Characterization Of Grazing Patterns:

Analyzing a Goat Herd Dynamics in Montesinho Natural Park

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“It don't take a genius to spot a goat in a flock of sheep.”

-Will Rogers-

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ACRONYMS

ALT	Altitude (metre)
RSP	Relative slope position
TWI	Topographic witness index
TRIC	Temporary rainfed and irrigated crops
CNTF	Chestnut forests
OAKF	Oak forests
MRPF	Maritime pine forests
ORCH	Orchards
IMPR	Improved pastures
SHRB	Shrubs
H’	Shannon diversity index
LGT	Length (metre)
DRT	Duration (minutes)
WS	Proximity to Winter solstice (Days)
SS	Proximity to Sumer solstice (Days)
AE	Proximity to Autumnal equinox (Days)
VE	Proximity to Vernal equinox (Days)
B-6AM	Difference between the start grazing time (Begin) and 6am (minutes)
E-6PM	Difference between end grazing time (End) and 6pm (minutes)

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ABSTRACT

This study investigates the grazing patterns of a goat herd within Montesinho Natural Park, emphasizing the interplay of environmental variables, seasonal dynamics, and land use types. The research uses GPS tracking data and GIS analysis, to explores how terrain or seasonal transitions, among other factors, could influence grazing patterns across different seasons. The findings highlight that oak forests support more extended and diverse grazing routes at higher altitudes during summer and autumn, contrasting with shorter, less varied routes observed in chestnut forests and orchards during winter and spring. Terrain variables like altitude, slope position, and land use like maritime pine forests significantly influence grazing patterns, especially in rugged terrains with lower topographic wetness. This study underscores the resilience of traditional grazing practices amidst environmental variability and offers insights crucial for sustainable livestock management and conservation efforts in rangeland ecosystems. As pastoral communities adapt to ongoing environmental changes, the research contributes valuable knowledge essential for developing adaptive strategies aimed to preserve biodiversity, enhance ecosystem resilience, and safeguard the cultural heritage of pastoralism in Montesinho Natural Park.

Keywords: Grazing patterns, Goat herd, Montesinho Natural Park, GPS tracking, GIS, Seasonal dynamics, Land use.

RESUMO

Este estudo investiga os padrões de pastoreio de um rebanho de cabras no Parque Natural de Montesinho, enfatizando a relação com variáveis ambientais, dinâmicas sazonais e tipos da terra. Utilizando dados de localização GPS e análise SIG, a investigação analysa a forma como factores como a altitude, a composição florestal (carvalho e castanheiro) e as transições sazonais influenciam os comportamentos de pastoreio dos caprinos ao longo das diferentes estações. Os resultados destacam a importância das florestas de carvalhos que beneficiam os percursos de pastoreio mais longos e mais diversificados a altitudes mais elevadas durante o verão e outono, contrastando com percursos mais curtos e menos variados que utilizam mais os soutos durante o inverno e a primavera. As variáveis físicas, como a altitude, a posição do declive, assim como certos tipos de utilização da terra, como os pinhais, influenciam significativamente os comportamentos de pastoreio, especialmente em terrenos acidentados afastados das linhas de água. Este estudo sublinha a resiliência das práticas tradicionais de pastoreio sujeita às alterações climáticas, e oferece conhecimentos cruciais para a gestão sustentável do pastoreio e para conservação dos seus ecossistemas. À medida que as comunidades pastoris se adaptam às mudanças climáticas, esta investigação contribui com conhecimentos para o desenvolvimento de estratégias adaptativas destinadas a preservar a biodiversidade, aumentar a resiliência dos ecossistemas e salvaguardar o património cultural da pastorícia no Parque Natural de Montesinho.

Palavras-chave : Padrões de pastoreio, Rebanho caprino, Parque Natural de Montesinho, Seguimento por GPS, SIG Variáveis ambientais, Dinâmica sazonal, Tipos de uso do solo.

