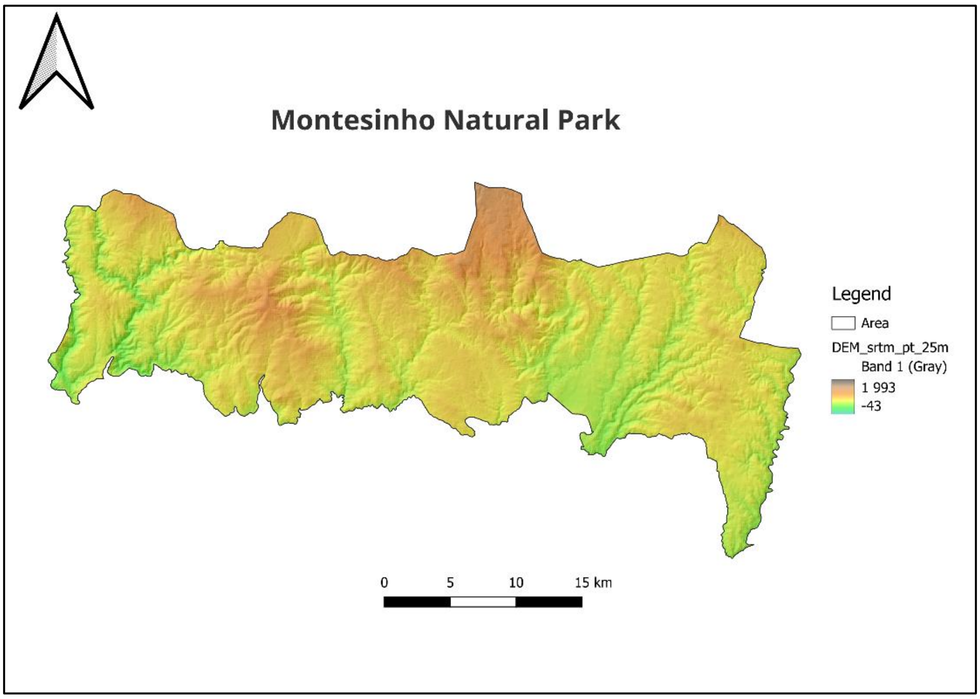


Figure 12. Elevation Distribution in Montesinho Natural Park Using Digital Elevation Model (DEM) Data

Montesinho is particularly noted for its biodiversity, hosting around 70% of Portugal's terrestrial animal species, including significant populations of Iberian wolves, golden eagles, and black storks. The varied vegetation features shrublands, heathers, and forests dominated by oak and chestnut trees, which are crucial for local agriculture and biodiversity (Castro et al., 2010). The park also showcases geomorphological features like deep valleys and high plateaus, adding to its scientific, ecological, and cultural importance (Pereira et al., 2007).

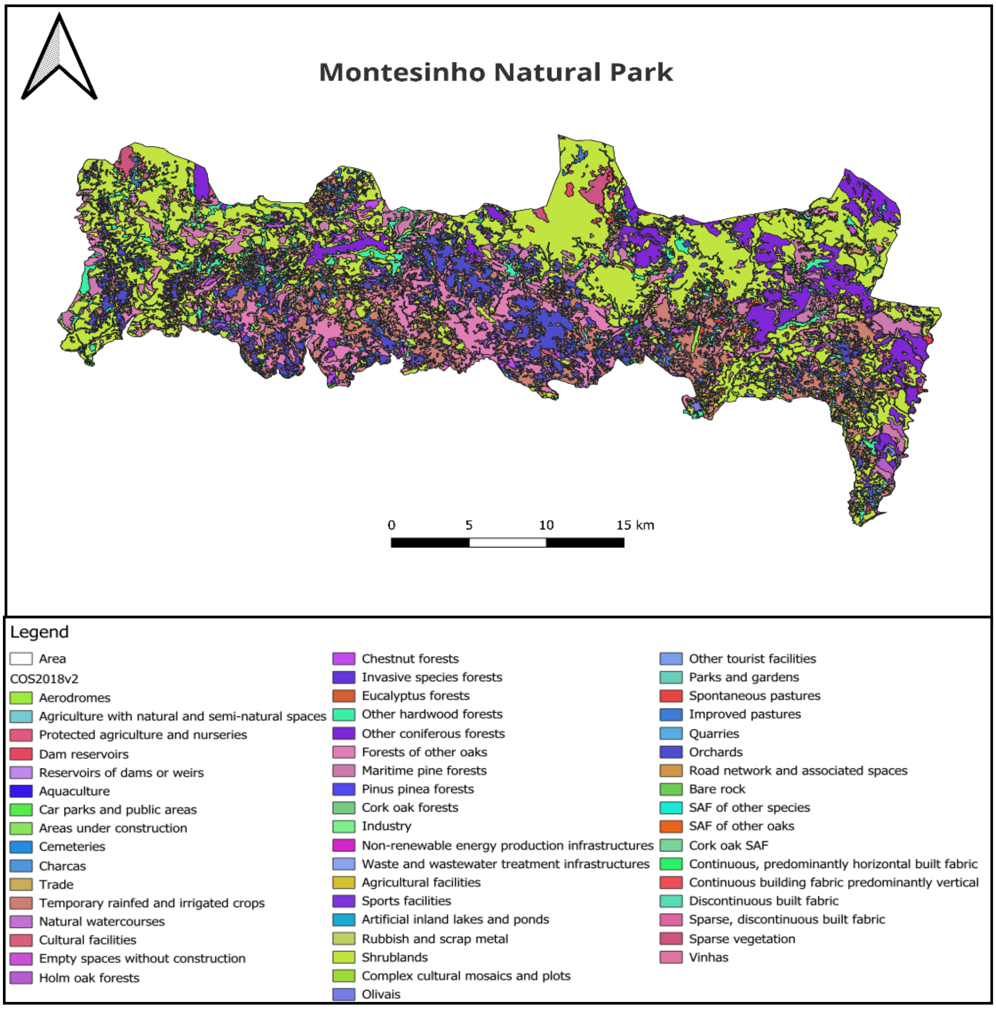


Figure 13. Land Use and Vegetation Types in Montesinho Natural Park According to the 2018 Land Use and Occupation Letter (COS2018v2)

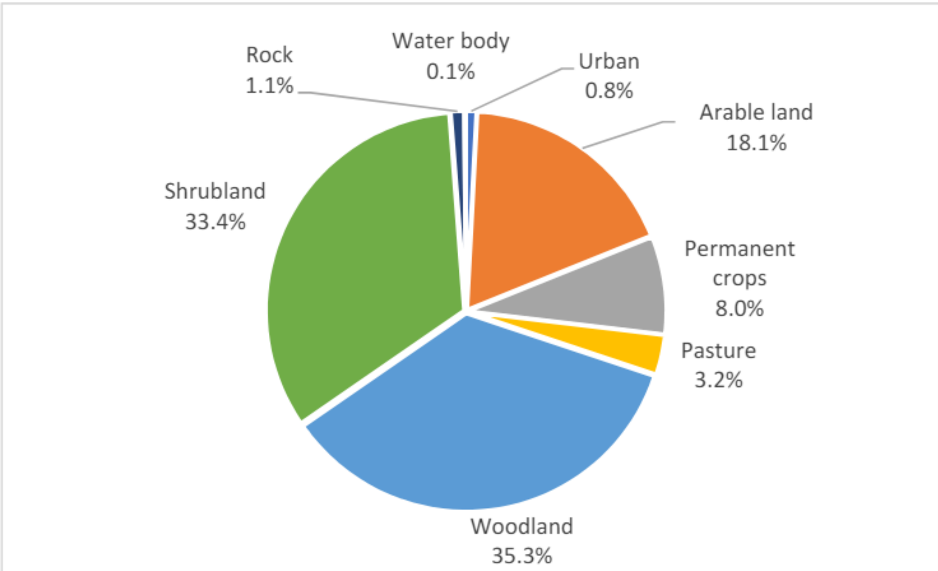


Figure 14. Land use (ha) in 2018. Source: Matos-Silva et al., 2022 own elaboration using data from (Castro et al., 2021).

The landscape of Montesinho Natural Park can be divided into five distinct units: Woodlands and rangelands, Rangelands with pineyards, Vinhais, Open landscapes, and Granite mountain (Castro et al., 2010).

The woodlands and rangelands, the largest unit, feature extensive oak woodlands and shrublands grazed by sheep and goats, providing high conservation value despite the challenging terrain (ICNF, 2019).

Figure 15. Dense Shrubland Associated with Oak Grove in Montesinho: Rich Biodiversity of Low and Tall Shrublands

The rangelands with pineyards are characterized by Mediterranean shrublands interspersed with pine forests and agricultural patches (ICNF, 2019).

Figure 16. Solitary Pine tree with Short and Tall Shrubs in Montesinho's Landscape

The Vinhais unit is marked by an agricultural mosaic and rural communities, fostering rich biodiversity and economic activities like chestnut orchards and livestock farming (ICNF, 2019).

Figure 17. Vinhais landscape

The open landscape near Bragança is defined by its simplicity and rectilinear farming patterns (ICNF, 2019).

Figure 18. Open landscape: cereal patches bordered by oak and ash trees

The granite mountain landscape, the highest and most rugged, features low shrubs, pastures, and rocky outcrops, creating a sense of isolation and grandeur (ICNF, 2019).

Figure 19. Montesinho Mountain Landscape: Cheira da Noiva-Porto de Sabor at 1300m ASL, with Ordovician Schists and Gamoneda Range. Source: (Pereira et al., 2005)

3.1.2 Climatic and Environmental Conditions

Montesinho Natural Park experiences a climate that transitions between temperate and Mediterranean, characterized by long, cold winters and short, warm summers. Average annual temperatures range from 8°C to 13°C, with yearly precipitation varying between 1,800 and 2,700 millimetres (Matos-Silva et al., 2022).These conditions contribute to the park's diverse ecosystems, which include shrublands, oak forests, and chestnut groves (Pôças et al., 2024).

The park's varied topography and climate support a wide array of flora and fauna, making it a significant area for ecological conservation. Additionally, Montesinho faces environmental challenges such as wildfires, which have shaped the vegetation and landscape over time (Dong et al., 2022). The climate significantly impacts pastoral activities, with local communities continually adapting to environmental changes to sustain traditional agricultural practices (Castro et al., 2021).

The climate in Trás-os-Montes is influenced by several mountain ranges, resulting in a continental climate with Mediterranean characteristics and pronounced dry summers. Annual precipitation is higher in the western and high-altitude areas, and there is a significant decrease towards the east due to the Föhn effect (Castro et al., 2010; ICNF, 2019).

3.2 Experimental Sites and Herds

3.2.1 Description of Study Area

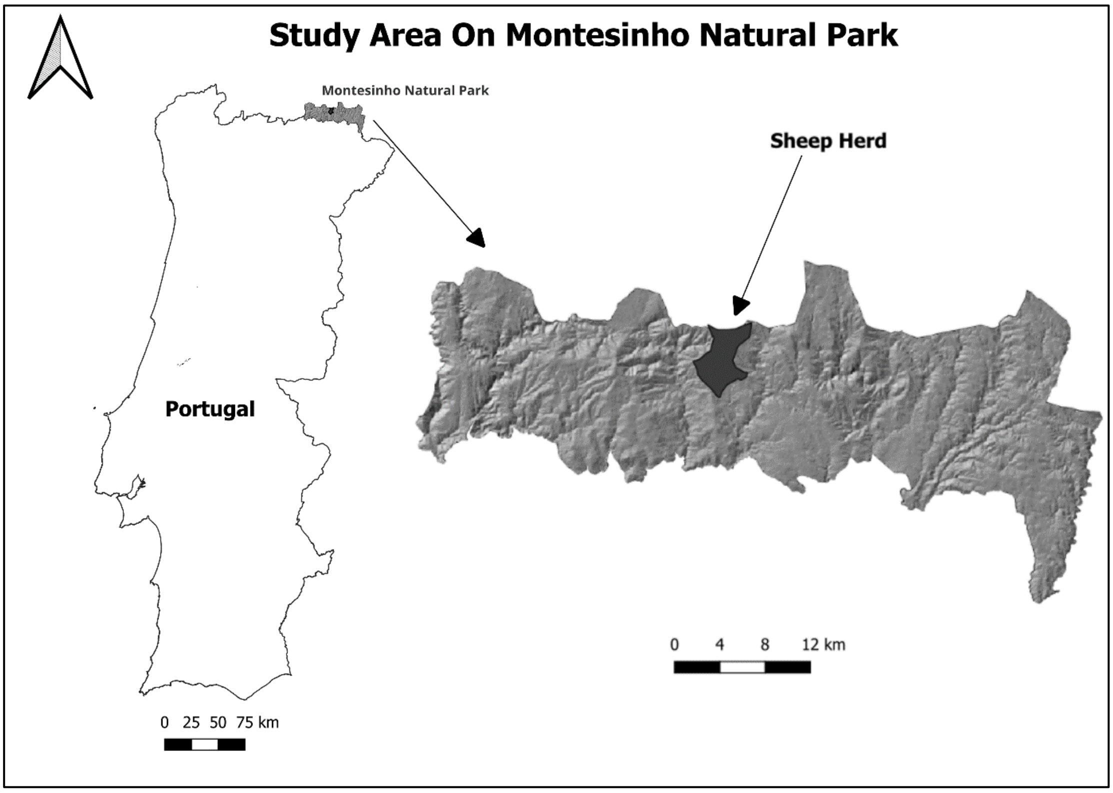


Figure 20. Study Area on the Montesinho Natural Park

The grazing zones of the sheep herd are situated within the province of Trás-os-Montes e Alto Douro, specifically within the sub-region of Coroa Montesinho, also known as Montesinho Natural Park. This park is located in the northeastern part of Portugal, near the border with Spain. Some records from this study also extend to areas just across the border in Spain. The sub-region is renowned for its breathtaking landscapes and rich biodiversity, making it an ideal setting for studying and analyzing the dynamics of the sheep herd and their interactions with the environment. The park's diverse terrain, which includes mountains, valleys, and forests, provides a variety of grazing habitats, influencing the movement and behaviour of the herd throughout the year.

- **Land use and land cover (LULC)**

Figure 21 displays the spatial distribution of various land use types within the study area, highlighted with colour coding, and overlaid with the movement paths of the sheep herd. Key land use types include forests of other oaks, shrublands, orchards, and temporary rainfed and irrigated crops. The black lines representing the sheep paths show a concentration in areas with diverse land use, indicating that the sheep herd utilizes different land types for grazing.

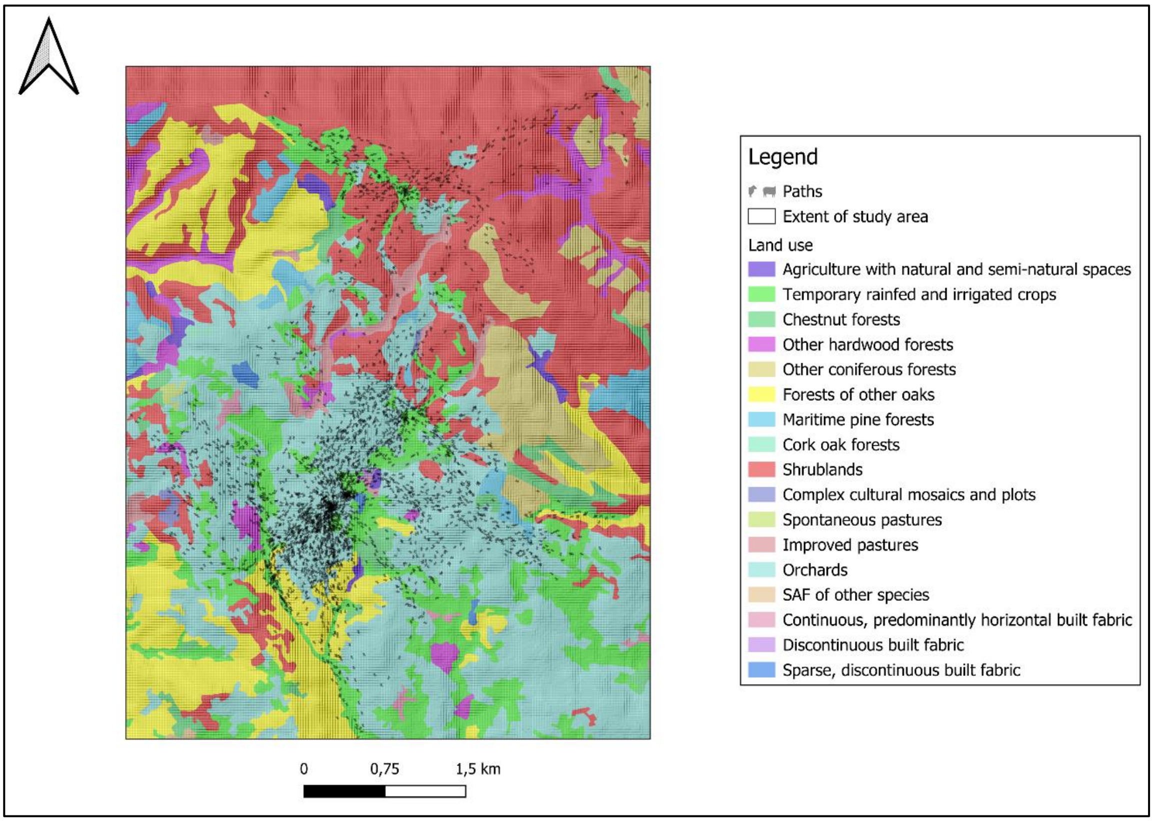


Figure 21. Land Use with Terrain Features and Sheep Movement Paths

Figure 22 is a pie chart that quantifies the percentage composition of each land use type within the study area. The chart reveals that forests of other oaks constitute the most considerable portion at 39%, followed by shrublands at 17%, orchards at 16%, and temporary rainfed and irrigated crops at 9%. Other hardwood forests account for 8%, other coniferous forests 4%, chestnut forests 2%, and maritime pine forests 3%.

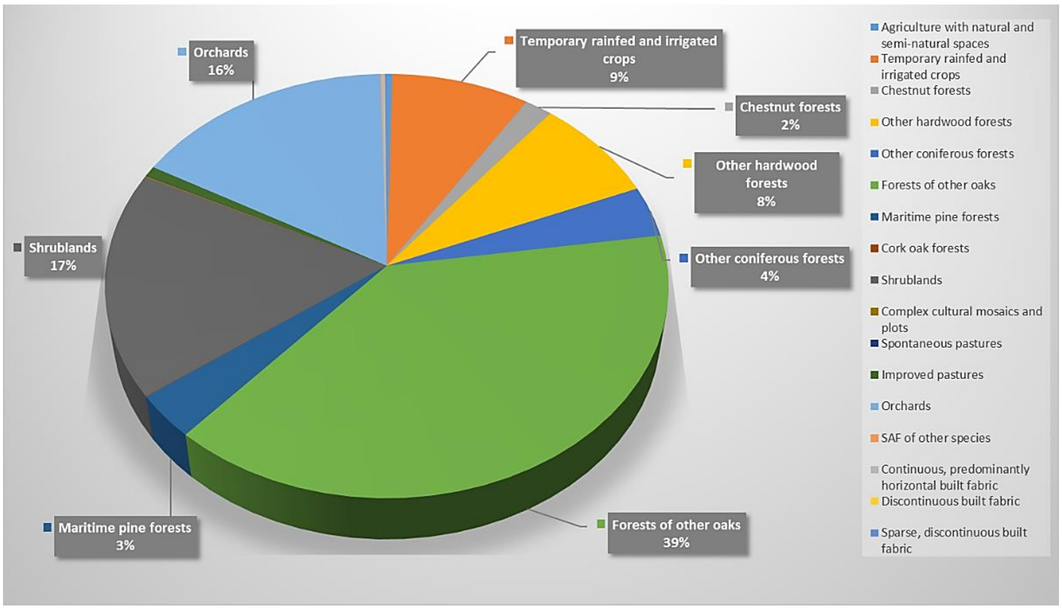


Figure 22. Percentage Composition of Land Use in the Study Area

- **Topographical Analysis of the Study Area**

Figures 23, 24 and 25 provide a comprehensive analysis of the topography within the study area of Montesinho Natural Park.

Elevation and Relative Slope Position

Figures 23 and 24 illustrate the elevation and relative slope position within the study area of Montesinho Natural Park. The elevation ranges from approximately 703 meters to 1145 meters, with green indicating lower elevations and brown/grey indicating higher elevations. This diverse topography influences grazing patterns, as higher elevations present more challenging terrain but offer cooler temperatures and different vegetation types. The relative slope position map, with values ranging from -0.271991 to 1.008242, shows steeper slopes in purple and gentler slopes in yellow. Steeper slopes may be less accessible for grazing, while gentler slopes are likely preferred due to easier terrain.

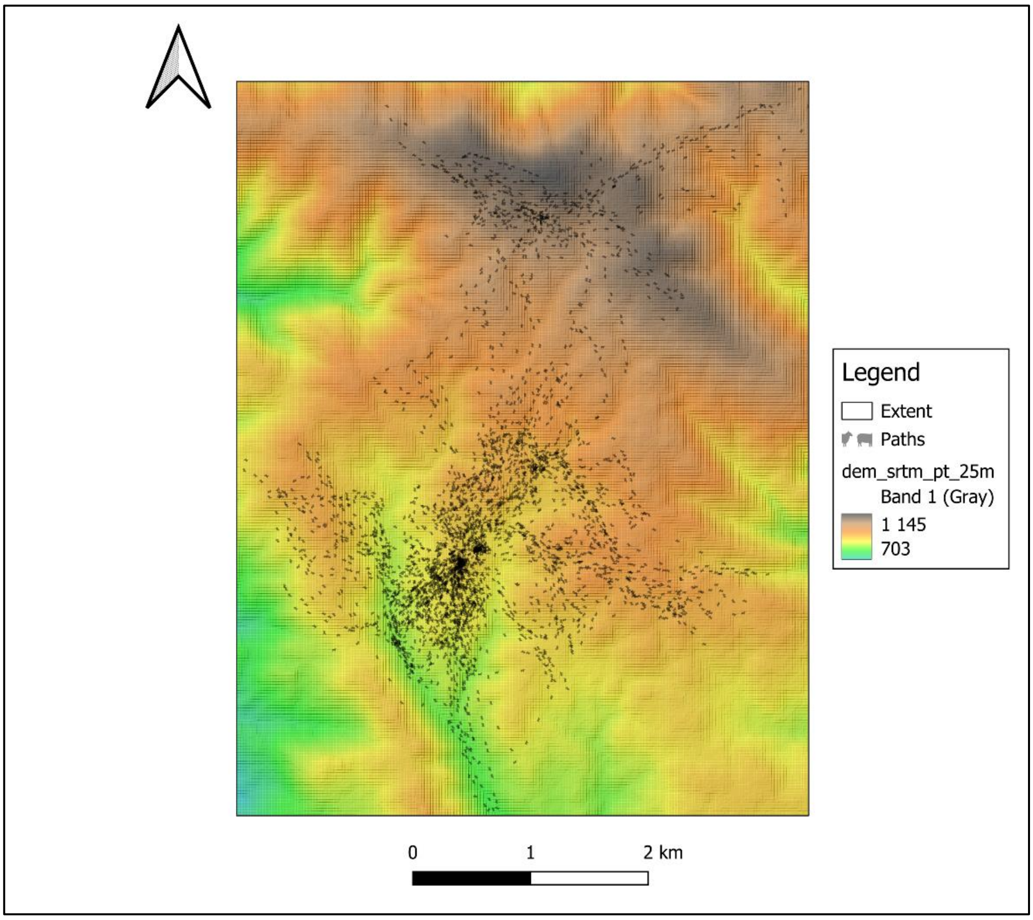


Figure 23. Elevation Map of the Study Area

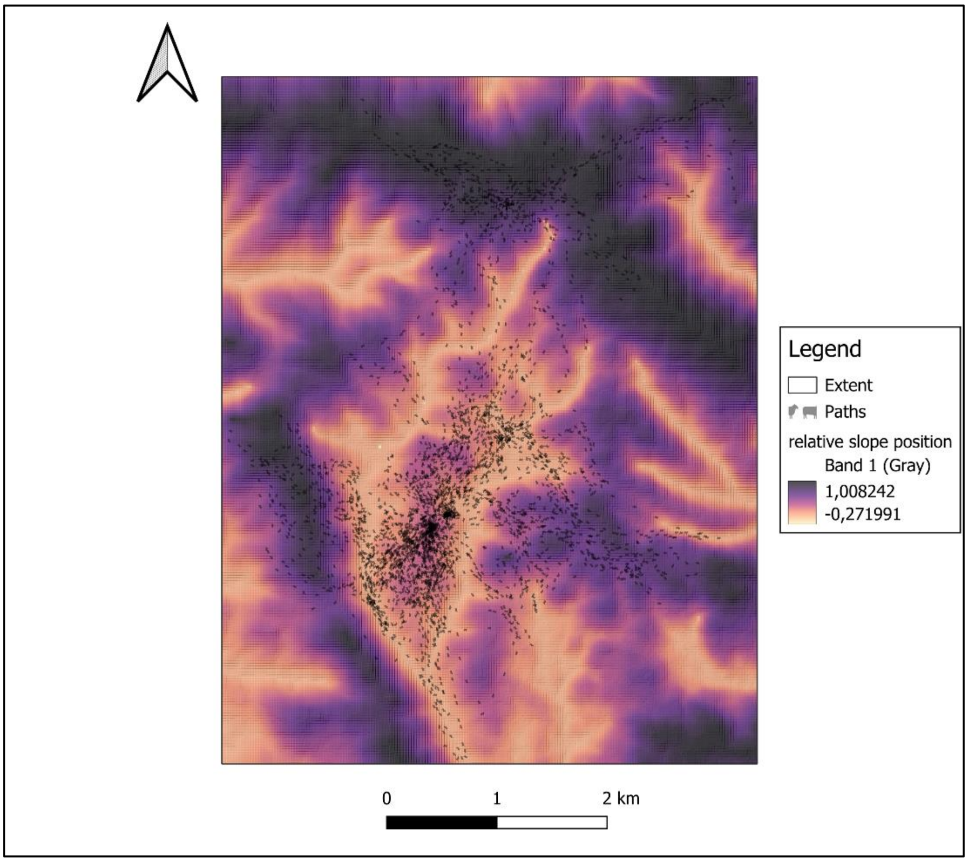


Figure 24.Relative Slope Position Map of the Study Area

- **Topographic Wetness Index (TWI):**

Figure 25 presents the study area's Topographic Wetness Index (TWI), with values ranging from approximately 3.735302 to 28.889948. The TWI is represented with a colour gradient from blue (lower wetness) to brown (higher wetness). Areas with higher TWI values indicate zones where water is likely to accumulate, suggesting these areas may be more suitable for vegetation growth, which can influence grazing patterns. Lower TWI values indicate drier areas, which might be less attractive for grazing due to reduced vegetation availability.

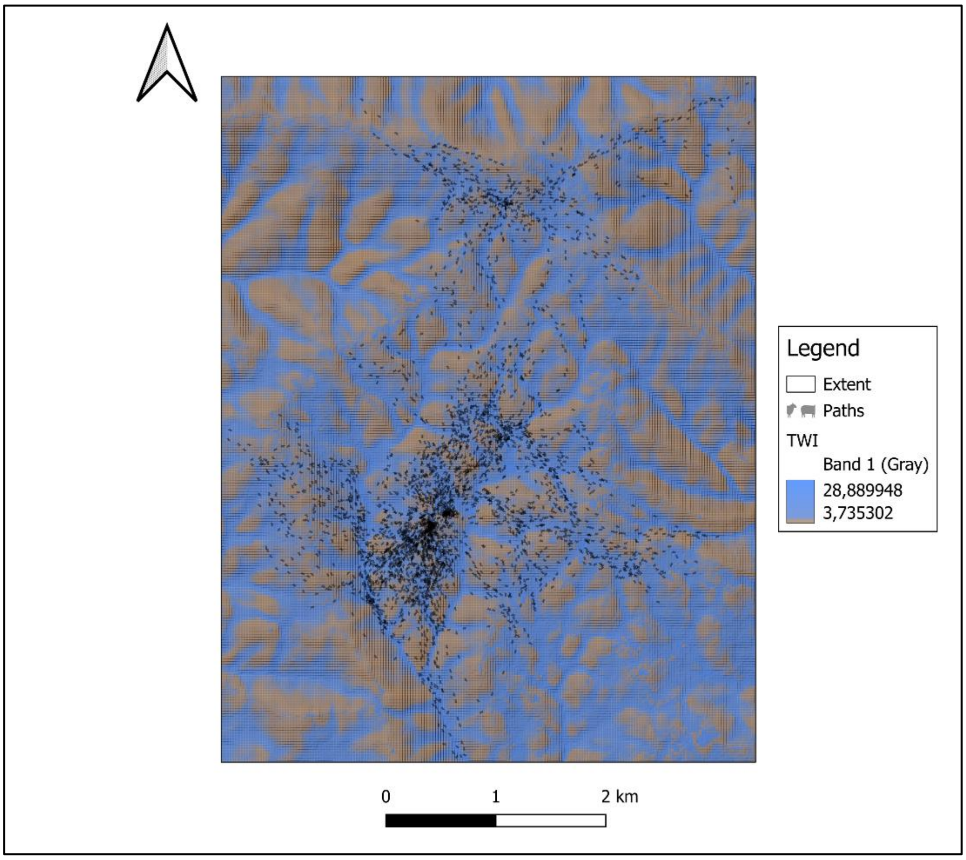


Figure 25. Topography Wetness Index Map of the Study Area

3.2.2 Herd Characteristics and Selection

One sheep from the herd was selected for GNSS tagging to monitor its grazing patterns. The selection criteria included the health and representative behaviour of the animal to ensure accurate data collection. The study focused on the grazing patterns of a sheep herd in the Montesinho Natural Park (Castro et al., 2023).

Breed Overview

The sheep breed studied is the Churra Galega Bragança Branca, a traditional breed well-adapted to the harsh environmental conditions of northeastern Portugal. Known for their resilience and high-quality meat production, these sheep are integral to the local pastoral system. The Churra Galega Bragança Branca breed is recognized for its robust build and ability to thrive in mountainous terrain. They have a high tolerance for the region's climatic extremes, including cold winters and hot, dry summers. This breed's grazing behaviour is influenced by the availability of forage, the topography, and the seasonal variations in climate. The herd size usually does not exceed 200 head, which allows for efficient management and monitoring of individual animals' health and grazing patterns (J. Castro et al., 2021; Rodrigues et al., 2006).

Adaptability and Resilience

The Churra breed's adaptability and resilience make it an ideal subject for studying the impacts of environmental variables on grazing behaviour and herd dynamics (Rodrigues et al., 2006). This breed has been maintained with careful genetic management to preserve its unique characteristics. The breed typically has black or brown patches around the eyes, muzzle, and ears. The wool is fine and greasy, covering most of the body except the head, anterior neck, belly, and legs. Males often have horns, while females usually do not. They are medium-sized, with high, thin but string legs often pigmented hooves. These sheep have a long tail and a robust constitution that makes them suitable for the rugged terrain of Montesinho Natural Park (ACOB, 2015; DGAV, 2018).

Management Practices

Management practices for the Churra Galega Bragança Branca include keeping the sheep outdoors for most of the year, often spending the night in gates or manure land. In summer, they graze at night to avoid high daytime temperatures, resting in shaded areas or wooded stands during the day to benefit from the shade. Their diet primarily consists of spontaneous herbs and shrubs, supplemented with hay and grains like rye or barley, depending on the season and reproductive management needs. Recent management improvements include increasing pasture areas, greater use of shelters, and enhanced forage production (ACOB, 2015; SPREGA, 2024).

Economic and Cultural Significance

The Churra Galega Bragança Branca is a breed with a solid historical and cultural background in the region. This breed has traditionally been used for meat, wool, and milk production, although its primary economic value today lies in meat production. Efforts to preserve and improve the breed have been ongoing, with initiatives to increase its population and maintain genetic diversity (Outor-Monteiro et al., 2005). The selection of the Churra Galega Bragança Branca for this study is based on its economic and cultural significance to the region. Understanding the grazing patterns of this traditional breed can provide insights into sustainable pastoral practices that balance livestock production with biodiversity conservation in Montesinho Natural Park.

(a) (b)

Figure 26. (a) Churra Galega Bragança Branca breed (DGAV, 2018) and (b) Geographical Distribution of the Breed in Portugal (SPREGA, 2024)

3.3 Data Collection

3.3.1 GNSS Collar Technology

One sheep from the herd was selected for GNSS tagging. A DOMODIS collar equipped with GPS technology for positioning and GLOBALSTAR technology for communication was used to collect the location data. This collar, powered by lithium-ion batteries (3.7 volts, 7.8 Ah), measured 115 mm × 65 mm × 40 mm and weighed 750 g, ensuring the weight was less than 1.5% of the animal's body weight (Castro et al., 2023).

The DOMODIS collars offer an extended battery life, with some models providing up to 4 months of autonomy, depending on the frequency of position updates. This extended battery life reduces the need for frequent battery replacements or recharges, minimizing disturbances to the sheep (DOMODIS, 2023). Data collection occurred continuously, except when the sheep was stationary, within the corral, or faced technical issues.

The initial data were collected from the DOMODIS website and were provided in .txt format. The data files, named EmitterData_0-4441563_2022 and EmitterData_0-4441563_2023, encompassed positional data for 2022 and 2023, respectively. The data for 2022 covered the period from January 17, 2022, to December 22, 2022, while the data for 2023 spanned from January 2, 2023, to June 8, 2023. Each dataset included each recorded position's date, time, latitude, and longitude.

3.4 Data Processing and Analysis:

The project coordinate reference system (CRS) used in QGIS for this study is ETRS89 / Portugal TM06. This CRS is designed explicitly for accurate geospatial analysis in Portugal, ensuring that all spatial data are aligned and accurately projected for the region of interest. Figure 27 provides a synthetic overview of the data processing and analysis steps.

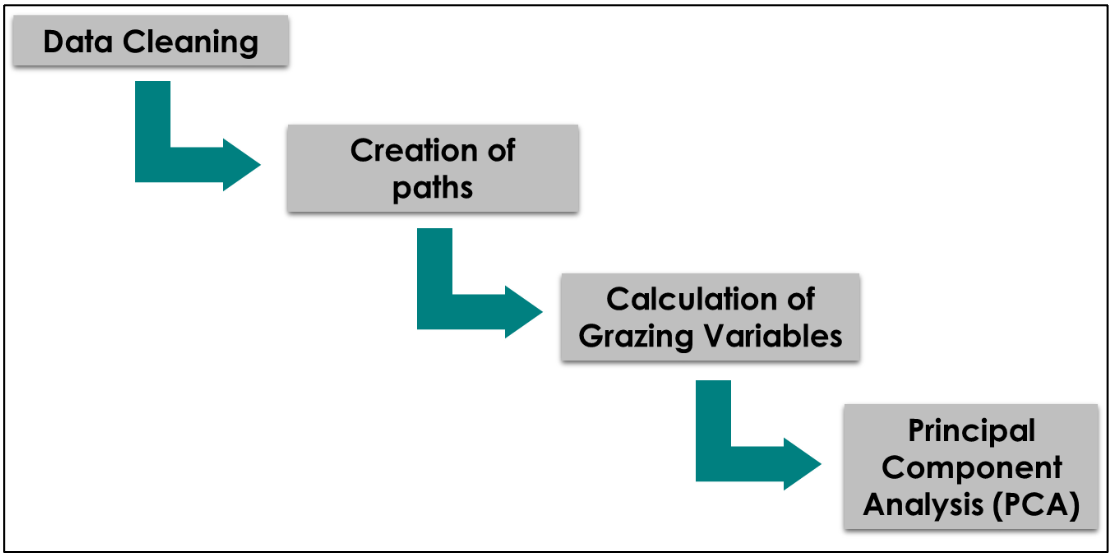


Figure 27. Overview of Data Processing and Analysis

3.4.1 Data Cleaning

The downloaded location data were cleaned using QGIS software by selecting and examining points within the attribute table to eliminate anomalies. The following steps outline the criteria and processes used to clean and include data points in the analysis, as mentioned by Castro et al. (2023):

Positional Accuracy:

The estimated positioning accuracy of the collar was between 2 and 10 meters. This criterion was based on the GNSS collar specifications, ensuring that the locations recorded were precise enough for detailed spatial analysis.

Temporal Consistency:

Data points were recorded at 5-minute intervals. Any deviations from this interval due to technical issues or collar malfunctions were excluded from the analysis. This consistency was crucial for maintaining the temporal resolution necessary for accurate movement and grazing pattern studies.

Anomaly Detection:

Anomalous data points that indicated implausible movements (e.g., jumps of more than 1,000 meters within a 5-minute interval) were removed. These anomalies were likely due to technical errors and did not reflect the actual movements of the sheep (stationary, within the corral). Positions more than 1,000 meters from the nearest recorded position were considered anomalies and removed, considering the improbability of such movement within the average interval between position recordings.

Sufficient Data Density:

Daily datasets containing fewer than ten valid positions were excluded. This threshold ensured that each day had sufficient data to construct meaningful grazing itineraries and density maps.

Exclusion of Non-Grazing Periods:

Positions recorded outside regular grazing schedules at night were eliminated, as they were attributed to corral physical characteristics allowing satellite communication. This exclusion helped to focus the analysis on actual grazing behaviour and patterns.

Consistency with Grazing Schedules:

Only data points within typical grazing hours (from morning departure to evening return) were included. This criterion ensured that the data represented the grazing activities accurately.

Removal of Redundant Data:

Redundant data points collected due to collar malfunctions (e.g., multiple readings at the exact location within a short period) were identified and removed. This step helped to streamline the dataset and improve the clarity of the analysis.

Battery Failures:

Battery failures were reported approximately every two months, requiring recharges that sometimes resulted in losing tracking data. Such instances were carefully documented and excluded from the analysis if they affected the data quality significantly.

By applying these criteria, the dataset was refined to include only the most accurate and relevant data points, providing a robust foundation for the subsequent analysis of grazing patterns and herd dynamics.

3.4.2 Creation of paths:

After the data were cleaned and the final points were obtained, the "Points to Path" plugin in QGIS transformed the daily grazing points into a single path. This path represents the movement of the sheep herd from the corral to their grazing areas and back. It automatically determines the start and end times of grazing for each day.

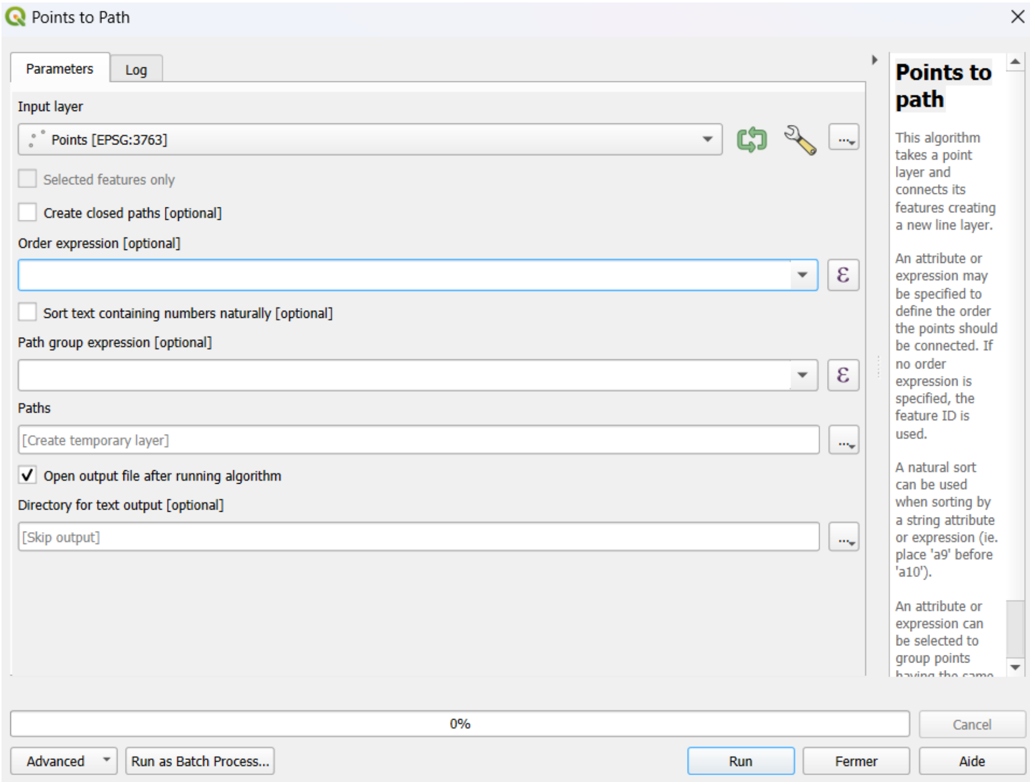


Figure 28. The plugin Points to Path from QGIS

3.4.3 Calculation of Grazing Variables

Figure 29 presents a schematic synthesis of the calculation of variables. This schematic provides an overview of the different steps involved in the variable calculation process.

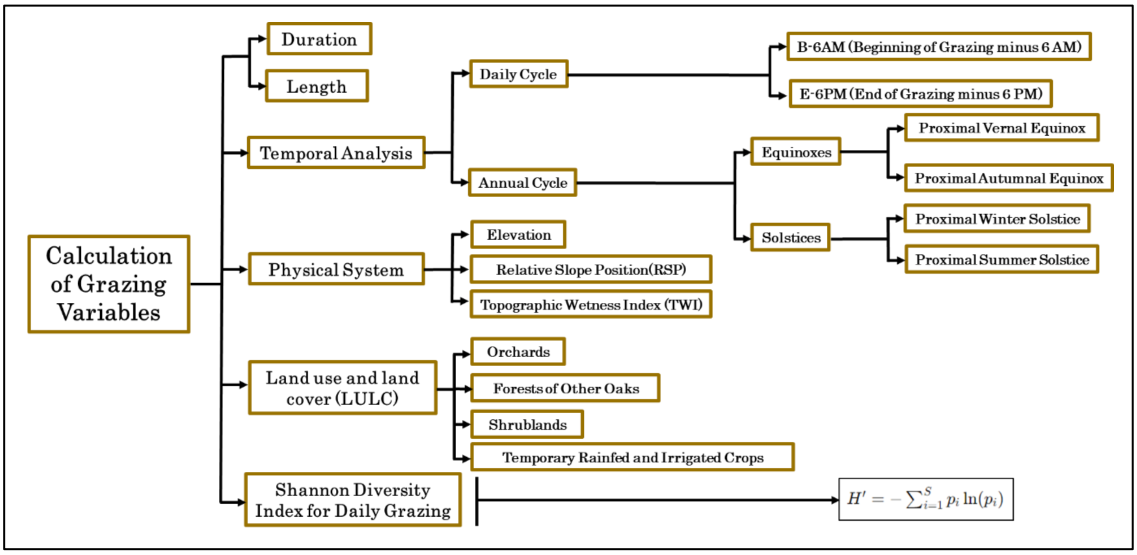


Figure 29. Schematic Synthesis of Grazing Variable Calculation

All variables were calculated using QGIS software with the open field calculator or by utilizing Excel to ensure precision and consistency in the analysis. This approach allowed for a robust and accurate determination of various grazing metrics, which is critical for understanding the grazing patterns and behaviours of the sheep herd.