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1. INTRODUCTION

Pastoralism is increasingly threatened by climate and landscape changes, posing significant risks to the sustainability of pastoral communities. In response, these communities adapt their practices to preserve their livelihoods and traditions (FAO., 2019). This research is part of the PASTOpraxis project, which examines the response of rangeland-based systems to climate change. By studying the interactions between herds and their landscapes, we aim to develop strategies to mitigate the impacts of climate change, thereby supporting traditional grazing practices for goats and sheep in the Montesinho Natural Park (Castro et al., 2022).

This study investigates the grazing patterns of a goat herd in the Montesinho Natural Park using GPS data to track their movements over a year. Our objectives include analysing the temporal and spatial variations in grazing paths, assessing seasonal changes in land usage, and exploring how landscape use correlates with the herd's needs for shelter, water, and food. These insights are essential for promoting sustainable livestock management and ensuring the ecological balance of grazing areas. Through this research, we seek to contribute to the resilience and sustainability of pastoral systems in the face of climate change.

The dissertation is structured into 5 chapters:

1. An introduction, first part of the report that introduces the subject.
2. An overview of the silvopastoral systems as well as the animal monitoring methods.
3. The presentation of the study area and description of the methods utilized.
4. Presentation of the results obtained and discussion.
5. Conclusions.

2. THE CONTEXT OF THE RESEARCH

2.1. Insights into Pastoralism: Definitions, Characteristics, and Mobility

2.1.1 Definitions and Characteristics

According to FAO, pastoralism, a livelihood system based on extensive livestock production, relies heavily on the mobility of animals and the communal use of natural resources. This practice allows pastoralists to capitalize on seasonal pastures, access vital resources like water and salt patches for animal health, and efficiently control diseases (Ruthenberg., 1980; Dixon et al., 2001). Around 200 million pastoralists raise livestock like cattle, sheep, goats, and camels in drylands, which cover over a third of the Earth's land and are unsuitable for crop cultivation. (FAO., 2019).

Pastoral systems can be categorized based on herd mobility patterns, resource use, and income generated from livestock and livestock products (Dong et al., 2011). These forms include nomadic pastoralism, which involves irregular movement patterns without permanent residences and transhumance, which features regular back-and-forth movements between locations, typically following seasonal cycles.

Other forms include pastoral farming/ranching, practised in high-income countries and characterized by managed ranches or pastures; agro-pastoralism, which relies on crop cultivation for livelihood with a smaller percentage of income from livestock and silvopastoralism, which integrates trees, forage, and livestock grazing to provide environmental benefits such as carbon sequestration. (Blench., 2001).

2.1.2 Mobility in pastoralism

Within these forms of pastoralism, various mobility patterns are recognized (Ruthenberg., 1980; Dixon et al., 2001). High mobility, irregular movement patterns, lack of permanent residences and crop cultivation characterize nomadism. Transhumance involves a permanent residence with herders moving animals to distant grazing areas on a seasonal cycle, such as between winter and summer pastures or high and low altitudes. Sedentary and semi-nomadism encompasses individuals with permanent residences who may engage in supplementary cultivation. Semi-nomadism involves animal owners roaming to distant grazing areas for extended periods, while partial nomadism includes livestock keepers residing in permanent settlements with herds grazing nearby. Sedentary animal husbandry keeps animals on the landholding or in the village throughout the year (Jenet et al., 2016).

2.1.3 Patterns of movements

Movements within pastoralism vary based on environmental conditions and household circumstances. These movements can be highly regular, following seasonal patterns along established corridors to specific pasture areas, or relatively random, opportunistically tracking rainfall with infrequent returns to the same land. Vertical mobility entails the regular movement of herds from valleys to mountains, a practice common in regions like Turkey, the Iranian plateau, North Africa, the Himalayas, Kyrgyzstan, and the Andes. Horizontal mobility is more opportunistic and primarily influenced by rainfall patterns (Jenet et al., 2016).

The inherent mobility in pastoralism is fundamental to the efficient use of rangelands, supporting sustainable livestock production and the livelihoods of millions of pastoralists worldwide. By categorizing pastoralism into different forms based on mobility patterns and resource use, we can better understand the diversity and adaptability of this vital livelihood system. This approach underscores the importance of mobility in maintaining the ecological and economic sustainability of pastoral practices globally (Blench., 2001; Dixon et al., 2001; Dong et al., 2011; Ruthenberg., 1980).