The QGIS Field Calculator is a tool used to calculate attribute data within GIS layers, such as determining the length or area of geometries. It supports various mathematical and conditional expressions, enabling users to update existing fields or create new ones based on these calculations (Mapscaping, 2023; QGIS Documentation, 2019).

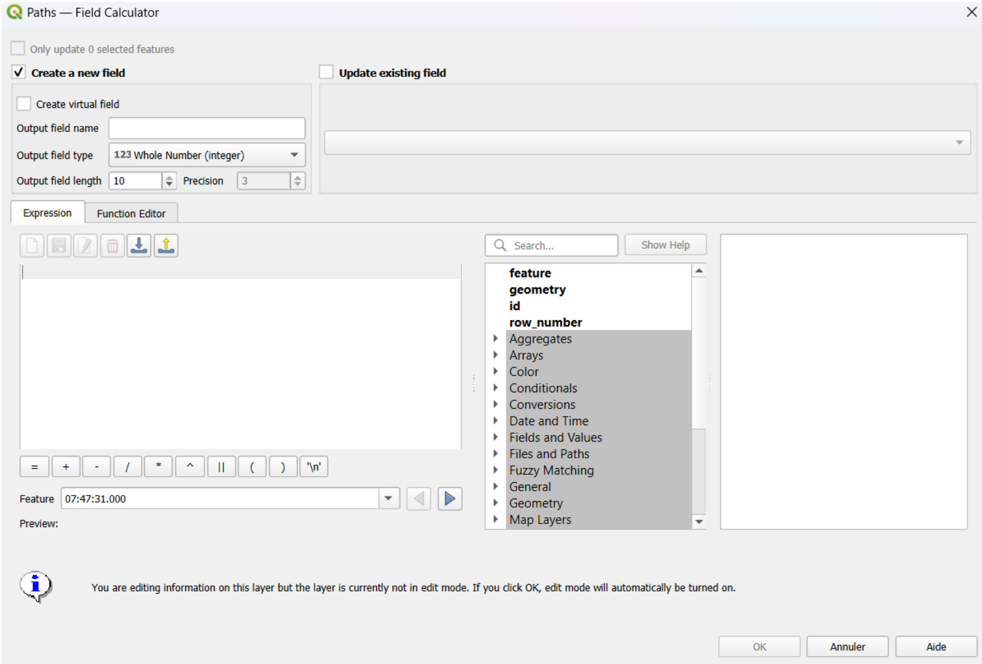


Figure 30. The open field calculator from QGIS

The following sections detail the specific variables calculated and their significance in the study:

3.4.3.1 Duration and length of grazing journey

The duration and length of grazing were calculated by analyzing the GNSS collars' temporal and spatial data points, measuring the time spent grazing and the distance travelled by the herd each day through the layer paths.

- **Length of grazing journey**

The length of the grazing journey was calculated using the expression $length in the open field calculator within QGIS. This expression computed the total distance travelled by the herd, measured in meters. By mapping the daily paths of the sheep, the length of each grazing session was accurately determined, providing insights into the spatial extent of grazing activities. The calculated lengths were crucial for understanding the range and movement patterns of the herd, which are essential for managing grazing areas and ensuring sustainable pasture use.

- **Duration of grazing journey**

The duration of grazing was calculated by determining the time spent grazing each day. This involved using the expression minute(to_interval("End" - "Begin")) in the open field calculator. This expression calculates the difference between the end and start times of grazing for each day, with the results expressed in minutes. By measuring the duration of grazing sessions, it was possible to analyze temporal patterns in grazing behaviour, such as the average length of time the herd spent grazing each day and variations across different days and seasons.

3.4.3.2 Temporal Analysis

Temporal analysis was conducted using both Excel and the QGIS Field Calculator to ensure accuracy and comprehensiveness in evaluating the grazing patterns of the sheep herd.

❖ **Daily Cycle: Grazing Start and End Times**

The variables for the daily cycle were calculated using the QGIS Field Calculator. Specifically, the start and end times of grazing were compared to fixed times (6 AM, 12 PM, 6 PM, and 12 AM) here is an example for 6AM using the expression minute(to_interval("Begin" - "6AM")). This process was repeated for the other times. From the eight total variables derived from these calculations, two key variables were selected: B-6AM and E-6PM:

B-6AM (Beginning of Grazing minus 6 AM): Captures the timing of the start of grazing relative to 6 AM, providing insights into the initial grazing behaviour and the factors influencing when sheep begin their daily routine.

E-6PM (End of Grazing minus 6 PM): Captures the timing of the end of grazing activity relative to 6 PM, crucial for understanding the duration and end patterns of grazing, indicating how long sheep graze and when they cease their activity for the day.

❖ **Annual Cycle: Solstices and Equinoxes**

For the annual cycle, Excel was used to calculate the proximity of grazing days to key seasonal markers: winter and summer solstices and autumnal and vernal equinoxes.

To calculate these variables, grazing path data for each day in 2022 and 2023 were analyzed. The process involved (Example Calculation for 2022):

- **Winter Solstice:** Calculate the absolute difference between each grazing date and December 21 for 2021, 2022, 2023 and 2024.
- **Summer Solstice**: Calculate the absolute difference between each grazing date and June 21 for 2021, 2022, 2023 and 2024.
- **Autumnal Equinox**: Calculate the absolute difference between each grazing date and September 22 for 2021, 2022, 2023 and 2024.
- **Vernal Equinox**: Calculate the absolute difference between each grazing date and March 20 for 2021, 2022, 2023 and 2024.

Computing Differences:

For each grazing date in 2022, the absolute difference in days between that date and the key dates of the solstices and equinoxes was calculated for 2021, 2022, and 2023. For each grazing date in 2023, the differences were calculated for 2022, 2023, and 2024.

Selecting Minimum Differences:

The minimum of these differences was selected to determine each grazing date's closest solstice or equinox.

Significance of Variables

- **Winter Solstice**: Understanding grazing behaviour near the shortest days and longer nights.
- **Summer Solstice**: Insights into how the longest days and shorter nights influence grazing patterns.
- **Autumnal and Vernal Equinoxes**: Critical for understanding changes in grazing habits due to transitions in day length and temperature.

These calculations measure how close each grazing event is to these key seasonal markers, offering valuable insights into seasonal grazing patterns and behaviour.

3.4.3.3 Physical System Analysis

The physical system analysis involved calculating variables using the Group Stats plugin in QGIS. Initially, the DEM_SRTM_PT_25, a Digital Elevation Model (DEM) derived from Shuttle Radar Topography Mission (SRTM) data specifically for Portugal with a resolution of 25 meters, was utilized. A DEM is a 3D representation of a terrain's surface created from elevation data, essential for understanding the topography of the grazing areas.

- **Calculation of Elevation**

Elevation values for each grazing point were directly generated from the DEM, providing a basis for further analysis of the grazing environment.

- **Calculation of Relative Slope Position and Topographic Wetness Index**

For the calculation of Relative Slope Position and Topographic Wetness Index, the SAGA Next Gen (System for Automated Geoscientific Analyses Next Generation) software was employed. SAGA Next Gen offers extensive geoprocessing tools for spatial data analysis, including terrain analysis, hydrological modeling, and statistical analysis. Using the Basic Terrain Analysis tool in SAGA, which leverages DEMs to understand topography, various landscape metrics such as elevation, slope, aspect, and curvature were derived without the need for a fill sinks operation beforehand, as the Basic Terrain Analysis tool performs this step automatically (QGIS in Mineral Exploration, 2024).

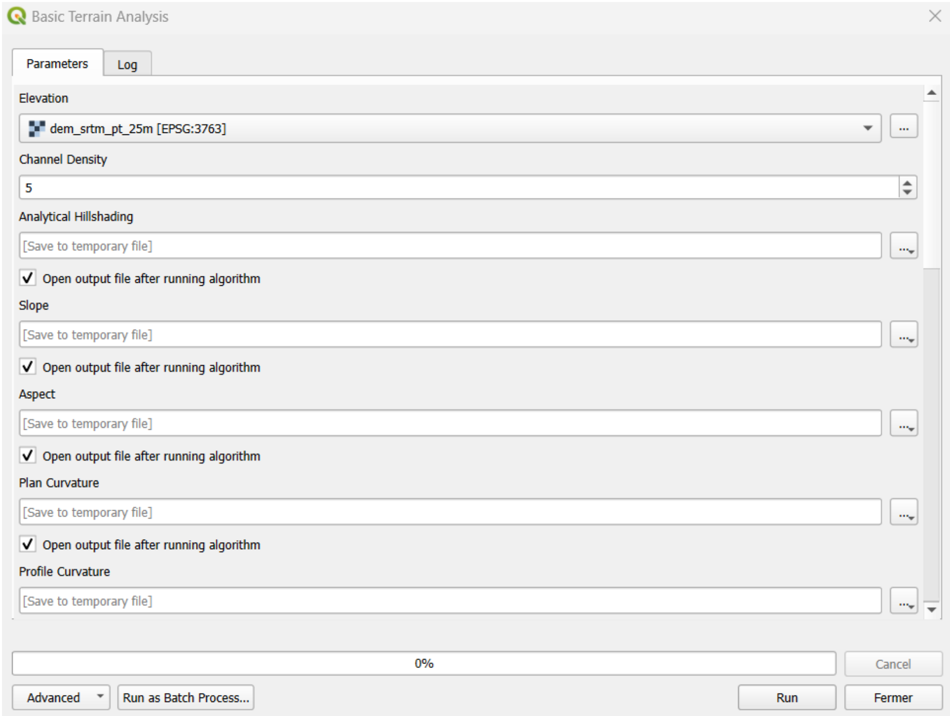


Figure 31. Basic Terrain Analysis Plugin

- **Relative Slope Position (RSP)**: Relative Slope Position (RSP) refers to the specific location of a point on a slope relative to the highest (ridge) and lowest (valley) points within a defined area or window. It is a normalized metric where 0 typically represents the lowest point (valley bottom), and 1 represents the highest point (ridge top). (Spatially Challenged, 2019).
- **Topographic Wetness Index (TWI)**: TWI measures the potential for water accumulation in a landscape. It combines local slope and upstream contributing area, providing insights into moisture availability, which can influence grazing behavior (Spatially Challenged, 2019).

These two parameters were chosen due to their relevance in understanding the environmental conditions influencing sheep grazing patterns. RSP helps identify grazing preferences relative to slope positions, while TWI offers information on moisture conditions, which are critical for effective pasture management.

- **Median Calculation for flock locations**

After calculating these three variables (Elevation, RSP, and TWI) for each grazing point, the median values for each variable were computed for each day's grazing data using the Group Stats plugin in QGIS. The Group Stats plugin performs summary statistics on attribute data, allowing the computation of various metrics such as sum, mean, median, and count, grouped by one or more fields in a vector layer's attribute table.

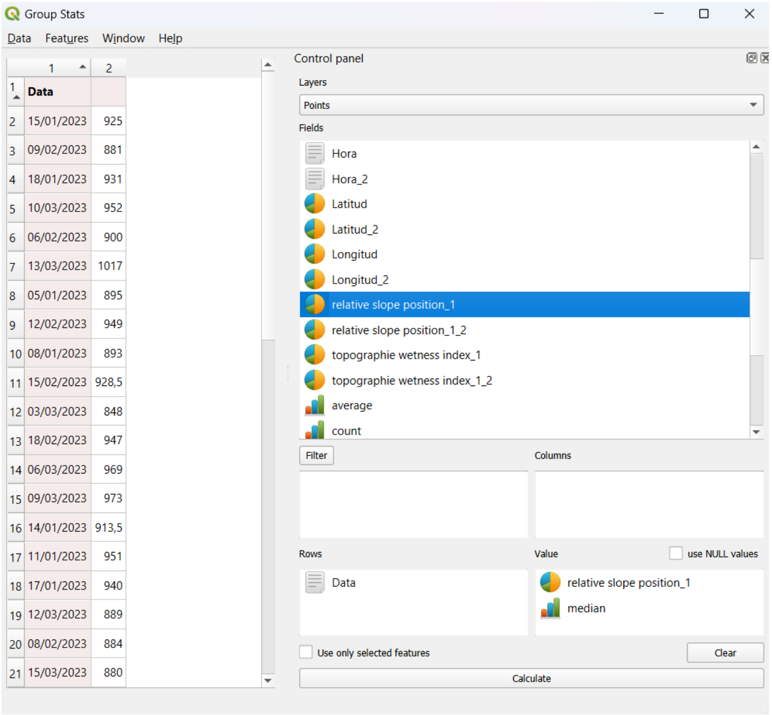


Figure 32. The Group Stats plugin

3.4.3.4 Land use and land cover (LULC)

For land use and land cover (LULC) analysis, the values of various LULC types or classes were calculated, focusing on the types where grazing was significant. Specifically, Temporary Rainfed and Irrigated Crops, Forests of Other Oaks, Shrublands, and Orchards were selected because these categories had a high percentage of grazing activity. LULC types with 1% or less values were excluded from the analysis to eliminate insignificant classes that do not substantially impact grazing patterns.

The LULC values were calculated by joining attribute values from the Land Use and Land Cover Map (COS2018n4)—the most detailed version of COS that comprehensively maps land use and cover in Portugal—to the attribute table of grazing points. This process allowed each grazing point to be defined by its corresponding land use type, facilitating a detailed analysis of the relationship between herd route and land cover.

Table 1. Descriptive Overview of the land use land cover

LAND USE LAND COVER	DESCRIPTION
ORCHADS	This category primarily consists of chestnut trees
SHRUBLANDS	Sparsely vegetated areas, sclerophyllous vegetation, transitional woodland–shrub
TEMPORARY RAINFED AND IRRIGATED CROPS	Agricultural lands that rely on seasonal rainfall and irrigation for crop production include a variety of cereal crops and forage crops
FORESTS OF OTHER OAKS	predominantly comprises various oak species

3.4.3.5 Shannon Diversity Index for Daily Grazing

The Shannon Diversity Index, often referred to as the Shannon-Wiener Index or the Shannon-Weaver Index, is a metric used to quantify biodiversity within a community by considering both species richness and evenness. This index is derived from information theory and was initially developed by Claude Shannon in 1948 as a means to measure entropy in a system, translating to ecological diversity (Clarke & Warwick, 2001; Magurran, 2021; Shannon & Weaver, 1949; Spellerberg & Fedor, 2003).

The Shannon Diversity Index (SDI) for daily grazing was calculated using Excel, employing the formula for the Shannon Diversity Index H′, which is expressed as:

$$H' = -\sum_{i=1}^{S} p_i \ln(p_i)$$

Figure 33. SDI Formula

Where:

- S represents the total number of species.
- p_i is the proportion of individuals or abundance of the i-th species relative to the total number of individuals across all species.
- $\ln(p_i)$ is the natural logarithm of p_i (Clarke & Warwick, 2001; Magurran, 2021; Shannon & Weaver, 1949; Spellerberg & Fedor, 2003).

And:

$$Pi = n/N$$

- n - Individuals of a given type/species; and
- N - Total number of individuals in a community,

By applying the SDI, the study aimed to quantify the heterogeneity of the grazing environment and its potential impact on grazing patterns and behaviours.

3.4.4 Principal Component Analysis (PCA)

Conducting PCA in RStudio

Principal Component Analysis (PCA) is a widely-used statistical method for the ordination and dimensionality reduction of multivariate datasets, with numerous adaptations for different goals and data types (Jackson, 1991; Jolliffe & Cadima, 2016; Thomas, 1988; Vieira, 2012). It was initially developed by (Pearson, 1901) and further refined by (Hotelling, 1933). PCA transforms the original, possibly correlated variables into a new set of uncorrelated principal components. The first principal component accounts for the maximum possible variance in the data, with each subsequent component accounting for progressively more minor variances. This method allows for the simplification of complex data structures, making it easier to visualize and interpret patterns within the data (Camargo, 2022).

Principal Component Analysis (PCA) was conducted using RStudio software to analyze the spatiotemporal variations in grazing patterns. The PCA was performed on an Excel file containing all the calculated variables. This approach aimed to synthesize the variations observed in the sheep's grazing throughout the year, providing a comprehensive understanding of the patterns and underlying factors influencing grazing behaviour.

3.4.5 Suitability Test for Principal Component Analysis (PCA)

Two key tests were conducted to assess the suitability of the dataset for Principal Component Analysis (PCA): Bartlett's Test of Sphericity and the Kaiser-Meyer-Olkin (KMO) Test. These tests determine whether the data meets the necessary assumptions and criteria for PCA.

3.4.5.1 Bartlett's Test of Sphericity

Definition and Explanation:

Bartlett's Test of Sphericity is a statistical test used to examine the hypothesis that a correlation matrix is an identity matrix. This test is crucial in factor analysis as it assesses whether the variables in the dataset are sufficiently correlated to provide a reliable basis for factor extraction.

- **Null Hypothesis (H0):** The correlation matrix is an identity matrix, implying that the variables are uncorrelated.
- **Alternative Hypothesis (H1):** The correlation matrix is not an identity matrix, indicating significant correlations among at least some variables.

The test computes a chi-square statistic based on the determinant of the correlation matrix. A significant chi-square value (p-value < 0.05) suggests that the null hypothesis can be rejected, and there are significant correlations among the variables, making them suitable for factor analysis or PCA (Bartlett, 1950; Cochran, 1983).

- **Function**: `cortest.bartlett(R, n)`
    - **R**: A correlation matrix of the dataset.
    - **n**: Sample size of the dataset.

3.4.5.2 Kaiser-Meyer-Olkin (KMO) Test

Definition and Explanation:

The Kaiser-Meyer-Olkin (KMO) Test measures how suited your data is for factor analysis. It quantifies the degree of shared variance among the variables. The KMO statistic ranges from 0 to 1, with higher values indicating that a significant proportion of variance is common variance, which is desirable for factor analysis.

- **Overall Measure of Sampling Adequacy (MSA):** Provides an overall indication of the suitability of the dataset for factor analysis.
- **MSA for Individual Items:** Assesses the adequacy of each variable individually.

Table 2. Kaiser-Meyer-Olkin (KMO) Measure Interpretation Guide

KMO Measure	*Interpretation*
$KMO \geq 0.90$	Marvelous
$0.80 \leq KMO < 0.90$	Meritorious
$0.70 \leq KMO < 0.80$	Average
$0.60 \leq KMO < 0.70$	Mediocre
$0.50 \leq KMO < 0.60$	Terrible
$KMO < 0.50$	Unacceptable

A high KMO value (≥ 0.60) for the overall indicates that factor analysis is appropriate for the data and if the MSA for each individual is (≥ 0.50) it is validate (Cerny & Kaiser, 1977; Kaiser, 1974).

- **Function**: `KMO(r)`
    - **r**: A correlation matrix or a data matrix (correlations will be found)

3.4.6 Data Visualization

Graphical Visualization

After calculating the variables, the data were exported to Excel for graphical visualization. Several summary tables and charts were generated to provide a comprehensive overview of the results:

- **Summary Tables**: These included the average and standard deviation of the physical system variables (elevation, relative slope position, topographic wetness index), as well as the duration and length of grazing sessions.
- **Charts**: The **Total Records by Month** chart displayed the number of grazing records for each month, highlighting seasonal trends and variations in grazing activity throughout the year. The **Distribution of Points by Day and Time** chart visualized the temporal distribution of grazing activities throughout the day, illustrating the times when grazing was most and least frequent. Additionally, the **Percentage Composition of Grazing Areas by Land Use and Seasons** chart showed how the grazing areas were composed of different land use types and how these compositions varied by season, offering a clear view of the relationship between land use and grazing behaviour over different periods.

Visualization and Interpretation Using RStudio

Further graphical representations were generated using RStudio, focusing on statistical and multivariate analysis:

- **Eigenvalues / Variances:** Graphs showing the distribution of eigenvalues and variances, indicate each principal component's importance.
- **Graph of Variables**: A graphical representation of how variables are correlated and their contributions to different dimensions.
- **Graph of Individuals**: Displays the individual grazing points and their distribution across the dimensions.
- **Biplot**: Combines the graphs of variables and individuals, showing the relationships between variables and grazing points in the same plot.
- **Contributions of Variables to the Dimensions**: Visualizes the contribution of each variable to the principal components.
- **Total Cos^2 of Variables on the Dimensions**: Indicates the quality of representation of each variable on the principal components.

4. Results and Discussion:

4.1. Descriptive statistics

As shown in Table 3, the descriptive statistics of the measured variables provide a comprehensive overview of the data collected annually and seasonally.

Table 3. Descriptive Statistics of Measured Variables

<table>
<tr><th></th><th>Variables</th><th>Acronyms</th><th>Type</th><th>Average</th><th>Standard deviation (SD)</th><th>Unit</th></tr>
<tr><td rowspan="10">Paths</td><td rowspan="5">Duration</td><td rowspan="5">DRT</td><td>Annual</td><td>541,914</td><td>296,194</td><td rowspan="5">Minutes</td></tr>
<tr><td>Spring</td><td>684,1923077</td><td>4362,248633</td></tr>
<tr><td>Summer</td><td>614,6885246</td><td>4122,442817</td></tr>
<tr><td>Autumn</td><td>625,962963</td><td>5304,230286</td></tr>
<tr><td>Winter</td><td>235,2391304</td><td>4549,634761</td></tr>
<tr><td rowspan="5">Length</td><td rowspan="5">LGT</td><td>Annual</td><td>4466,685</td><td>1643,950</td><td rowspan="5">Meters</td></tr>
<tr><td>Spring</td><td>307,5650761</td><td>1717,452112</td></tr>
<tr><td>Summer</td><td>275,9467063</td><td>1464,511768</td></tr>
<tr><td>Autumn</td><td>177,5604949</td><td>1824,93897</td></tr>
<tr><td>Winter</td><td>52,61144142</td><td>1543,544023</td></tr>
<tr><td rowspan="3">Points</td><td>Elevation (a.s.l)</td><td>ALT</td><td rowspan="3">Annual</td><td>935,878</td><td>73,521</td><td>Meters</td></tr>
<tr><td>Relative Slope Position</td><td>RSP</td><td>0,342</td><td>0,240</td><td>Dimensionless</td></tr>
<tr><td>Topographic Wetness Index</td><td>TWI</td><td>7,683</td><td>2,404</td><td>Dimensionless</td></tr>
</table>

The descriptive statistics of the measured variables provide insights into the grazing patterns of sheep in Montesinho Natural Park across different seasons. The annual average duration of grazing sessions is approximately 542 minutes, with seasonal variations indicating longer grazing times in spring and autumn (684 and 626 minutes, respectively) compared to winter (235 minutes). This duration of grazing sessions suggests that environmental conditions in winter might limit grazing time, likely due to harsher weather or reduced forage availability. Similarly, the annual average grazing path length is around 4467 meters, with a notable decrease during winter (53 meters), indicating shorter travel distances due to the cold weather limiting their travel distances and energy conservation needs. High standard deviations, particularly in spring and autumn, reflect considerable variability in grazing patterns within these seasons. The physical environment, characterized by an average elevation of 936 meters, a Relative Slope Position of 0.342, and a Topographic Wetness Index of 7.683, suggests a moderate slope position and a fairly wet terrain, influencing forage distribution and quality.

Table 4. Locations records, number of grazing journeys, and maximum daily records for experimental herd

	Total records	Records after database cleaning	Deleted Records	Grazing journeys	Daily maximum records
Sheep	13510	5646	7864	186	57

The data processing for the experimental sheep herd involved an initial collection of 13,510 records, which were reduced to 5,646 records after database cleaning, resulting in the deletion of 7,864 records. The substantial data cleaning highlights the importance of ensuring data quality and accuracy for reliable analysis. The herd undertook 186 grazing journeys, with the daily maximum records documented on September 5, 2022, reaching 57 records.

Table 5. Location, altitude, breed, and size of experimental herds

Herd	Corral location	Elevation at the corral (a.s.l.)	Breed	Herd size
Sheep	102805.77,252654.62	1084	Churra Galega Bragança Branca	The herd size typically does not exceed 200 head
	102293.65,249826.74	904		

The experimental sheep herd is located at two different corrals with varying altitudes. The first corral is situated at coordinates 102805.77, 252654.62, at an elevation of 1084 meters above sea level, while the second corral is at coordinates 102293.65, 249826.74, at an elevation of 904 meters. The breed of the sheep is Churra Galega Bragança Branca, and the herd size typically does not exceed 200 head. During the orchard harvest period, sheep cannot be in the same place as the harvest to avoid disturbing it. Consequently, they change corrals and move to the mountains at higher elevations to graze. This practice adapts the silvopastoralism system, where perennial crops like orchards coexist with grazing. The presence of a shepherd ensures that the sheep can navigate between these areas efficiently, maintaining a mixed system that integrates agriculture and livestock.

4.2. Data Visualization

Distribution of Points by Day and Time:

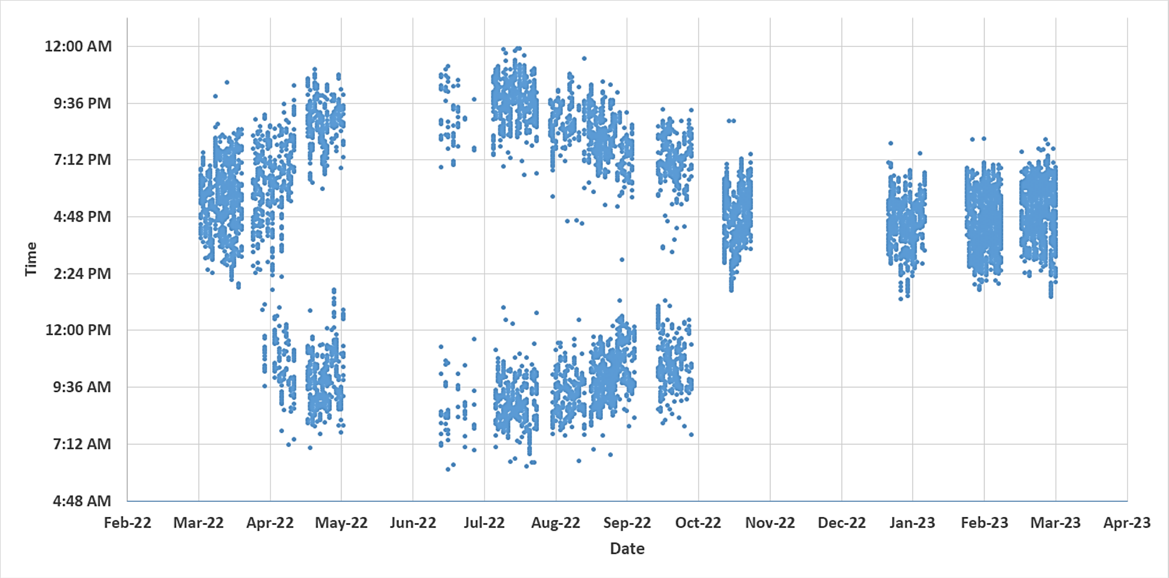


Figure 34. Distribution of Points by Day and Time

The scatter plot illustrates the temporal distribution of recorded points for the sheep herd from March 2022 to March 2023. In March 2022, the distribution was typical, with grazing starting around 2 PM and ending at approximately 7 PM. From May to October, there is a noticeable gap during midday, which is attributed to the hot weather, necessitating rest periods in the shade. During this period, grazing typically starts early at around 7 AM, pauses at about 12 PM due to high temperatures, and resumes at approximately 6 PM when it is colder, continuing until late between 10 PM and 12 AM. These pauses and resumes explain the different distribution of points observed during these months. By the start of autumn in November, the distribution pattern returns to the more stable base seen in March, continuing through the winter until March 2023. During these colder months, grazing starts later in the day and ends earlier in the evening due to the freezing temperatures in the early morning and the need to return early as temperatures drop at night. This consistent pattern highlights the influence of seasonal temperature variations on the grazing behaviour of the sheep herd.

Total Records by Month:

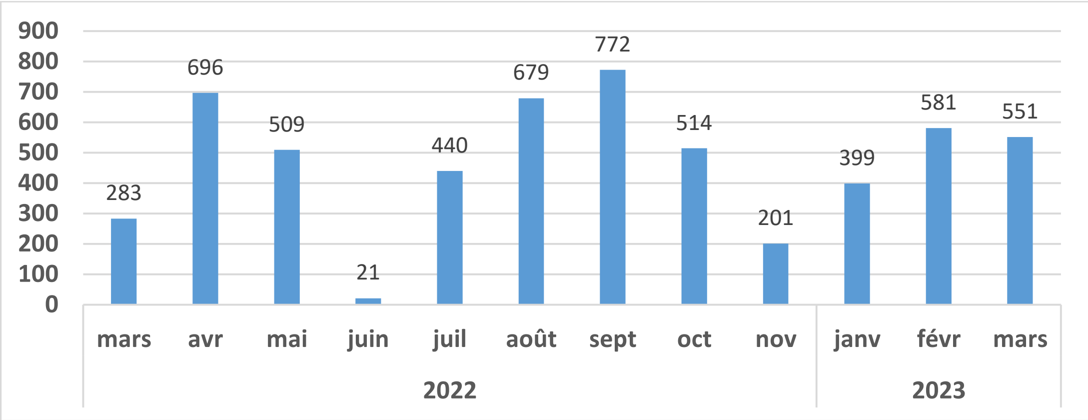


Figure 35. Monthly Sheep Herd Total Records

The bar chart shows the monthly distribution of records from March 2022 to March 2023. The number of records peaks in September 2022 with 772 records, followed by high counts in April (696) and August (679). There is a notable drop in June 2022, with only 21 records. Other months like March 2022 (283), May 2022 (509), July 2022 (440), October 2022 (514), and November 2022 (201) display moderate counts. The trend continues into 2023, with January (399), February (581), and March (551) maintaining relatively high record counts.

Percentage Composition of Grazing Areas:

- **By Land Use:**

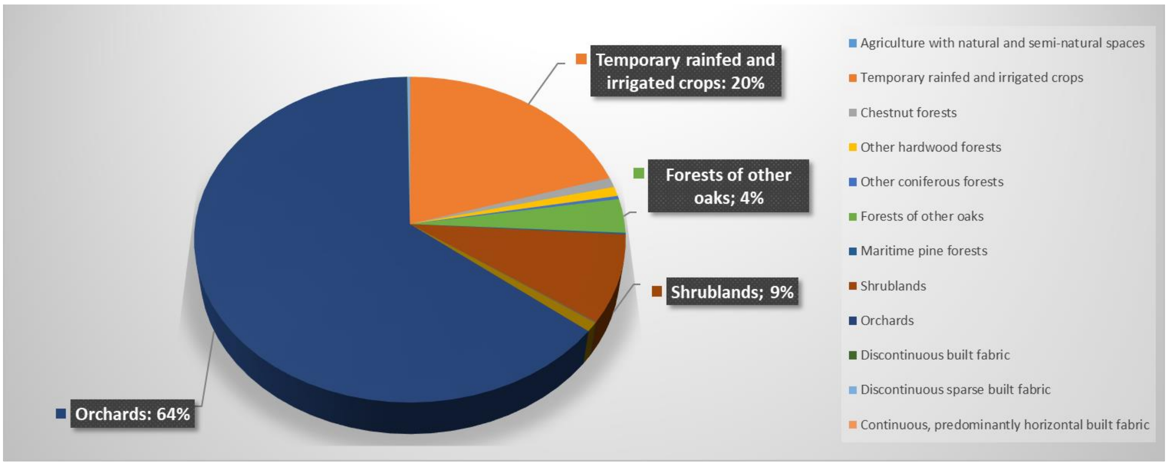


Figure 36. Percentage composition of grazing areas for the herd

The pie chart illustrates the various land uses where the sheep grazed over the year. The legend includes all land use categories, but the chart highlights only the primary preferences: Orchards (64%), Temporary Rainfed and Irrigated Crops (20%), Shrublands (9%), and Forests of Other Oaks (4%). For clarity, land use categories with less than 1% were excluded from the chart. Orchards are generally chestnut forests, and the category "Forests of Other Oaks" typically refers to oak forests. This composition indicates a strong preference for grazing in chestnut orchards, followed by temporary rainfed and irrigated crops, with less frequent grazing in shrublands and oak forests.

- **By Season:**

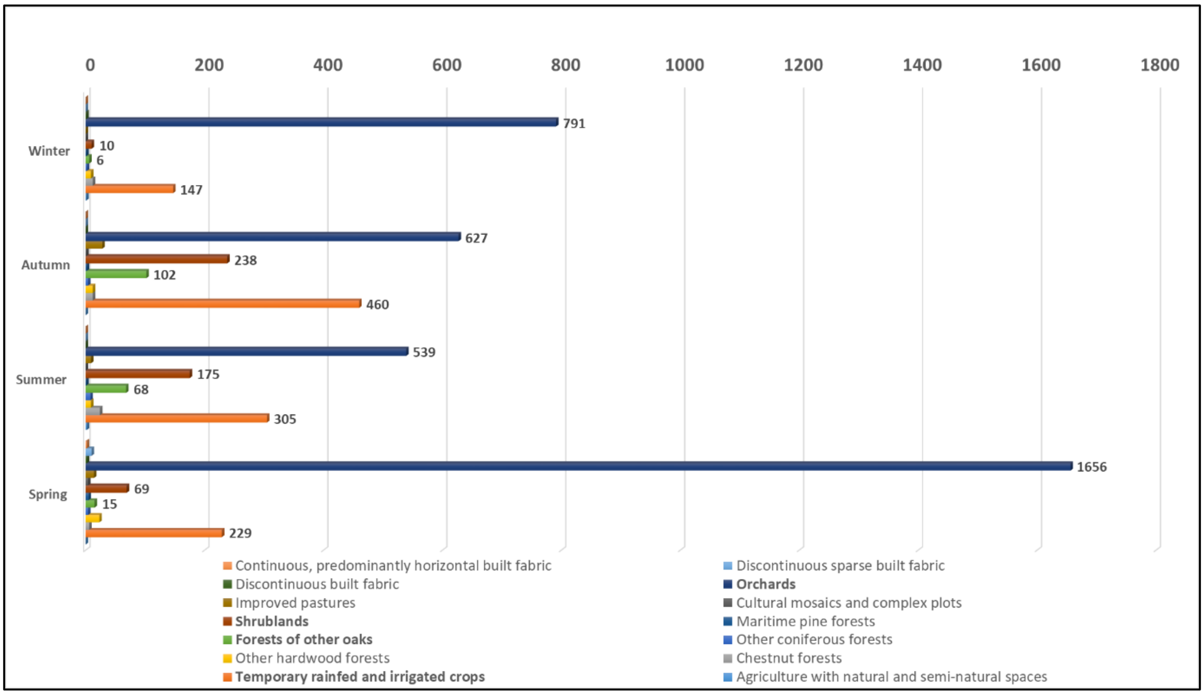


Figure 37. Percentage composition of grazing areas for the herd by season

The bar chart presents the seasonal distribution of grazing areas. The percentages of grazing in each season are Spring (36.10%), Summer (20.20%), Autumn (26.32%), and Winter (17.38%). Observations highlight the dominant presence of blue in all seasons, indicating that orchards (generally chestnut forests) are the primary grazing areas throughout the year. The importance of orange (Temporary Rainfed and Irrigated Crops) and brown (Shrublands) is also evident, particularly in Spring and Summer, reflecting a significant preference for these land uses during warmer months. The green section (Forests of Other Oaks) shows moderate use, with more presence in Autumn and Winter. This seasonal variation indicates a flexible grazing strategy, with a higher reliance on orchards across all seasons, supplemented by other land uses like rainfed and irrigated crops, shrublands, and oak forests, depending on seasonal availability and environmental conditions.

4.3. Inferential Statistics

Having examined the descriptive statistics, the analysis now moves on to inferential statistics, which allow a deeper interpretation of the results and reveal more nuanced insights into the grazing patterns and behaviour of the sheep herd.

4.3.1 PCA Results

The suitability of the data for Principal Component Analysis (PCA) was assessed using Bartlett's Test of Sphericity and the Kaiser-Meyer-Olkin (KMO) Test. Bartlett's Test of Sphericity yielded a Chi-square value (X^2) of 5284.348 with 120 degrees of freedom and a p-value of 0. The very small p-value (less than 0.05) indicates that the null hypothesis can be rejected, confirming that the correlations between variables are statistically significant, thereby making the data suitable for factor analysis or PCA. Additionally, the KMO Test reported an Overall Measure of Sampling Adequacy (MSA) of 0.72, further supporting the adequacy of the data for PCA.

Table 6. MSA for each variable

Variable	***MSA***
LGT	0.54
DRT	0.80
WS	0.64
SS	0.64
AE	0.64
VE	0.67
RSP	0.77
TWI	0.53
ALT	0.74
TRIC	0.70
OAKF	0.81
SHRB	0.82
ORCH	0.81
H’	0.62
B-6AM	0.75
E-6PM	0.92

Interpretation:

- **Overall KMO:** An overall MSA of 0.72 is considered mediocre. The threshold for acceptable adequacy is usually 0.60. Therefore, the data is just above the acceptable level for factor analysis.
- **MSA for individual items:** All individual MSA scores are above 0.50, indicating that all variables are validated for use in factor analysis. Here, the lowest MSA is 0.53 (TWI), which is just above the threshold. Variables like E-6PM, OAKF, SHRB, and ORCH have relatively high MSA scores (> 0.80), indicating they are quite suitable for factor analysis.

Conclusion:

Table 7. KMO and Bartlett results

KMO and Bartlett's Test		
Kaiser-Meyer-Olkin Measure of Sampling Adequacy		0.72
Bartlett's Test of Sphericity	Approx. Chi-Square	5284.348
	df	120
	Sig.	0

- **Bartlett's Test:** Indicates that the data is suitable for factor analysis or PCA due to significant correlations among variables.
- **KMO Test:** Indicates that the overall adequacy of the sample is mediocre but acceptable. And the MSA prove that all variables are validated for use in factor analysis.

Ggcorrplot: Visualization of a correlation matrix using ggplot2:

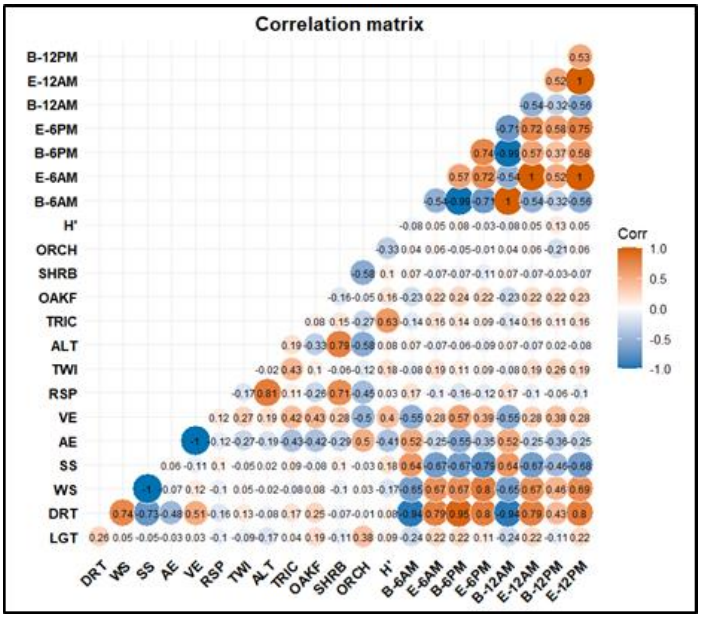


Figure 38. Correlation matrix of all the variables

The correlation matrix visualized using `ggcorrplot` reveals significant relationships between various study variables. After examining and eliminating some variables, several strong correlations emerge. For the daily cycle, only two variables were retained:

- **B-6AM:** was retained due to its strong positive correlations with other early morning start times, representing when grazing activities typically begin. This variable is crucial for understanding early morning grazing behaviour influenced by cooler temperatures and forage availability, providing insights into daily activity patterns and optimizing grazing schedules.

- **E-6PM:** was retained because of its strong positive correlations with other evening end times, indicating when grazing activities usually conclude. This variable is essential for understanding evening grazing cessation influenced by decreasing light levels, optimizing daily grazing schedules and ensuring herd welfare.

All variables (WS, SS, AE, and VE) were kept for the annual cycle to comprehensively understand the seasonal influences on grazing behaviour. Each variable represents a significant seasonal marker, allowing for a detailed analysis of how grazing patterns shift throughout the year. This inclusive approach ensures a robust understanding of the seasonal dynamics affecting the herd.

Eigenvalues / Variances:

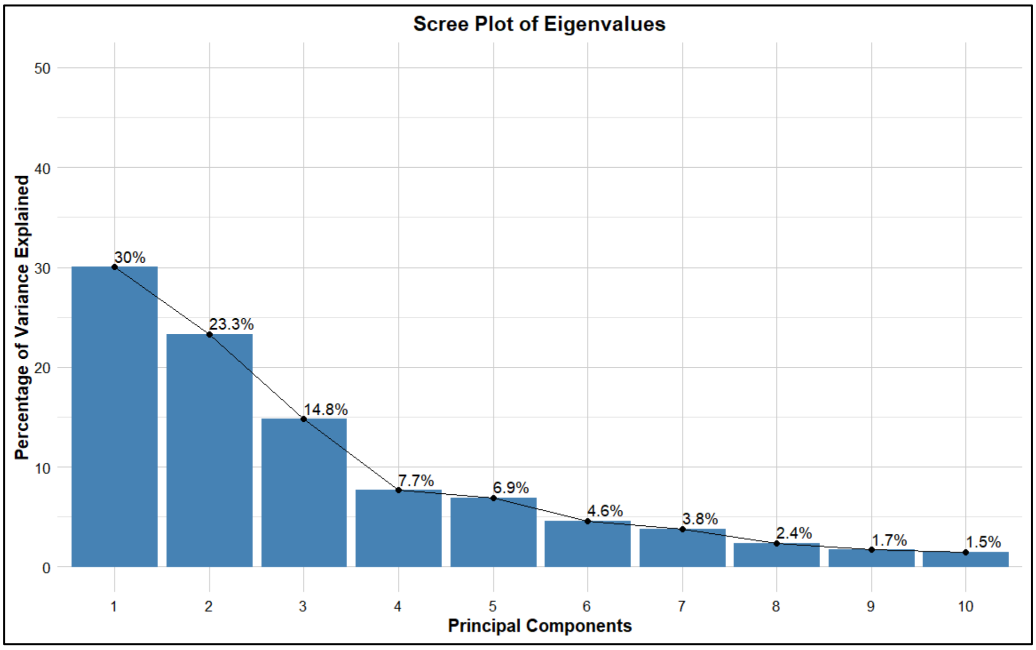


Figure 39. Eigenvalues of the PCA

The scree plot of eigenvalues shows that the first three principal components account for the majority of the variance in the dataset. The first principal component explains 30% of the variance, capturing the most significant variation. The second principal component explains 23.3% of the variance, and the third accounts for 14.8%. Together, these three components explain approximately 70% (68.1% of the total variance), indicating that they encompass the most crucial information in the data. This substantial percentage suggests that focusing on these first three components is sufficient for understanding the primary patterns and relationships within the dataset.