2.2. Mountain’s farming systems and silvopastoral systems in northern Portugal

2.2.1 Mountain’s farming systems

Agricultural and food systems are crucial economic and developmental drivers in many mountains region. They generate income through products sold in local and urban markets and employ a substantial portion of the population, especially in developing countries. Mountain farming systems have adapted to challenging local conditions using advanced techniques such as terrace farming. This method allows for productive agriculture on steep terrains and vital in sustaining ecosystems by stabilizing land, reducing soil erosion, and preventing nutrient leaching (Romeo., 2021).

Mountain farming systems vary based on climatic conditions, slope, and elevation. They can be broadly classified as follows (El Solh., 2019):

- Pastoral Livestock Production System: A grazing-based system where livestock feed on natural vegetation and rangelands, including grasses, legumes, shrubs, and other forage, throughout the year.
- Agropastoral Livestock System: An integrated system combining crop, livestock, and rangeland production. It includes various livestock, natural pastures, field crops such as barley, forage crops, shrubs, and trees, along with by-products of these crops.
- Rainfed Agriculture Production System: This system is found in areas with more than 400 mm of rainfall during the rainy season. It often employs conservation agriculture practices, like minimal soil disturbance, stubble retention, and crop rotation. These practices are essential for conserving soil moisture and reducing erosion, ensuring sustainable soil productivity.
- Irrigated Agriculture Production System: This system practised in arid and semi-arid mountain areas with less than 350 mm annual rainfall. Irrigation sources include deep wells, river water, and harvested rainwater from catchments and dams. Farmers often diversify production to ensure food security, focusing on high-value crops such as vegetables, fruit trees, and ornamentals.
- Forestry System or Agroforestry: Provides essential livelihoods and environmental goods and services in mountain areas, including timber, fuelwood, carbon storage, and other products that improve the lives of mountain communities.

2.2.2 Silvopastoral Systems in Portugal

Silvopastoral systems are essential for sustainable agriculture and ecosystem management in Portugal. They include Olive Tree, Montado, Chestnut, and Pyrenean Oak systems (Castro., 2008).

The Portuguese montado is a prominent silvo-pastoral system, like Spain's dehesa, covering roughly 800,000 hectares predominantly in the Alentejo region. It integrates extensive livestock grazing with the cultivation of cork oak (*Quercus suber*) and holm oak (*Quercus ilex*). These systems span about 3.5–4.0 million hectares across the southwestern Iberian Peninsula, playing essential roles in Southern European agriculture and ecological balance (Pinto-Correia et al., 2011).

In northern Portugal, the primary systems involve sweet chestnut (Castanea sativa Mill.) and Pyrenean oak (*Quercus pyrenaica Willd*) (Castro., 2008).

2.2.2.1 Pyrenean Oak System

The Pyrenean oak is a significant species in the Iberian Peninsula, especially in the transitional Mediterranean regions of Spain, France, Portugal, and northern Morocco. In Portugal, these oaks cover approximately 62,000 hectares, primarily in the Bragança region, which accounts for 40% of the total forest area. (Carvalho et al., 2023).

These woodlands are increasingly recognized as silvopastoral systems, showcasing the mutual benefits between livestock and trees. Communally managed, these forests provide forage and welfare benefits to small ruminants like sheep and goats through fertilization and encroachment control (Castro., 2008).

2.2.2.1.1 Seasonal Dynamics

Seasonal dynamics in woodland utilization by sheep and goats reveal distinct patterns in their behavior and diet. From May to October, sheep predominantly use the woodlands for shelter and rest, allocating 20-30% of their resting time to this environment. In contrast, goats exhibit a pronounced dependence on woodland foliage, particularly during the months of August and September. During the period from September to November, both species shift their dietary focus to acorns, incorporating them significantly into their nutrition. In the winter months, sheep markedly reduce their time in the woodlands, while goats maintain a notable presence, spending approximately 10% of their time grazing on understory shrubs and grass. These findings underscore the seasonal variations in habitat use and dietary preferences among these species (Castro., 2008).