Contributions of Variables to the Dimensions:

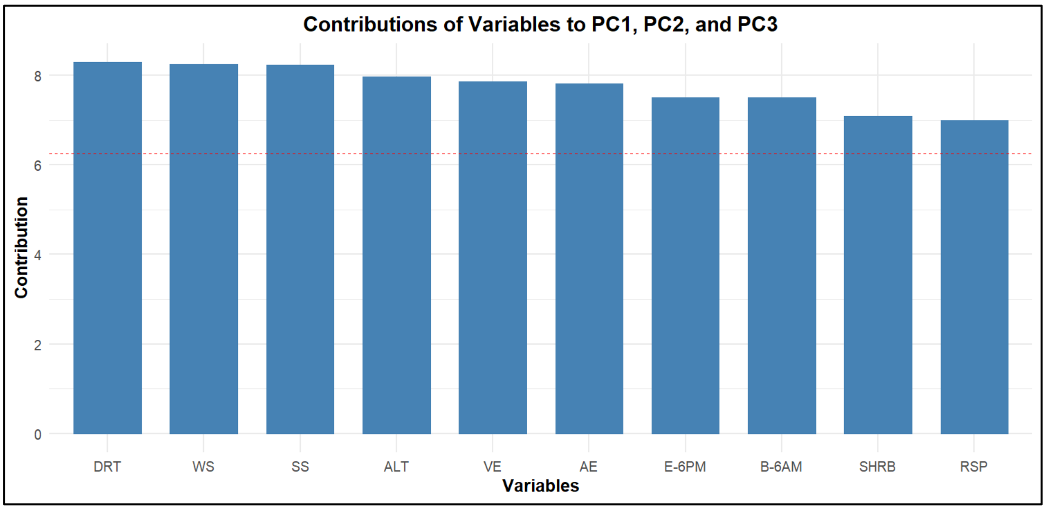


Figure 40. Contributions of Variables to PC1, PC2, and PC3

The bar chart highlights the key variables contributing most significantly to the first three principal components. Each of these variables has a contribution value above the threshold line (6), indicating their significant roles in explaining the variance in the dataset. The variables are crucial in understanding the underlying patterns captured by the principal components.

The contributions of variables to the first three principal components (PC1, PC2, and PC3) reveal distinct patterns and provide insights into different aspects of grazing behaviour and environmental influences.

PC1: Temporal Variables (30%):

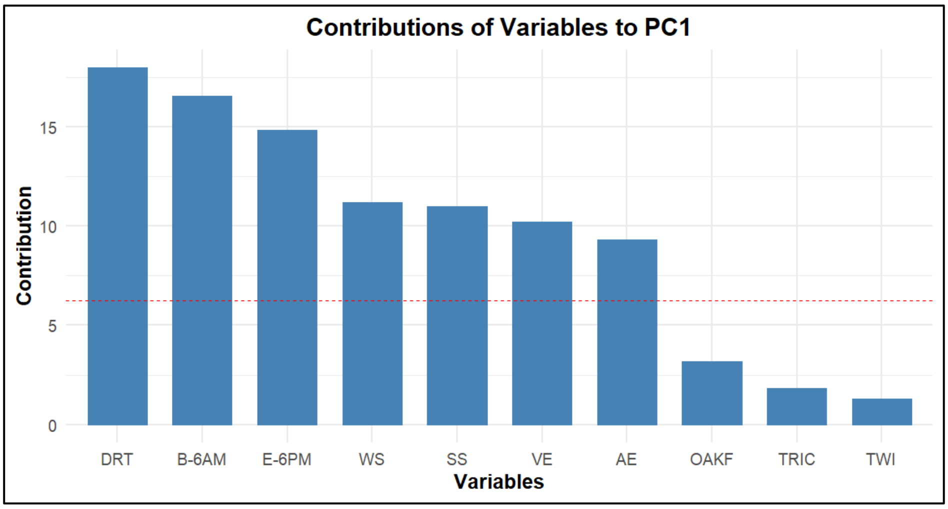


Figure 41. Contributions of Variables to PC1

The first principal component (PC1) is primarily influenced by temporal variables. Key contributors include Duration, Begin minus 6 AM, and End minus 6 PM, along with seasonal markers like the Proximity to Winter Solstice, Proximity to Summer Solstice, Proximity to Vernal Equinox, and Proximity to Autumnal Equinox. This suggests that PC1 captures the temporal dynamics of grazing activities, reflecting how grazing patterns vary throughout the day and across different seasons.

PC2: Land Use, Topography, and Equinoxes (23.3%):

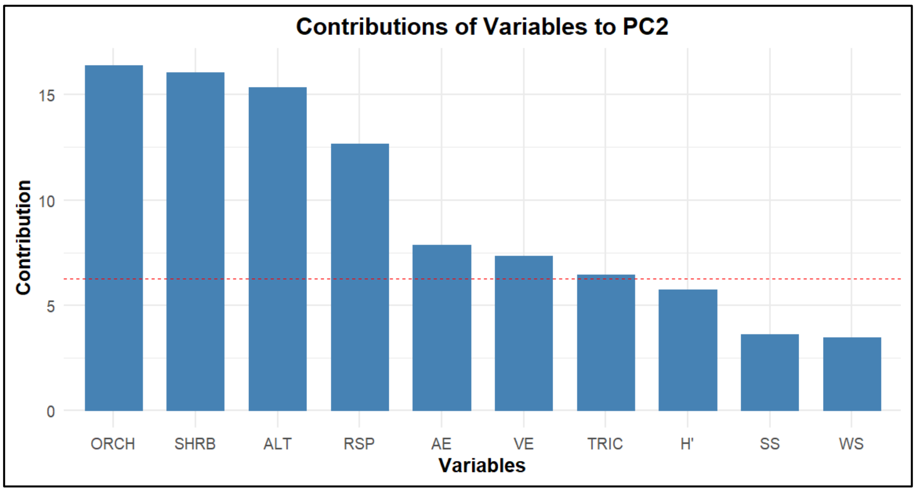


Figure 42. Contributions of Variables to PC2

The second principal component (PC2) is mainly driven by land use and topography variables. Significant contributors include Orchards (ORCH), Shrublands (SHRB), Elevation (ALT), and Relative Slope Position (RSP), along with some influence from the equinoxes (Proximity to Autumnal Equinox (AE) and Proximity to Vernal Equinox (VE)). These variables indicate that PC2 captures the spatial distribution of grazing areas, emphasizing the importance of different land uses, physical terrain characteristics, and seasonal equinox markers in shaping grazing patterns.

PC3: Topography, Land Use, and Solstices (14.8%):

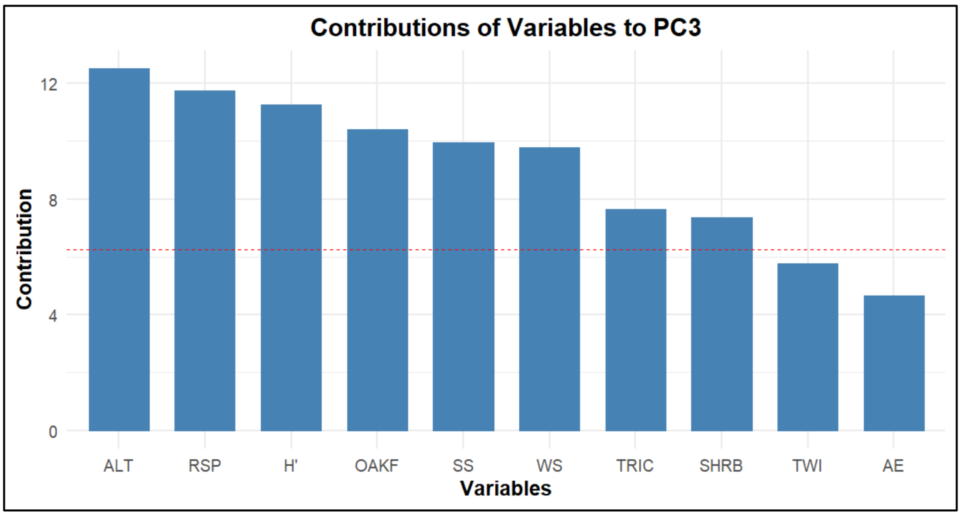


Figure 43. Contributions of Variables to PC3

The third principal component (PC3) is predominantly influenced by topography variables, including Elevation (ALT) and Relative Slope Position (RSP), as well as land use variables like Shannon Diversity Index (H’), Oak Forests (OAKF), and Temporary Rainfed and

Irrigated Crops (TRIC). Additionally, it includes the Proximity to Summer Solstice (SS) and Proximity to Winter Solstice (WS). These variables suggests that PC3 provides insights into how physical terrain, land use diversity, and specific seasonal markers interact to influence grazing patterns.

Combination:

The theory of pastoralism states that there are different scales of decision-making for this activity. First is the shepherd's decision, which involves determining the larger area of the grazing domain they will go to (decision on where to graze today). However, within the grazing area, the animal decides what to eat, choosing between leguminous plants, cereals, or grass based on its preference. On the other hand, the shepherd, aided by dogs, guides the overall movement and location of the herd. In the middle, there is a synergy in decision-making between the shepherd and the herd's behaviour: if the shepherd observes that the sheep prefer grazing in a particular area, they remain there. The shepherd's observation and grazing knowledge are fundamental in providing the best grazing areas according to the sheep’s preferences. If the shepherd notices a decrease in grazing quality or the sheep do not prefer the area, they move to a better area. Our study aims to elucidate this dynamic interplay of decisions.

Temporal and Land Use Influences on Grazing Patterns: Analysis of PC1 and PC2 (55.3%):

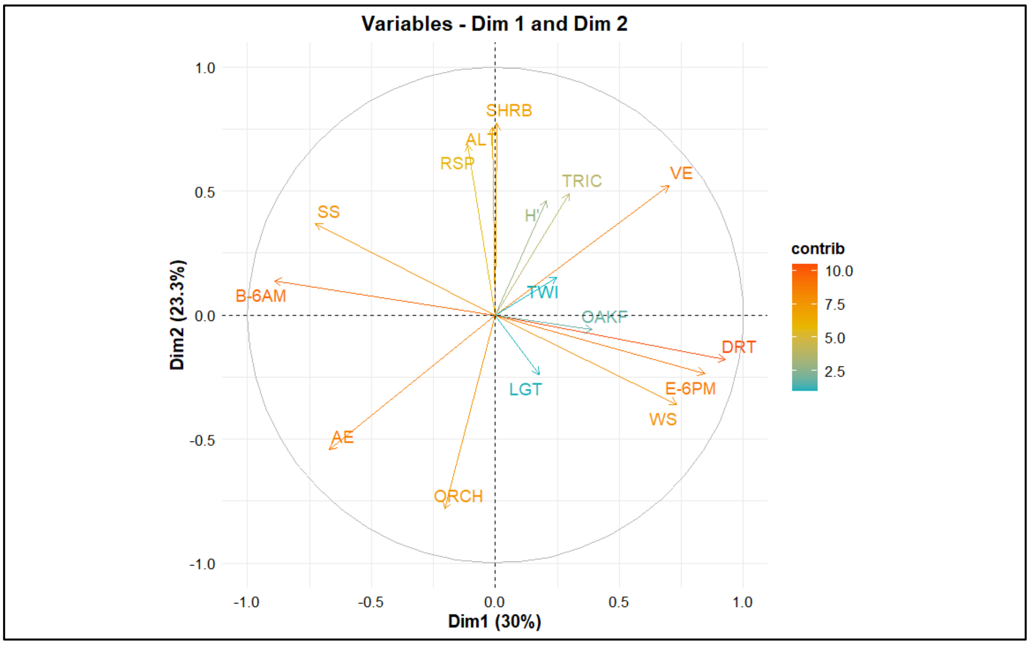


Figure 44. Contributions of variables for the combined PCA plot of PC1 and PC2

The combined PCA plot of PC1 and PC2 further illustrates the distribution of these variables. Variables such as TWI (Topographic Wetness Index), OAKF (Forests of Other Oaks), and LGT (Length) were eliminated from further analysis due to their low contributions, as indicated by their blue colour in the plot. This decision was based on their minimal impact on the variance explained by the first two principal components, thus allowing the focus to remain on the most influential factors.

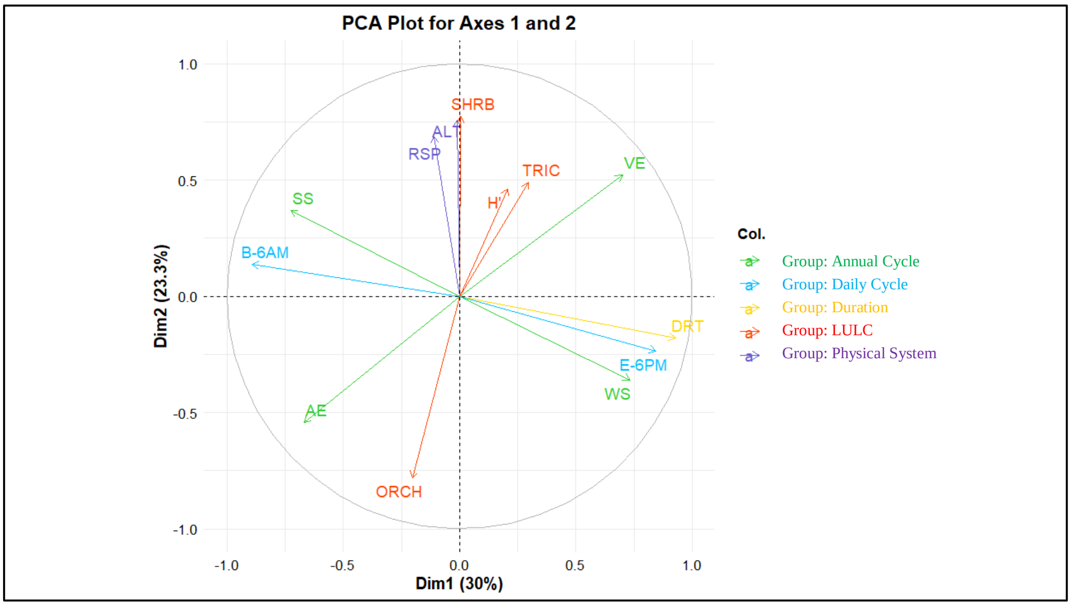


Figure 45. PCA Plot for Axes 1 and 2

The combined PCA plot for axes PC1 and PC2 explains 55.3% of the variance in the dataset. The variables remaining after the elimination of those with low contributions are illustrated in the plot, making the graphic more readable.

Significant Patterns and Findings:

Duration (DRT) and End minus 6 PM (E-6PM) are highly correlated with the Winter Solstice (WS), indicating that **grazing sessions are more extended and end later during the winter months**. The cooler temperatures during the winter solstice may allow for extended grazing periods as the sheep do not need to rest as frequently to avoid heat stress. Thus, the grazing journey can extend into the late afternoon. The Shannon Diversity Index (H') shows strong correlations with Temporary Rainfed and Irrigated Crops (TRIC) and Shrublands (SHRB), suggesting that **diverse plant habitats in these areas provide a variety of forage options**, enhancing the sheep's diet quality. The Summer Solstice (SS) is correlated with the beginning time of grazing (B-6AM) and the Autumnal Equinox (AE), highlighting that **grazing starts earlier in the morning during summer to avoid heat stress**. This pattern likely continues into the autumnal equinox, where the temperatures begin to moderate, but the days are still relatively long, allowing early morning grazing to remain advantageous. H' and TRIC also correlate with the Vernal Equinox (VE), reflecting that the **spring season brings increased plant growth and forage availability**, influencing the diversity of grazing areas. SHRB, RSP (Relative Slope Position), and ALT (Elevation) are positioned between SS and VE but lean slightly towards SS, indicating that **shrublands, slope, and elevation are essential in late spring and early summer grazing.**

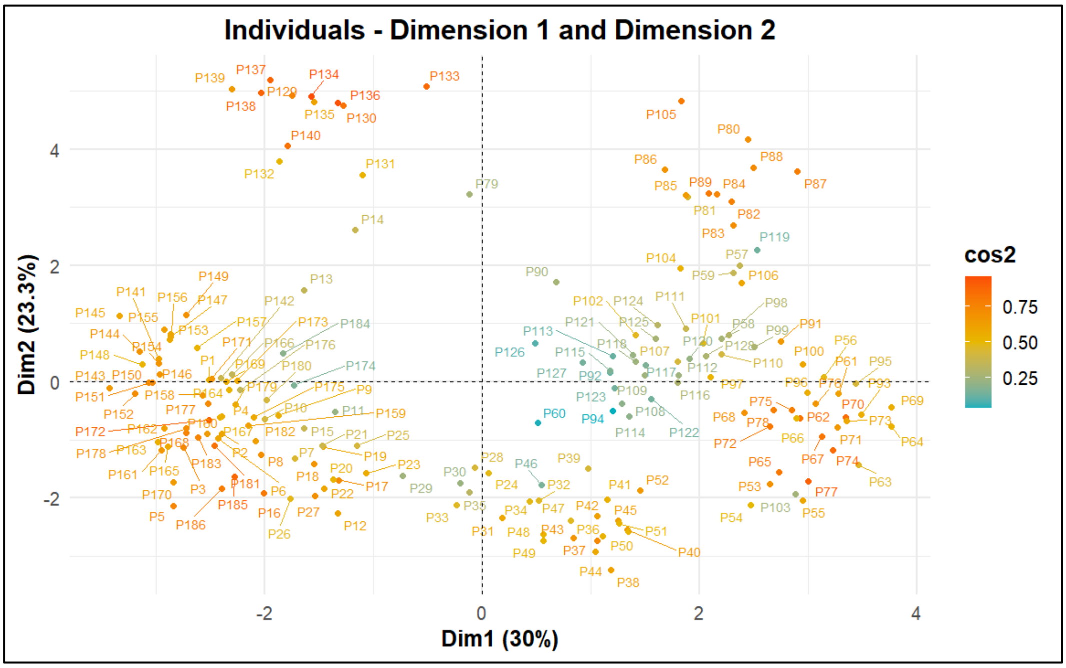


Figure 46. The quality of representation of the individuals

The graphic illustrates the quality of representation of the individuals (each day of grazing) using PCA for dimensions 1 and 2, with red points indicating very typical grazing routes and blue points representing less typical routes. Points further from the origin are more typical, better representing the first two principal components. The blue points do not define a specific type of grazing based on agriculture, land use, or temporal patterns.

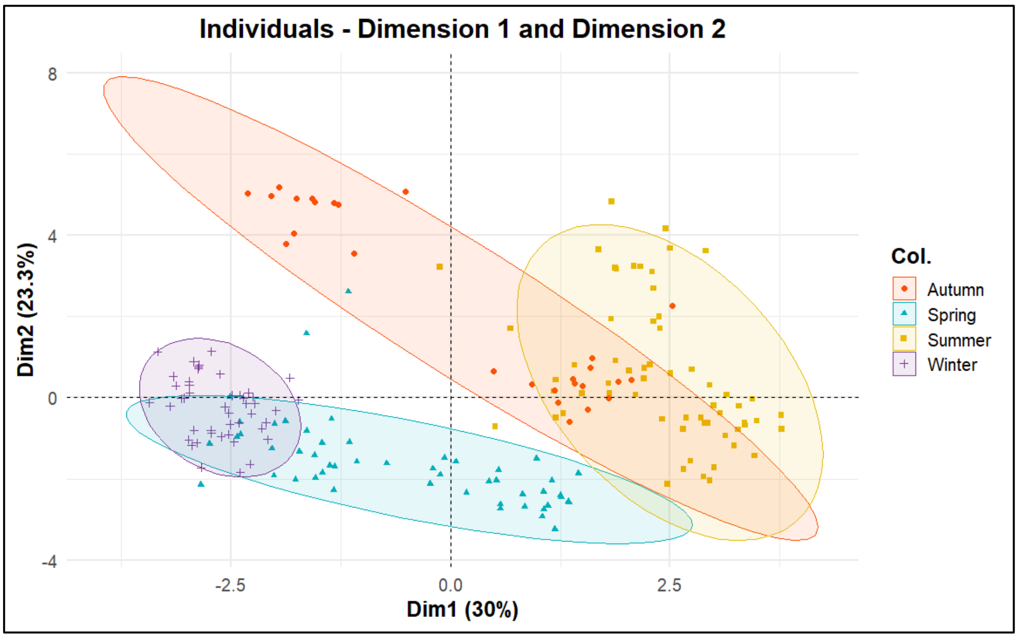


Figure 47. Representation of the individuals by seasons

Figures 46 and 47 illustrate the **typical grazing routes (red points) tend to align with seasonal clusters**, indicating that seasonal variation significantly impacts the typicality of grazing routes. **Autumn and summer show more dispersed patterns**, reflecting varied grazing behaviour due to environmental conditions and forage availability. At the same time, **winter and spring have more concentrated patterns**, with winter showing the slightest variation, likely due to harsher weather conditions limiting grazing options. Approximately all the blue points are within autumn and summer, indicating less typical grazing routes during these seasons. Furthermore, **winter and spring are grouped similarly**, and **autumn and summer are grouped together**, suggesting that grazing behaviour is more consistent within these seasons.

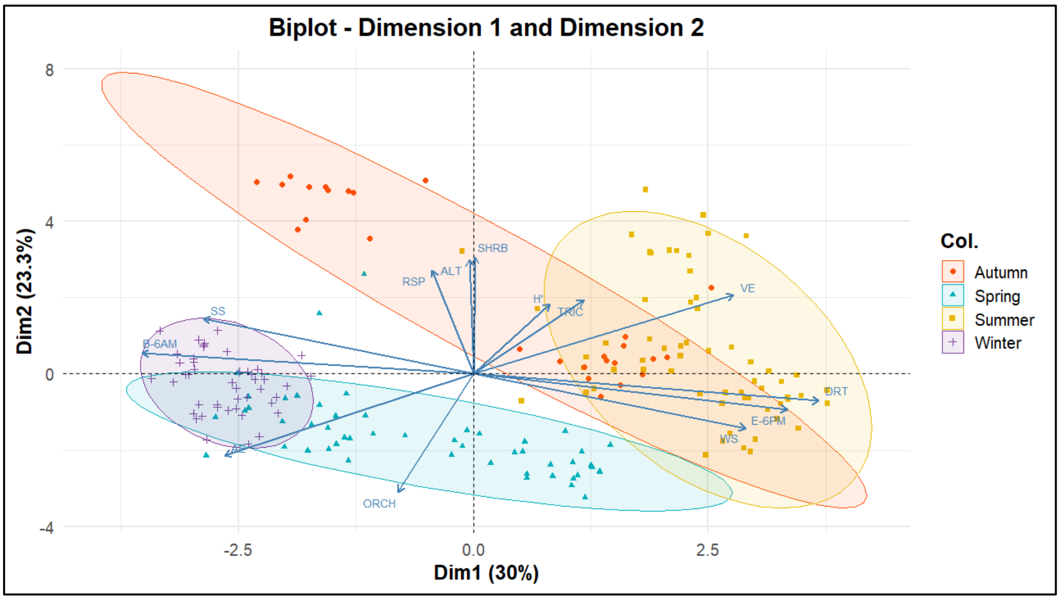


Figure 48. Biplot of dimensions 1 and 2

The biplot combines the variables and the individuals, showing their relationships. **Winter (purple)** grazing points are concentrated and close to the origin, indicating less variation, with variables like B-6AM and SS associated, suggesting earlier grazing start times and adaptation to colder temperatures and shorter daylight. **Spring (cyan)** points are spread along Dimension 1 and strongly associated with the ORCH variable, reflecting a preference for grazing in orchards where fresh forage is abundant due to the season's new growth. **Summer (yellow)** points are dispersed and aligned with variables like VE, DRT, and E-6PM, indicating longer grazing durations and later end times as sheep maximize feeding during longer days but adjust to midday heat by grazing early and late. **Autumn (red)** points show significant dispersion along both dimensions, linked to SHRUB, ALT, and RSP, highlighting varied grazing patterns driven by the availability of diverse forage in shrublands and the influence of topographical features like elevation and slope, which offer different types of forage and microclimates.

Temporal and Topographical Dynamics in Grazing Behaviour: Analysis of PC1 and PC3 (44.8%):

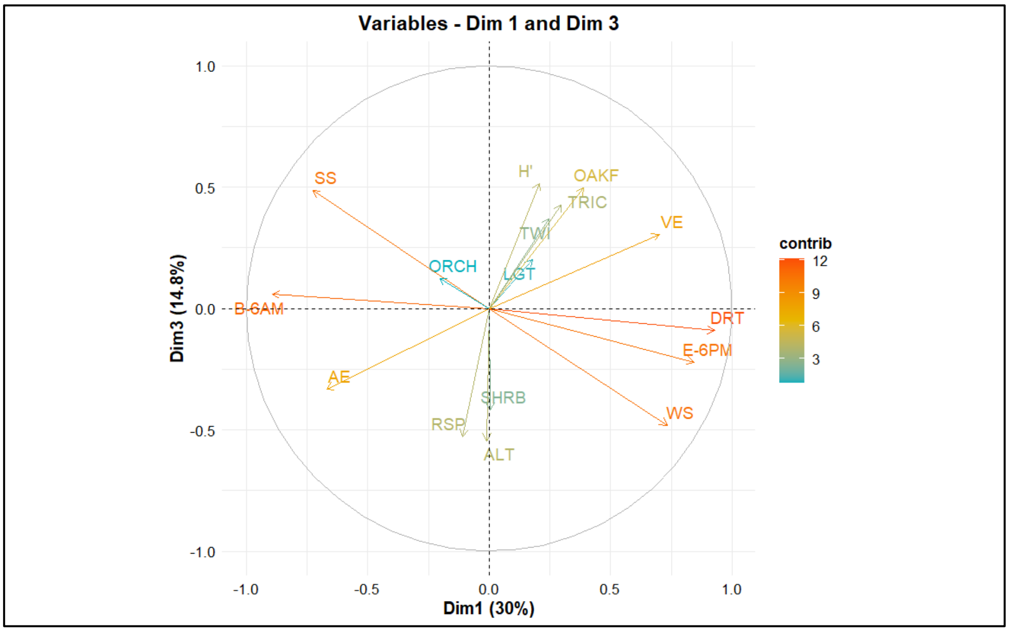


Figure 49. Contributions of variables for the combined PCA plot of PC1 and PC3

The combined PCA plot for axes PC1 and PC3 highlights the relationships between temporal and topographical variables influencing grazing behaviour. After reviewing this plot, variables ORCH (Orchards), LGT (Length), and SHRB (Shrublands) were eliminated due to their low contributions, as indicated by their blue colour. With the elimination of less significant variables, the focus shifts to understanding the critical interactions between the remaining temporal and topographical factors that drive grazing dynamics.

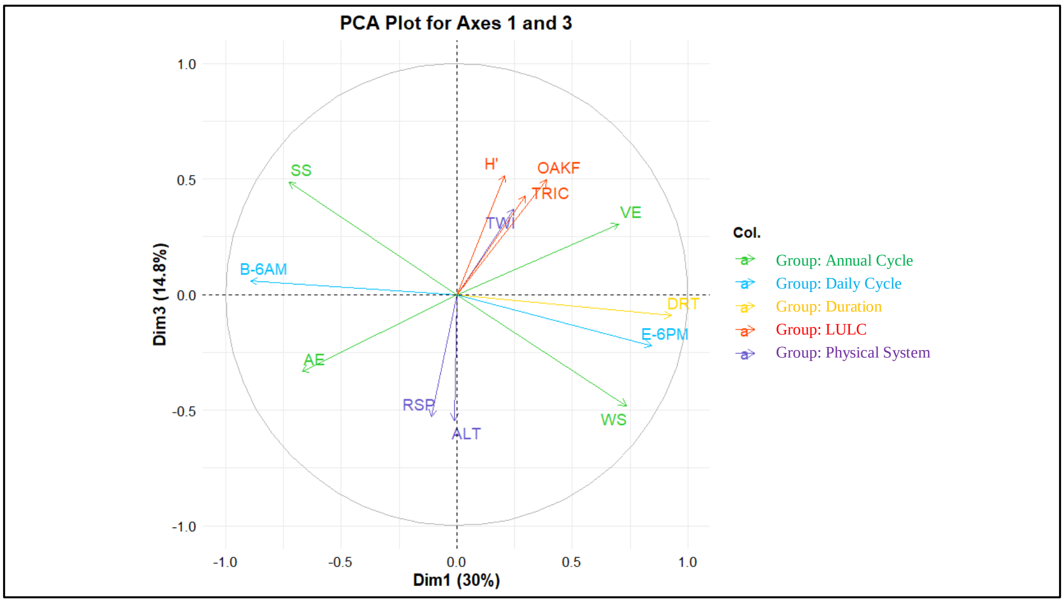


Figure 50. PCA Plot for Axes 1 and 3

RSP (Relative Slope Position) and ALT (Elevation) are correlated and move more towards the Autumnal Equinox (AE), indicating that topographical features such as slope and elevation are particularly influential during the autumn season. As temperatures cool and daylight decreases, sheep prefer grazing areas with varied elevations and slopes, providing different types of forage and microclimates beneficial during this transitional period. TWI (Topographic Wetness Index), TRIC (Temporary Rainfed and Irrigated Crops), OAKF (Forests of Other Oaks), and H' (Shannon Diversity Index) are correlated with the Vernal Equinox (VE), reflecting the significant impact of spring on grazing patterns. Spring increases daylight and warming temperatures, enhancing plant growth and forage availability. The TWI indicates moisture-retaining areas crucial for nutritious forage growth, while TRIC and OAKF provide diverse and abundant forage options, as shown by their correlation with H', which measures plant diversity. This diversity is vital during spring when sheep need high-quality forage after the resource-scarce winter.

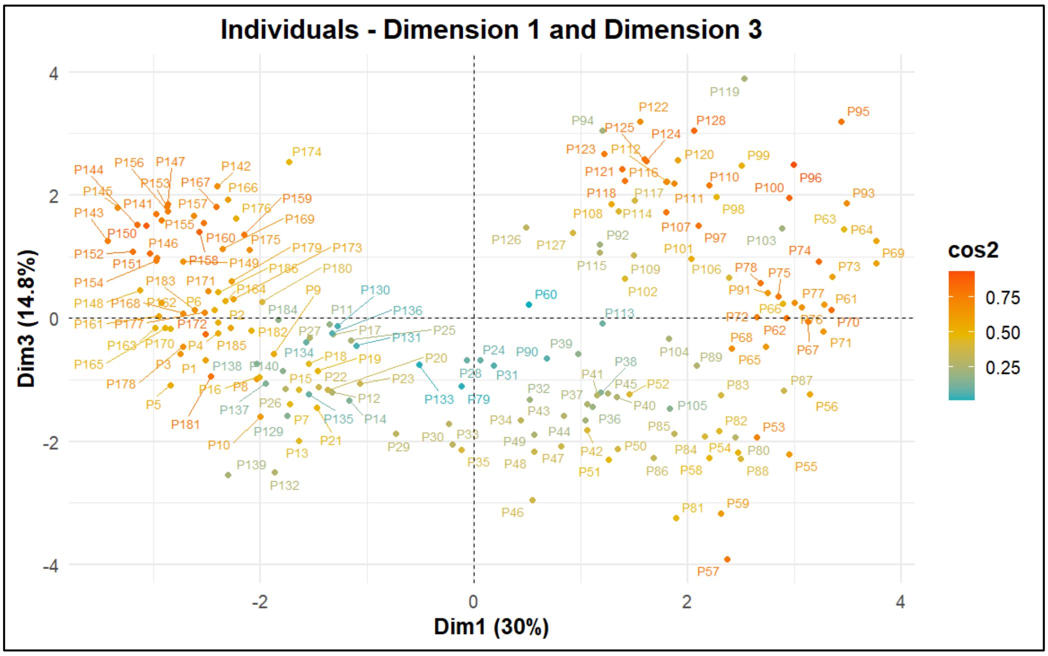


Figure 51. The quality of representation of the individuals

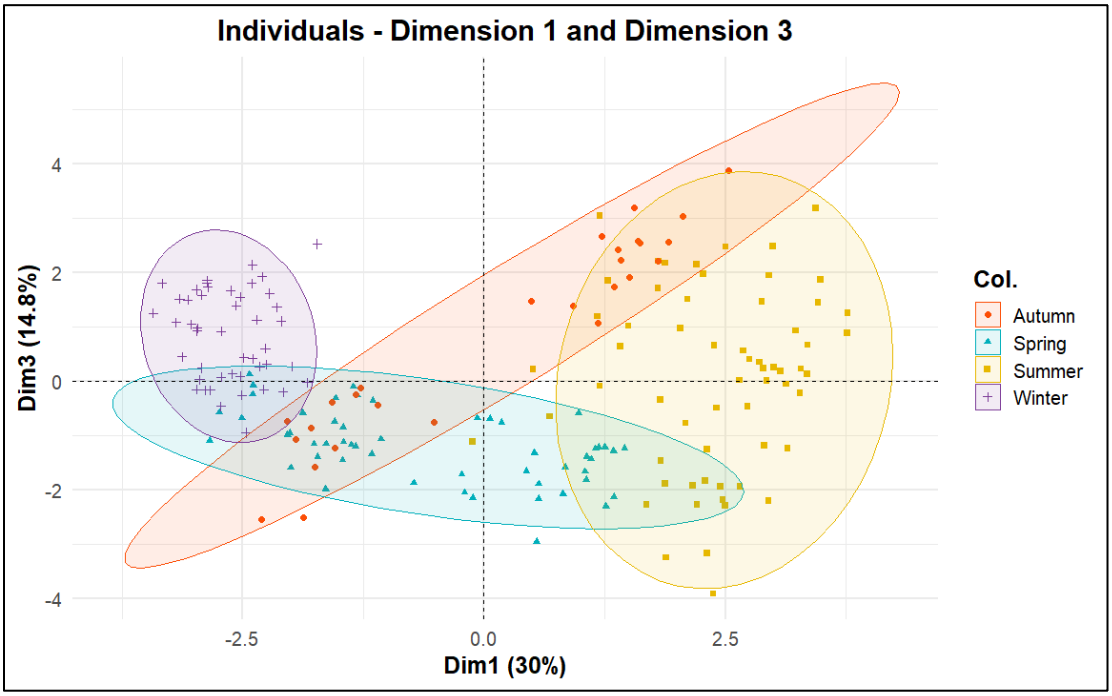


Figure 52. Representation of the individuals by seasons

Graphs 51 and 52 show red points indicating very typical grazing routes and blue points representing less typical routes. Points further from the origin are more typical, showing better representation by these dimensions. The blue points, which are not very typical, are primarily within spring and autumn, indicating that grazing patterns in these seasons are less defined by the variables used in the analysis. **Autumn (red)** points are widely spread, indicating diverse grazing patterns influenced by varying forage availability and environmental conditions. **Spring (cyan)** points are more concentrated, showing a more uniform grazing pattern due to consistent forage growth. **Summer (yellow)** points are dispersed, reflecting varied grazing behaviour to cope with heat stress and forage distribution. **Winter (purple)** points are close to the origin and more concentrated, indicating less variation in grazing routes due to harsh weather conditions limiting grazing options. The ellipses in each season's cluster indicate the distribution and variability of grazing routes, with more expansive ellipses in autumn and summer showing more significant variability and narrower ellipses in winter and spring, indicating more consistent grazing patterns.

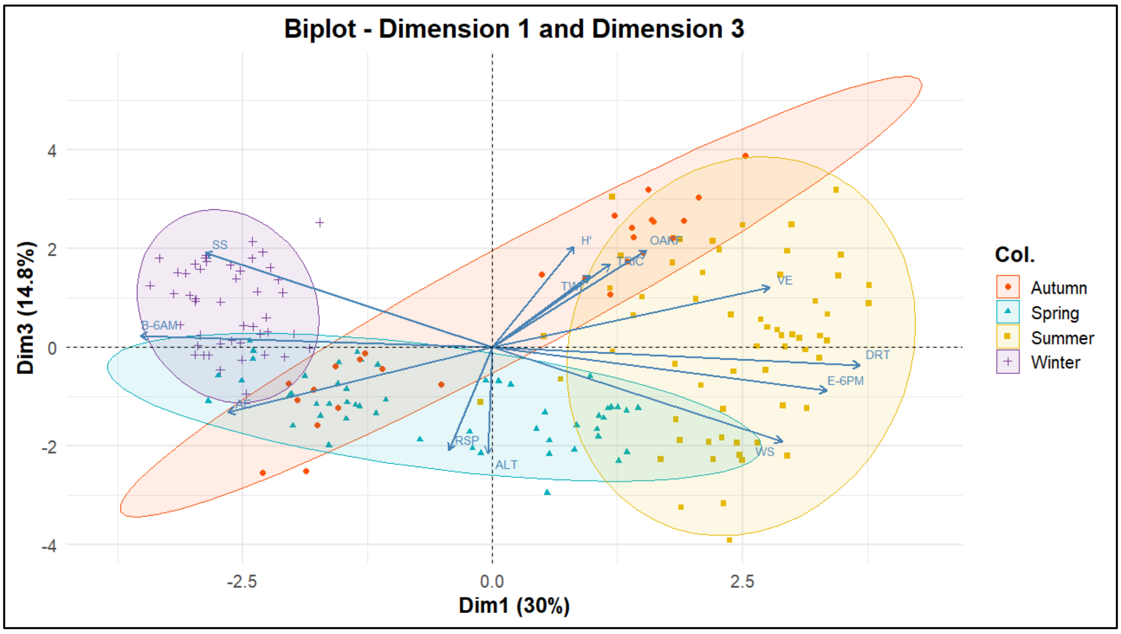


Figure 53. Biplot of dimensions 1 and 3

Winter (purple) points are concentrated and close to the origin, associated with variables like B-6AM and SS, indicating earlier grazing start times and adaptation to colder temperatures and shorter daylight. **Spring (cyan)** points are spread along Dimension 1 and associated with RSP and ALT, reflecting a preference for grazing in areas with varied slope and elevation due to new forage growth. **Summer (yellow)** points are dispersed and aligned with VE, DRT, and E-6PM, suggesting longer grazing durations and later end times to avoid the midday heat, as well as the influence of the Vernal Equinox on plant growth. **Autumn (red)** points show significant dispersion along both dimensions, linked to SHRUB, ALT, and RSP, highlighting varied grazing patterns driven by the availability of diverse forage in shrublands and the influence of topographical features. The ellipses indicate the distribution and variability of grazing routes, with more expansive ellipses in autumn and summer showing more significant variability and narrower ellipses in winter and spring indicating more consistent grazing patterns. Approximately all the blue points, which are not typical, are within spring and autumn, indicating less defined grazing patterns during these seasons. **The shepherd controls the time of departure and return based on the topography, using altitude and valleys to manage temperature extremes; they go up the mountain if it is hot and descends to the valleys if it is cold.** This links with the correlation of TWI (Topographic Wetness Index), RSP (Relative Slope Position), and ALT (Elevation), showing that topographical features influence the shepherd's decisions to optimize grazing.

Land Use/Topography and Seasonal Variability in Grazing: Analysis of PC2 and PC3 (38.1%):

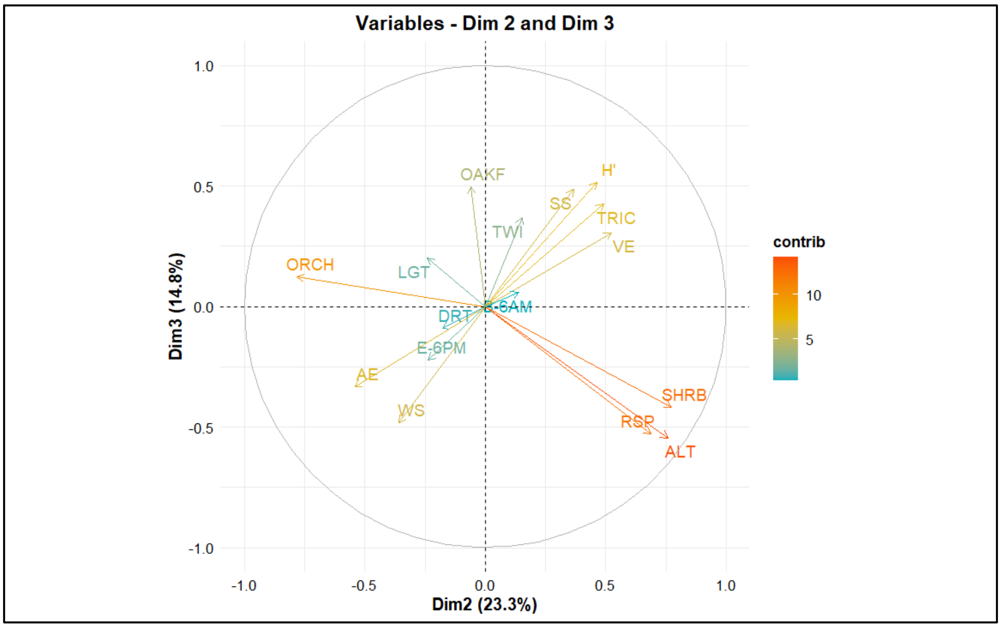


Figure 54. Contributions of variables for the combined PCA plot of PC2 and PC3

The combined PCA plot for axes PC2 and PC3 highlights the relationships between land use, topographical variables, and seasonal variability in grazing behaviour. **After reviewing this plot, variables B-6AM (Begin minus 6 AM), E-6PM (End minus 6 PM), and DRT (Duration) were eliminated** due to their low contributions, as indicated by their blue colour. This decision helps to focus on the variables with significant impacts on grazing patterns.

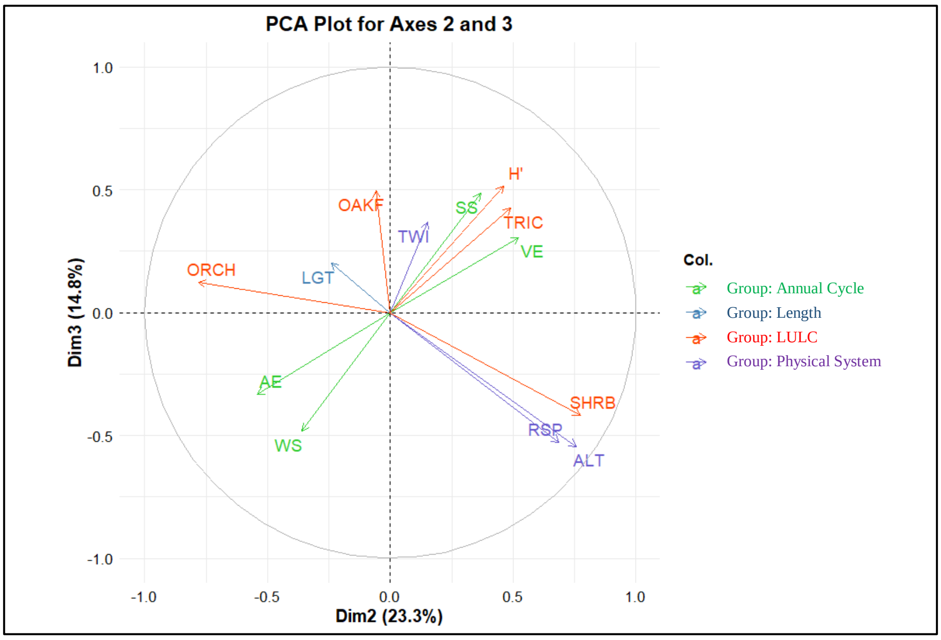


Figure 55. PCA Plot for Axes 1 and 3

RSP (Relative Slope Position) and ALT (Elevation) are highly correlated with SHRB (Shrublands), suggesting that shrublands, which are typically found in higher altitudes and steeper slopes in Portugal, provide essential forage diversity and microclimates that support grazing activities, especially in transitional seasons like autumn and spring. This indicates that grazing in these areas involves navigating varied topography, offering different vegetation types and shelter. The strong correlation between RSP and ALT can be explained by the fact that **the landscape often becomes steeper as elevation increases, resulting in a higher relative slope position**. Therefore, areas with high elevation naturally have more pronounced slopes, which are characteristic of mountainous and hilly regions where shrublands are prevalent. **LGT (Length) is correlated with ORCH (Orchards) and OAKF (Forests of Other Oaks), and ORCH is negatively correlated with SHRB**, emphasizing the altitudinal differences between these land uses. Orchards, primarily chestnuts, are situated in lower altitudes, providing consistent and accessible forage. The negative correlation between orchards and shrublands highlights the contrasting environments the sheep must adapt to, with longer grazing routes in orchards and forests due to the even distribution of forage in these lower areas. **H' (Shannon Diversity Index) and TRIC (Temporary Rainfed and Irrigated Crops) are correlated with TWI (Topographic Wetness Index)**, reflecting that moisture-retaining areas support a higher diversity of plant species, crucial for maintaining a nutritious and varied diet for the sheep. These regions become vital during the spring and summer seasons when diverse forage is most needed for the sheep's nutritional needs. Water and diverse crops enhance forage quality and availability, contributing to more productive grazing periods.