2.2.2.2 Chestnut system

Chestnut forest ecosystems cover about 35,000 hectares in Portugal, with only 10% used for timber production. Most cultivation is focused on nut production, particularly in the Bragança region, which accounts for 46% of the chestnut area and produces the DOP (denomination of origin protected) varieties "Castanha da Terra Fria" and "Castanha da Padrela."In Bragança, chestnut orchards (*soutos*) are often intercropped with cereals for sheep grazing. These orchards have low planting densities, allowing for crop cultivation and animal grazing. Sheep consume leftover chestnuts post-harvest and graze on understory species when cereals are absent (Castro., 2008).

2.2.2.2.1 Management Practices

The management practices include:

- Pruning: Occurs every three years to enhance fruiting.
- Ploughing: Performed three to five times annually for weed control and harvesting facilitation, although it has negatively impacted soil health and spread ink disease. Farmers are now adopting silvopastoral practices to reduce ploughing and its adverse effects.

Pyrenean oak and chestnut trees can be combined into silvopastoral systems when coppiced. Historically used for rapid timber production, many coppice areas are now over-matured and abandoned. However, in some regions, chestnuts from coppices are still utilized by animals, primarily goats and pigs (Castro., 2008).

2.2.2.3 Grazing systems

Small ruminant production systems in Northeastern Portugal heavily rely on extensive grazing of naturally occurring plants, guided by shepherds along daily routes that traverse diverse land uses, varying in duration and layout throughout the year (Castro et al., 2010). Flocks in this region exhibit a sophisticated landscape utilization pattern shaped by factors such as time of day, seasonal variations, and the availability of different land types for activities like browsing, grazing, resting, and transit. Sheep predominantly graze on annual and perennial crops, meadows, and shrubs often bordered by hedgerows or riparian trees, whereas goats show a broader preference for browsing, particularly favouring scrublands (Castro et al., 2010).

There are distinct grazing patterns differences between sheep and goats: sheep prefer agricultural areas like fallow cereal fields and various pastures, whether natural or artificial, while goats prefer forested areas such as matorrals and forests. Goats also cover longer distances at a quicker pace during grazing, reflecting their adaptation to foraging across more dispersed resources, including forested areas, whereas sheep concentrate their grazing activities closer to agricultural surfaces near villages, resulting in shorter routes (Castro et al.,2004).

2.3.Pastoralism and climate changes

Global warming of 1.5°C and 2°C will be surpassed during the 21st century unless there are substantial reductions in carbon dioxide and other greenhouse gas emissions in the coming decades. Global surface temperatures are projected to rise the end of the twentieth century under all considered emissions scenarios (IPCC., 2023). The resulting changes in the physical climate system, particularly more intense extreme events, have negatively impacted natural and human systems globally. These impacts include the loss and degradation of ecosystems such as tropical coral reefs; decreased water and food security; increased infrastructure damage; higher mortality and morbidity rates; human migration and displacement; damaged livelihoods; worsened mental health issues; and heightened inequality. (IPCC., 2023).

2.3.1 Impact of climate changes on pastoral livestock production systems

Climate change poses significant challenges to livestock production systems, affecting both direct and indirect animal health and productivity aspects. Directly, higher temperatures contribute to reduced feed intake and lower milk and meat production, while heat stress impairs reproductive performance and immune functions, leading to increased mortality rates. Indirectly, climate change alters crop yields used for livestock feed, shifts pasture composition and quality, reduces water availability, increases variability in seasonal resources, and enhances the frequency of extreme weather events. These compounding factors heighten susceptibility to diseases, pests, and parasites, compromising overall livestock health and productivity (Collier et al., 2018).

Furthermore, climate changes pose significant risks to the diversity of pastoral livestock, particularly affecting locally adapted breeds more than exotic breeds. The need to enhance efficiency in low-input and extensive production systems, driven by escalating food demand and climate challenges, may result in the disappearance of economically less viable locally adapted breeds (Hoffmann., 2010).