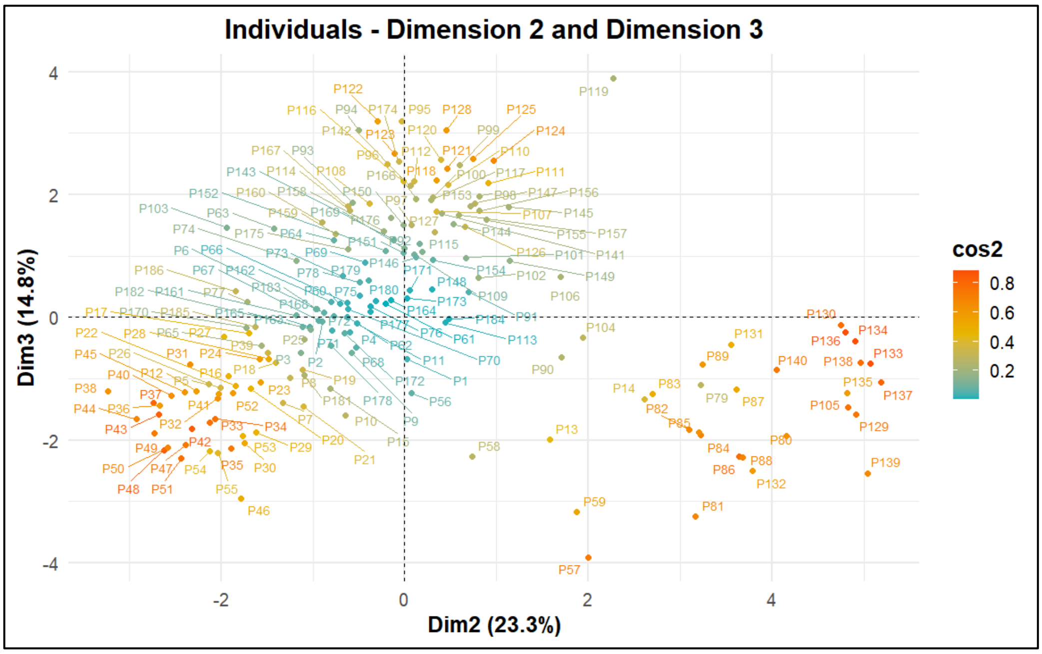


Figure 56. The quality of representation of the individuals

The graphic illustrates the quality of representation of individuals (each day of grazing) using PCA for dimensions 2 and 3, with red points indicating very typical grazing routes and blue points representing less typical routes. Points further from the origin are more typical, showing better representation by these dimensions.

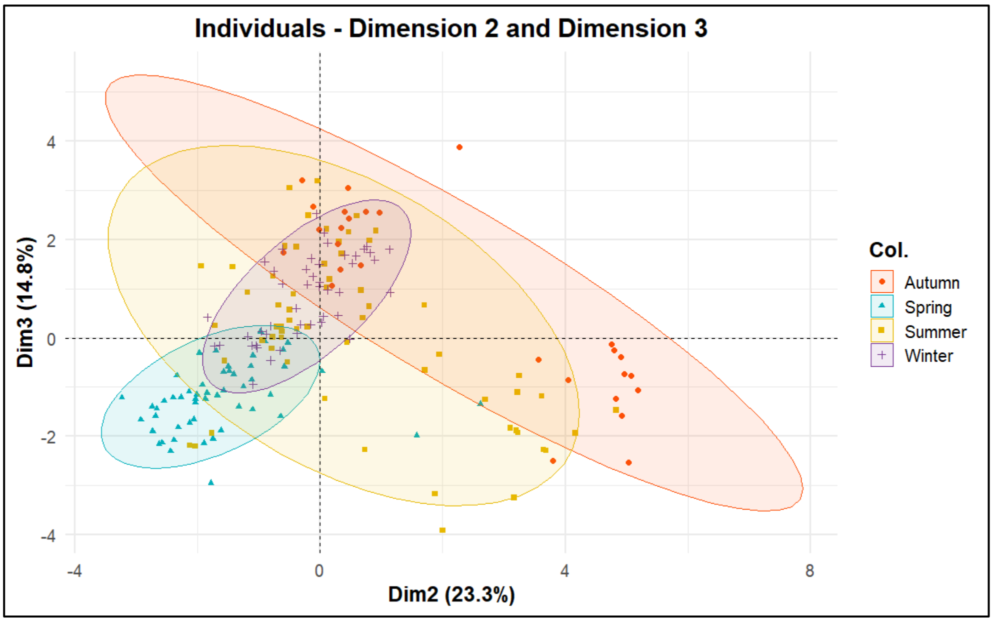


Figure 57. Representation of the individuals by seasons

Autumn (red) points are widely spread along both dimensions, indicating diverse grazing patterns due to varied environmental conditions and forage availability. **Spring (cyan)** points are more concentrated, showing a more uniform grazing pattern likely due to consistent forage growth. **Summer (yellow)** points are dispersed, reflecting varied grazing behaviour to cope with heat stress and forage distribution. **Winter (purple)** points are closer to the origin and more concentrated, indicating less variation in grazing routes due to harsher weather conditions limiting grazing options. The ellipses in each season's cluster indicate the distribution and variability of grazing routes, with more expansive ellipses in autumn and summer showing more significant variability and narrower ellipses in winter and spring indicating more consistent grazing patterns. The blue points, representing less typical routes, are mostly mainly the winter, summer, and spring seasons, highlighting the variability and adaptability required in these periods.

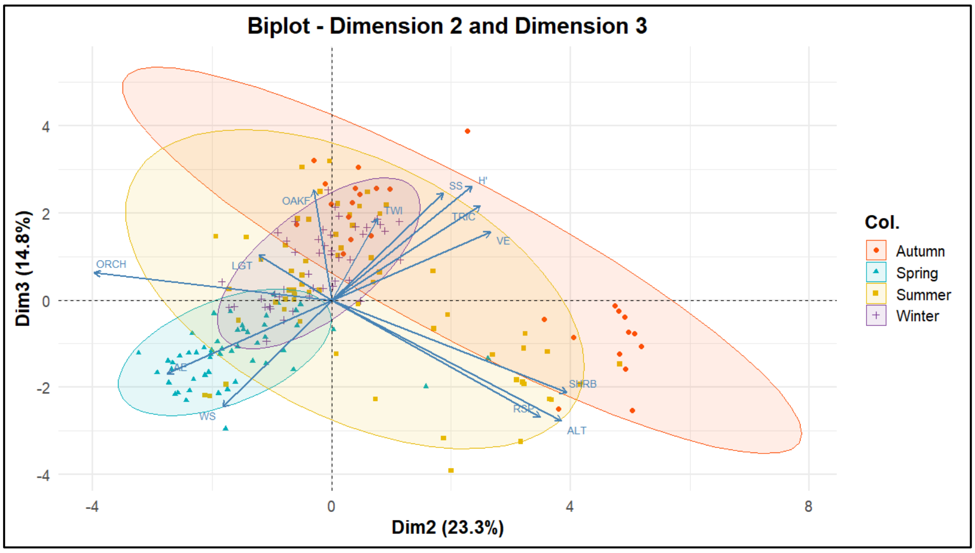


Figure 58. Biplot of Dimensions 2 and 3

RSP (Relative Slope Position) and ALT (Elevation) are highly correlated with SHRB (Shrublands), indicating that shrublands, typically found in higher altitudes and steeper slopes, are essential grazing areas during summer and autumn. These areas provide diverse forage options and cooler microclimates necessary for grazing during these seasons. **LGT (Length)** is related to summer and winter grazing patterns, reflecting the need for longer routes to find dispersed forage during dry summer and adequate forage under harsh winter conditions. **ORCH (Orchards)** shows strong relevance in spring, winter, and summer, offering fresh forage during spring, shelter and consistent forage in winter, and shade and diverse forage in summer. **OAKF (Forests of Other Oaks), TWI (Topographic Wetness Index), H' (Shannon Diversity Index), and TRIC (Temporary Rainfed and Irrigated Crops)** are significantly related to winter, summer and autumn grazing, highlighting areas with high plant diversity and moisture retention. These areas provide consistent forage in winter and essential moisture and diverse plant species during summer and autumn, supporting nutritious and varied diets for the sheep.

4.4. Overall Synthesis and Implications

The study of sheep grazing patterns in Montesinho Natural Park has provided valuable insights into their behaviour and the environmental factors influencing their grazing activities. Seasonal variability is crucial in determining the duration and length of grazing sessions. Longer grazing periods in spring and autumn reflect favourable climatic conditions and the availability of diverse forage, while shorter sessions in winter align with harsher weather conditions that limit grazing opportunities. This pattern is consistent with traditional herding practices in the Trás-os-Montes and Alto Douro regions, where herders adapt grazing schedules to cope with heat, cold, and frost (Castro et al., 2021).

Orchards, particularly chestnut forests, emerge as the dominant grazing areas, accounting for 64% of the total grazing area across all seasons. These areas provide consistent and accessible forage, especially in spring, winter, and summer, offering fresh growth, shelter, and shade. Sheep have been used for centuries to graze orchard understory vegetation (Wilson & Hardestry, 2006). Temporary rainfed and irrigated crops, shrublands, and forests of other oaks also significantly contribute to grazing, particularly during specific seasons when their productivity peaks (Mosquera-Losada et al., 2009). In the grazing field, shrublands in the mountains are typically found in high altitudes, while orchards are located in lower altitudes. This demonstrates the varied grazing landscapes the sheep utilize throughout the year.

Grazing is a very seasonal activity influenced by time, season, and sheep behaviour. During the summer, sheep graze early in the morning and late in the evening, resting in forested areas during the hottest parts of the day, and in winter, grazing starts later in the morning to avoid frost (Castro et al., 2021). Sheep at pasture choose to use shade in the hottest part of the day (Knight et al., 2023). Sheep spent more daytime on grazing itineraries than goats independently of the season, averaging 504 minutes per day compared to 409 minutes per day (Castro & Fernández-Núñez, 2016). The shepherd plays a crucial role in controlling the departure and return time based on the climate. The shepherd must choose grazing locations each day based on available resources, making very cultured decisions that consider cultivation practices and resource availability (Castro, 2000). Grazing is done based on resources, requiring adaptive management to ensure the best yearly grazing outcomes.

Seasonal changes influence grazing behaviour, with grazing patterns shifting to early mornings and late evenings with midday resting periods in forested areas during summer. The use of altitude and valleys helps manage temperature extremes; for example, the sheep can graze up the mountain if it is hot and descend to the valleys if it is cold. This links with the correlation of TWI (Topographic Wetness Index), RSP (Relative Slope Position), and ALT (Elevation), showing that topographical features influence the shepherd's decisions to optimize grazing conditions.

During the orchard harvest period, sheep cannot graze in the same place as the harvest, so they change corrals to avoid disturbing the harvest. Therefore, they move to the mountains to graze. This practice is part of a silvopastoral system, where perennial crops like orchards are integrated with grazing, under the continuous supervision of the shepherd (Castro et al., 2021). This mixed system ensures that sheep find forage near the village in pastures and agricultural byproducts, utilizing more distant rangelands only when access to cultivated fields is not allowed during growing and harvest periods. Sheep grazing in chestnut orchards and shrublands offers several benefits and is influenced by various environmental factors. The shade provided by chestnut trees creates a microclimate that can help sheep maintain their thermal comfort, which is particularly important during hot weather. Sheep will naturally seek out shaded areas when temperatures exceed 24°C to reduce heat stress, which can enhance their overall welfare and productivity (Garmendia et al., 2022; Ghahramani et al., 2019)

Climate change presents a significant challenge to this grazing system, given the sensitivity of the activity to climatic conditions (Thornton et al., 2009). Changes in climate will greatly affect grazing patterns, with potential impacts on forage availability, the length of grazing seasons, and the overall health and productivity of the sheep. The expected expansion of permanent crops and forest areas could disrupt grazing routes, and the decrease in arable land and shrubland areas is likely to influence species selectivity in an environmentally changing context (Castro et al., 2021). Forages constitute 75 to 90 percent of the total diet for sheep (Umberger, 2009). The difference in day lengths between summer and winter also affects grazing behaviour, necessitating adaptive coping strategies for longer or shorter days. As climate change progresses, it will be crucial to develop and implement grazing management practices to mitigate these impacts, ensuring the sustainability and resilience of grazing activities in Montesinho Natural Park.

Overall, the study reveals that adaptive grazing management strategies are essential to optimize the health and productivity of the sheep herd throughout the year. Considering the intricate interplay between topographical features, land use types, and seasonal changes ensures sustainable and effective grazing practices in Montesinho Natural Park.

5. Conclusion

This study comprehensively analyses the grazing patterns of the Churra Galega Bragançana Branca sheep breed in Montesinho Natural Park, utilising GNSS collar data integrated with GIS and analysed through RStudio. The findings offer insights into the spatial and temporal dynamics of sheep grazing behaviour, influenced by seasonal and climatic variations.

Key Findings

- **Seasonal and Climatic Variations:** The longer grazing journeys observed in spring and autumn suggest that sheep have a greater need for forage during these seasons. The research identified significant correlations between grazing patterns and environmental variables such as elevation, relative slope position, and topographic wetness index.
- **Land Use and Grazing Efficiency:** Diverse land use types, including orchards, shrublands, and temporary crops, are critical in optimising grazing efficiency. The study highlights how shepherds utilise these varied landscapes to create a mosaic of grazing routes that enhance resource use and herd management.
- **Integration of Traditional and Modern Practices:** The research underscores the importance of combining traditional pastoral knowledge with modern monitoring techniques. This integration is crucial for sustaining grazing practices amid changing environmental conditions and addressing the challenges of climate change.

Implications for Pastoral Practices and Conservation

The findings of this study have several practical implications:

- **Adaptive Grazing Management:** The results can inform adaptive grazing management strategies considering seasonal and topographic variations to optimise resource use and maintain herd health.
- **Conservation Efforts:** Understanding the interaction between grazing patterns and landscape features can support conservation efforts by promoting sustainable land use practices that preserve biodiversity and ecosystem services.

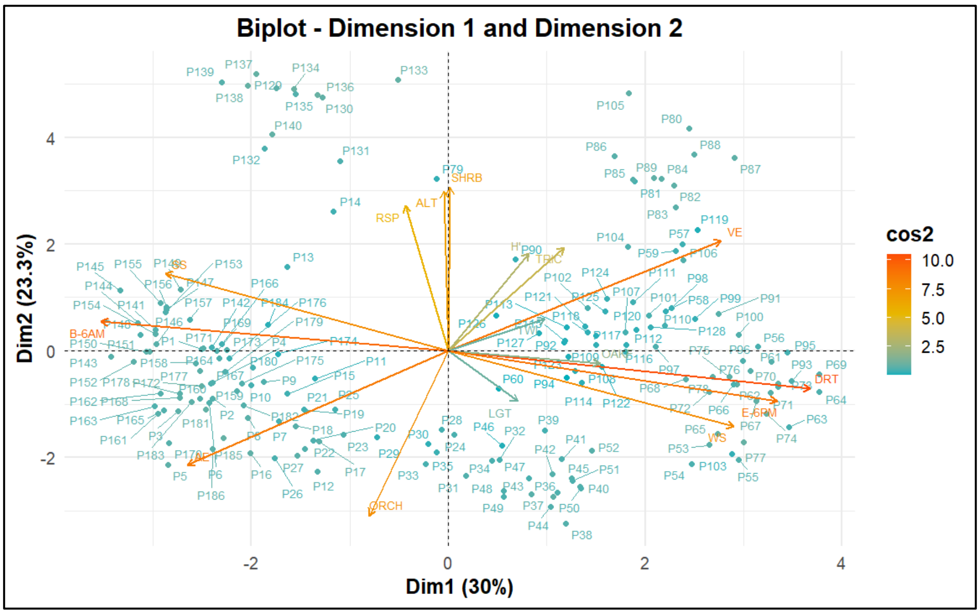
Limitations and Future Research

While this study provides valuable insights, it is limited to a single herd and region. Future research should expand to multiple herds across different regions to validate and generalise these findings. Additionally, investigating the long-term impacts of climate change on grazing patterns will be essential for developing resilient pastoral systems.

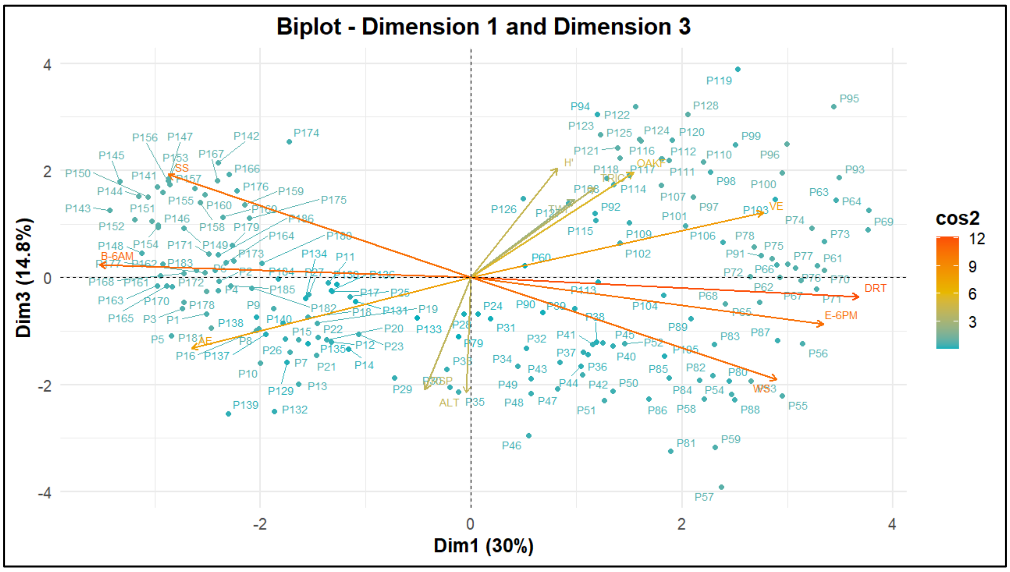
Final Thoughts

This research contributes to the broader understanding of sustainable livestock management by offering detailed insights into the dynamics of sheep grazing patterns. By integrating advanced monitoring technologies with traditional pastoral practices, this study sets a foundation for future research to enhance the sustainability and resilience of pastoral systems in the face of environmental changes.

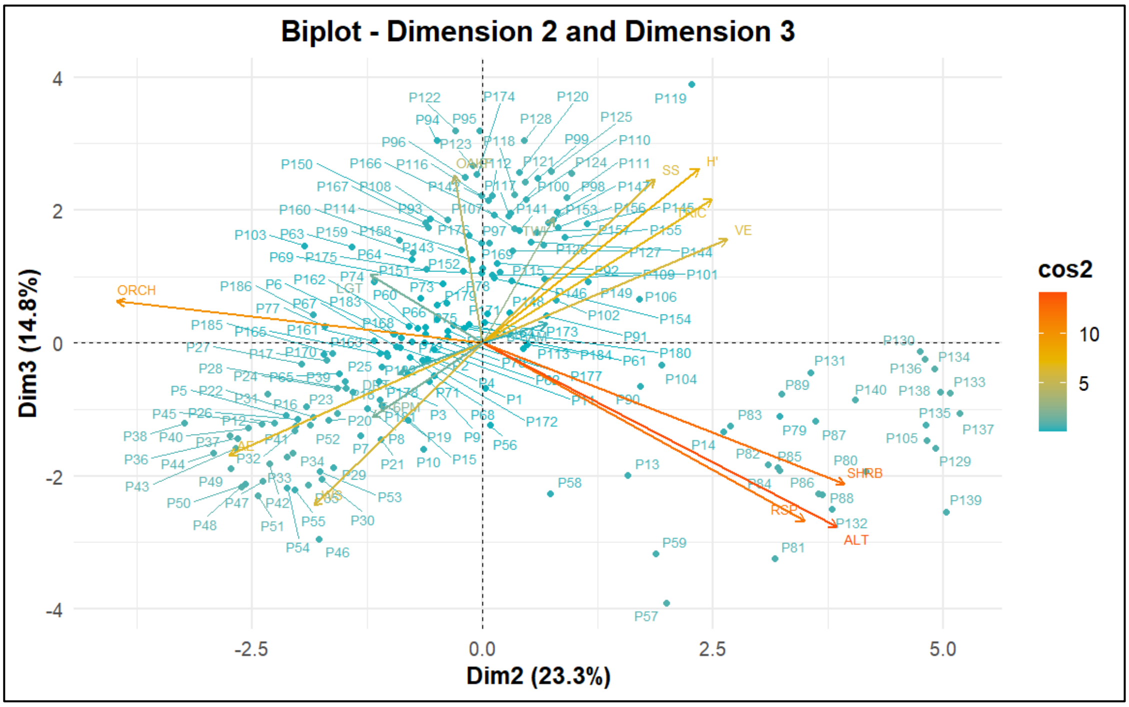
6. Appendices



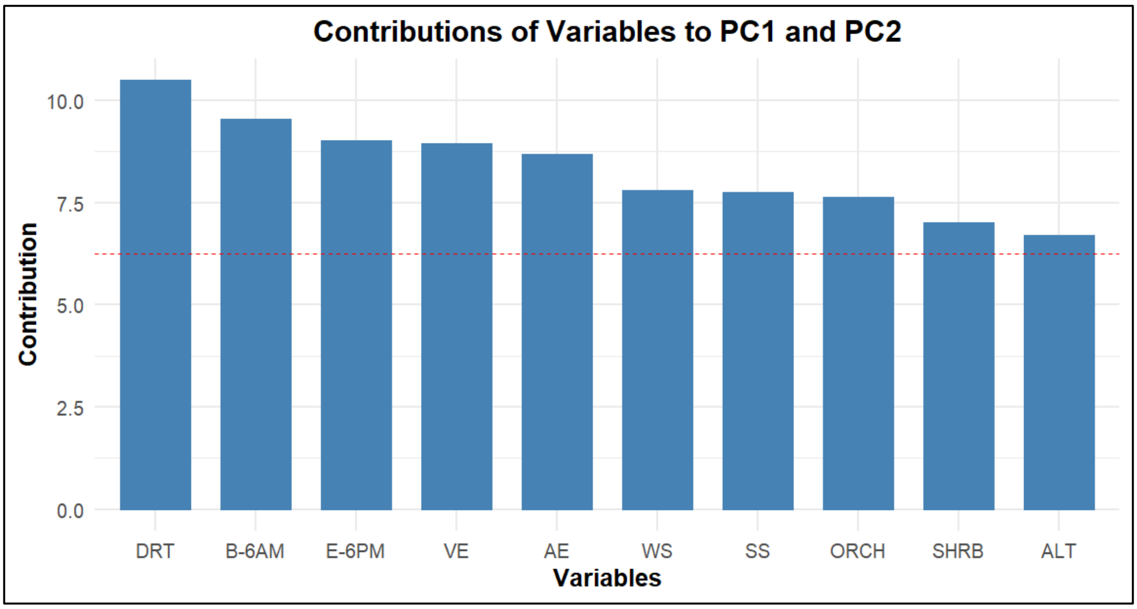
Appendix 1. Biplot of Dimension 1 and Dimension 2 with Cosine Squared (cos2) Values



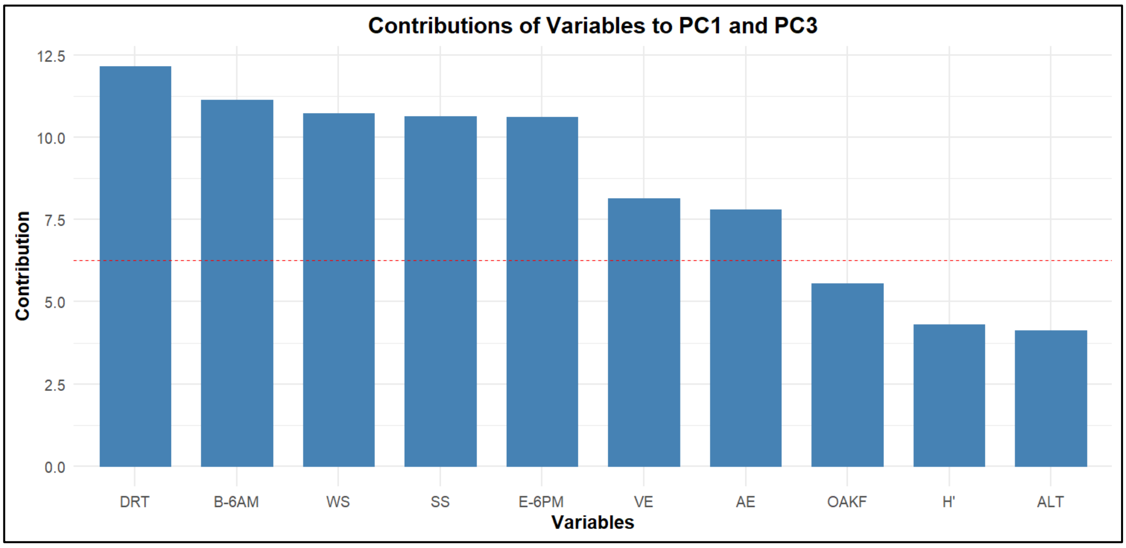
Appendix 2. Biplot of Dimension 1 and Dimension 3 with Cosine Squared (cos2) Values



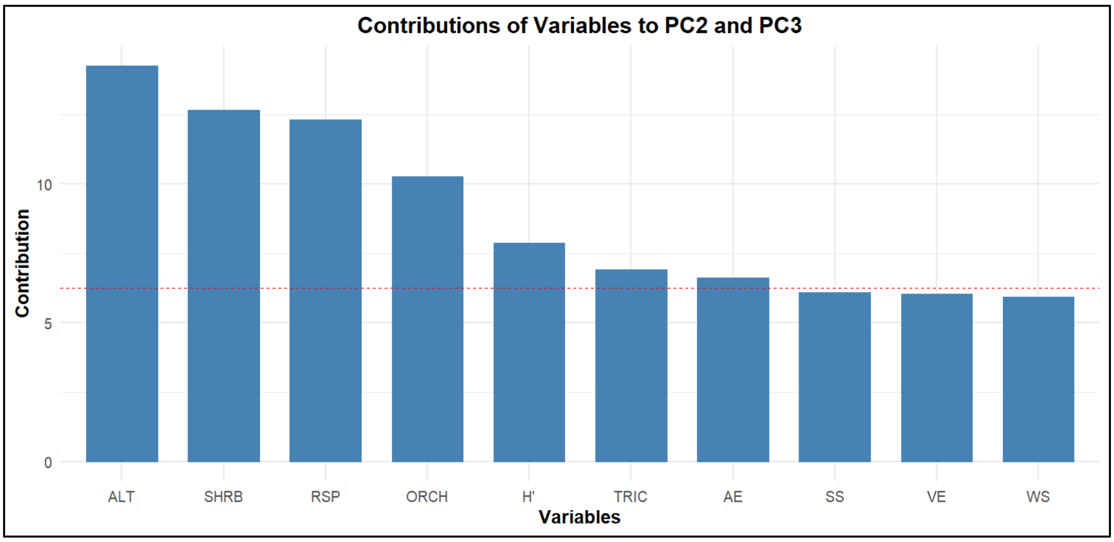
Appendix 3. Biplot of Dimension 2 and Dimension 3 with Cosine Squared (cos2) Values



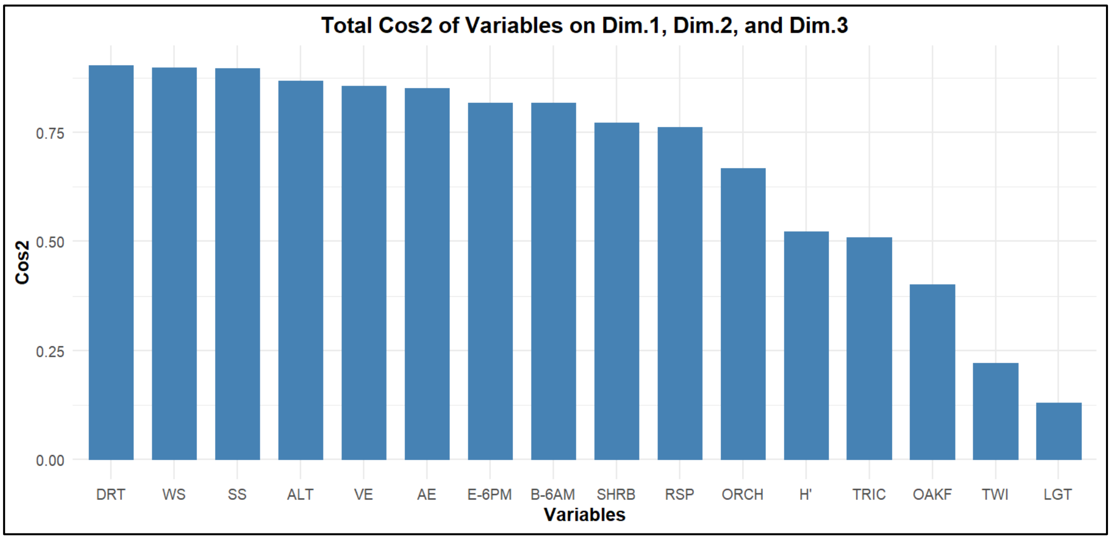
Appendix 4. Contributions of Variables to Principal Components 1 and 2



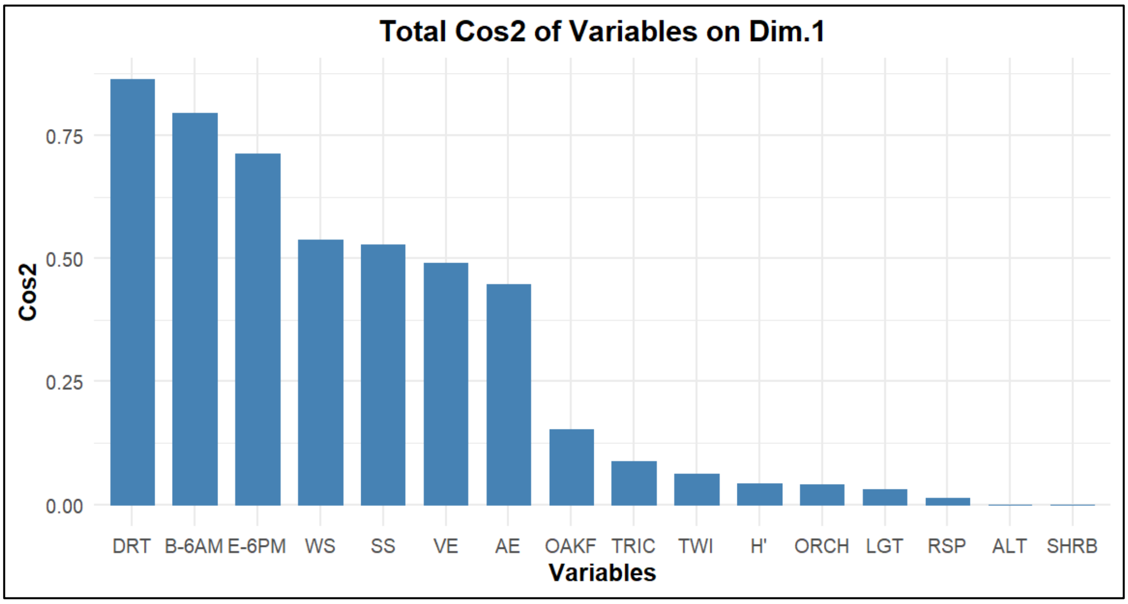
Appendix 5. Contributions of Variables to Principal Components 1 and 3



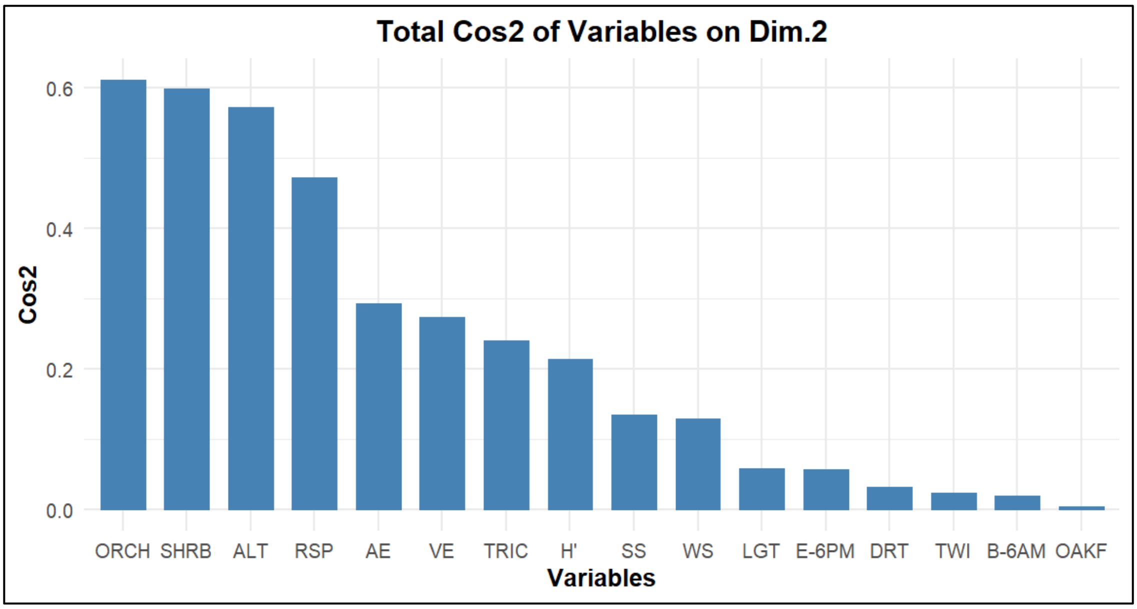
Appendix 6. Contributions of Variables to Principal Components 2 and 3



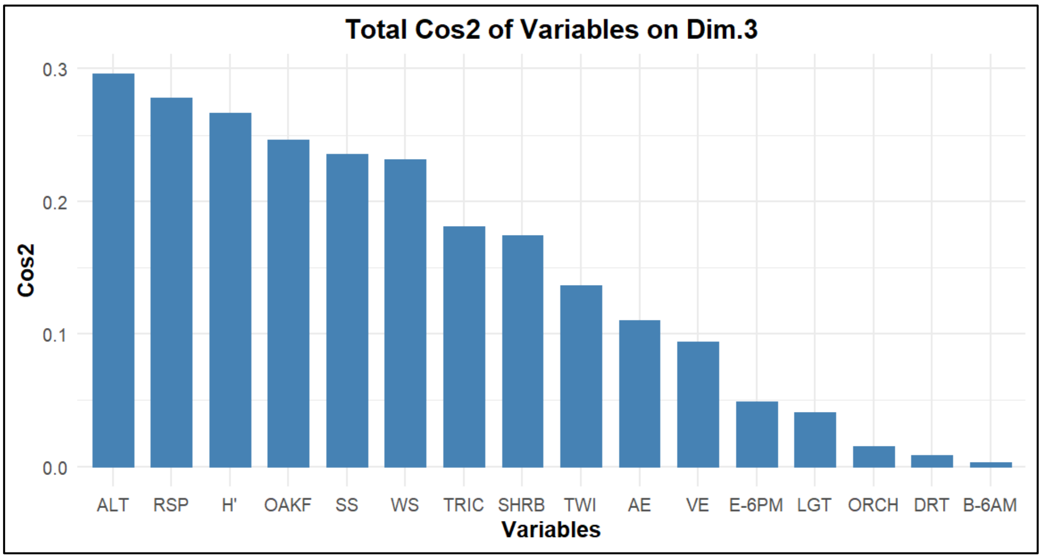
Appendix 7. Total Cos2 of Variables on Dimensions 1, 2, and 3



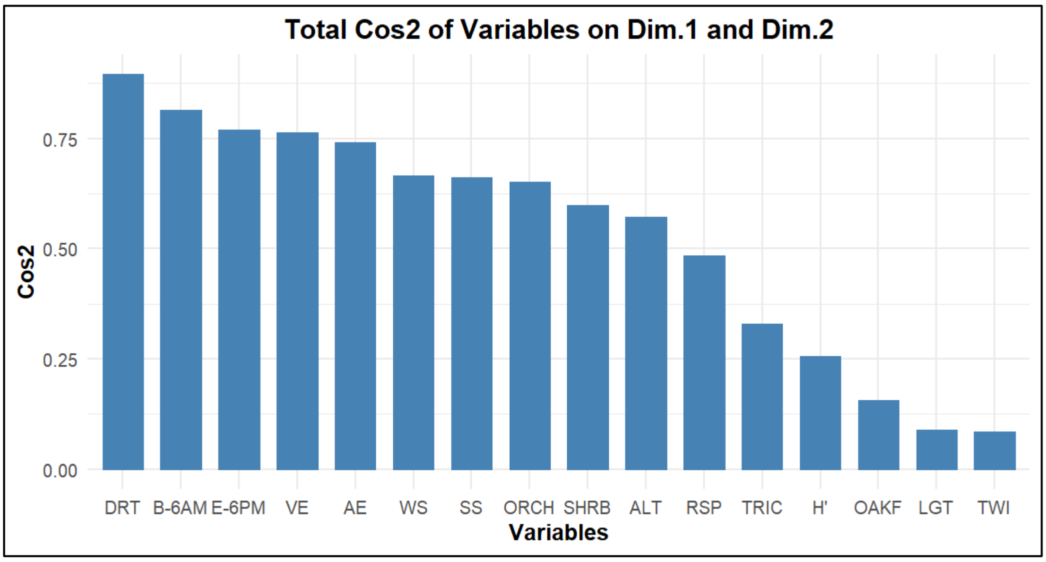
Appendix 8. Total Cos2 of Variables on Dimension 1



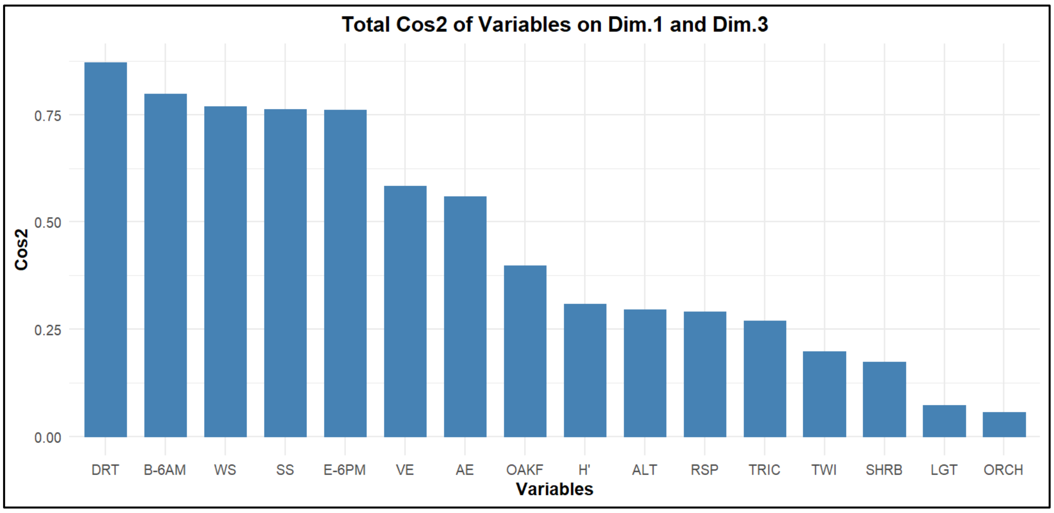
Appendix 9. Total Cos2 of Variables on Dimension 2



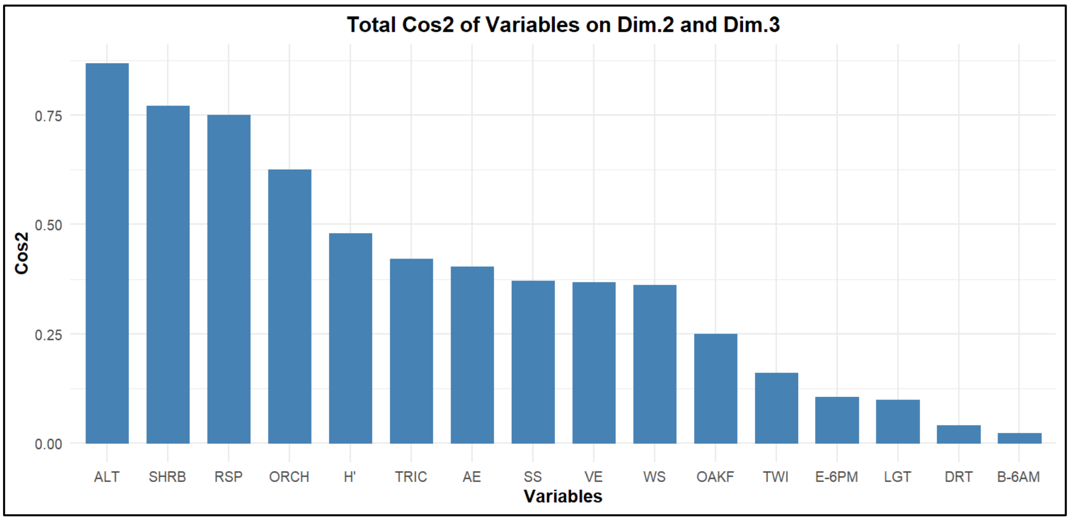
Appendix 10. Total Cos2 of Variables on Dimension 3



Appendix 11. Total Cos2 of Variables on Dimensions 1 and 2



Appendix 12. Total Cos2 of Variables on Dimensions 1 and 3



Appendix 13. Total Cos2 of Variables on Dimensions 2 and 3

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