The effects of climate change on livestock vary across regions and production systems (Nardone et al., 2010). For instance, projections indicate substantial declines in biomass yield and variability in pastureland availability, with significant shifts from herbaceous to woody vegetation in many rangelands (Godde et al., 2020). This trend favours goats over cattle and sheep in these regions. Additionally, the response of pasture grass species to climate change depends on their metabolic pathways, with warm-season C4 grasses benefiting from rising temperatures and cool-season C3 grasses favoured by increased CO2 concentrations (Reeves et al., 2014).

2.3.2 Impact of Pastoral Livestock Systems on Climate Change: Challenges and Opportunities

Agricultural and food systems play a significant role in global greenhouse gas (GHG) emissions, accounting for about 35% of total emissions (IPCC., 2023). Within this sector, livestock production alone contributes 14.5% of anthropogenic GHG emissions, with methane as the primary contributor at 44%, followed by nitrous oxide (29%) and carbon dioxide (27%) (Gerber et al., 2013).

Most of GHG emissions from livestock production originate from enteric fermentation, manure management, feed production, and energy consumption. Enteric fermentation and feed production are particularly prominent in ruminant systems, contributing 45% and 39% of emissions, respectively (Gerber et al., 2013). Cattle dominate these emissions, accounting for 65% of the sector's total, while other livestock such as pigs, poultry, buffaloes, and small ruminants contribute smaller proportions (Gerber, et al., 2013). Methane emissions from enteric fermentation are higher in mixed farming systems (64%) compared to grazing systems (35%) (Neely et al., 2009).

Despite these emissions, pastoral livestock systems offer environmental advantages over intensive systems (Houzer & Scoones., 2021). They consume less water, relying mainly on rainfall rather than groundwater, which conserves critical water resources (Nardone et al.,2010). Additionally, pastoral systems recycle manure naturally, enriching soil health and reducing the need for synthetic fertilizers. Grazing animals on natural pastures improves soil health and biodiversity by facilitating seed germination through ingestion and excretion (Jenet et al., 2016; Houzer & Scoones., 2021).

Shepherding practices further enhance these benefits by managing vegetation levels to control fire risks, thereby preserving traditional landscapes of cultural and historical value (Castro et al., 2022). However, pastoralists face challenges such as land use conflicts and marginalization, which hinder their adaptive capacity against climate change impacts (Jenet, et al., 2016; Uddin & Kebreab., 2020).

In response, regenerative production systems like silvopastoral, intercropping, and conservation agriculture offer promising avenues for carbon sequestration and emissions reduction. Silvopastoral systems, for instance, enhance soil carbon restoration effectively and provide resilience against climatic extremes by integrating diverse vegetation. Furthermore, compounds found in forbs, shrubs, and tree leaves can mitigate methane and nitrous oxide emissions, highlighting the additional benefits of these practices (Uddin & Kebreab., 2020).

2.4.Location and Tracking Technologies

Since the commercial development of GPS-based telemetry systems in 1991, these technologies have rapidly evolved, driven by environmental awareness and the need for detailed wildlife impact studies and habitat conservation efforts. Modern GPS units enable comprehensive data collection, including geographic coordinates and sensor information, supporting various retrieval methods such as radio-activated release, satellite links, and local communication links (Rodgers., 2001).

Inspired by wildlife ecologists, livestock researchers are adopting traditional field methods to enhance GPS-based research. Small-scale, high-frequency GPS data are pivotal in refining behavioural models and determining optimal sampling intervals. Integrate sensors with GPS data captures specific behaviours, crucial for understanding large-scale animal interactions and landscape preferences (Swain et al., 2011).

Animal tracking technologies encompass diverse methods, including radio-based systems, RFID, UWB, Bluetooth, and remote sensing. Each technology offers unique advantages: radio-based systems use proximity detection for tracking, RFID provides variable accuracy, and UWB ensures high precision in indoor environments. Bluetooth offers moderate accuracy, while remote sensing via satellites, aircraft, and UAVs facilitates extensive monitoring but faces regulatory and computational challenges (Cosby et al., 2021).

Central to these technologies are Global Navigation Satellite Systems (GNSS) like GPS, which are managed by the U.S. NAVSTAR constellation. Other countries have developed complementary systems to provide independent positioning services (Official U.S. government information about the Global Positioning System).

2.4.1 Applications of GPS Technology in Livestock Management

GPS technology plays a crucial role in tracking animal movements and habitat preferences. It uses satellite radio signals to pinpoint locations, aiding in studying movement patterns and grazing behaviours. Frequent location recordings reveal grazing sites, while GPS data also analyse animal interactions and assess pasture utilization's impact on group dynamics (Herlin et al., 2021).

Table 1- Examples of Applications of GPS Technology in Livestock Management

Species	Technology	Aim	Citation
Beef cattle	GPS Collar	Grazing behaviour	(Anderson, et al., 2012)
Sheep	GPS Collar	Adjusting GPS tracking protocol for better land management	(Castro et al., 2022)
Beef cattle	GPS Collar	Grazing behaviour	(Ganskopp & Bohnert., 2009)
Cattle and sheep	GPS Collar	Grazing behaviour and preference according to animal's species	(Putfarken et al., 2008)
Cattle and goats	GPS Collar	To investigate spatio-temporal differences in grazing patterns and land use preferences of cattle in southwestern Madagascar using GPS tracking collars	(Feldt & Schlecht., 2016)
Goats	GPS Collar	Assess spatio-temporal movement patterns, seasonal variation in grazing intensities, and daily trajectories	(Akasbi., 2012)

2.4.2 Advanced Integration of GPS and Sensors for Animal Behaviour and Habitat Insights

Animal location data is often combined with relevant environmental information, such as vegetation type, topography, proximity to water, and distance to human activities and infrastructures, to evaluate habitat selection (Herlin et al., 2021).

Integrate GPS and sensor technologies enhances understanding the animal's location and its behaviour or health attributes (Cosby et al., 2021). Studies have combined GPS data with automated activity sensors that track head position, jaw movements, and body movements. However, the interpretation of this data often categorizes the animal as either active (feeding or walking) or inactive (resting), without further nuance (Schlecht et al., 2004).

Table 2-Examples of integration of GPS and Additional Technologies in Livestock and Wildlife Tracking

Species	Technology	Aim	References
Beef/cattle	GPS collars, pedometers and heart rate sensors	to compare BeefmasterSimford crosses and Baladi cattle grazing behaviour	(Aharoni, et al., 2013).
sheep and cattle	sensors that logged animal positions and urine volumes	To study the correlation between grazing and urination	(Betteridge et al., 2010).
sheep	headmounted 3D activity meters, as well as 2D activity meters and GPS receivers,	to evaluate the animals' ability to find and feed on high-quality forage patches	(Virgilio et al., 2018)
Sheep	GPS, LiDAR, VNIR	To monitor spatial behavior of grazing sheep	(Plaza, et al., 2022).

2.4.3 Challenges and Innovations in GPS Technology for Livestock Management

GPS technology offers substantial benefits for livestock management but faces significant challenges that hinder its widespread adoption and effectiveness. One primary obstacle is the high cost of GPS-embedded devices, which makes them economically unfeasible for many farmers (C. Aquilani et al., 2022).

Innovations such as low-cost collars made from commercial off-the-shelf components have been developed to address this issue. However, these alternatives often suffer drawbacks like limited battery life and lack of wireless data transmission capabilities (Karl & Sprinkle., 2019).

Battery lifespan remains critical, particularly in remote rangeland environments where frequent manual interventions for battery changes are impractical. Solar-powered GPS devices have been introduced to mitigate this issue, enabling continuous tracking throughout the grazing season without the need for frequent battery replacements (C. Aquilani et al., 2022).

The accuracy of GPS positioning can vary widely due to factors such as satellite coverage, topography, and device type, impacting the reliability of location data. This variability leads to two main types of errors: unsuccessful fixed acquisitions, resulting in missing location data, and location inaccuracies, leading to incorrect data (D'Eon et al., 2002).

GPS tracking in rugged terrains with steep gorges and dense vegetation also presents significant limitations. In these environments, signal reception is often compromised, particularly for robust collars that rely on standard batteries. These constraints affect the precision needed for detailed behavioural studies, making them unsuitable for high-resolution tracking of free-ranging animals (Buerkert & Schlecht., 2009).

To enhance tracking reliability, integrating GPS with barometric devices offers a promising solution by compensating for altitude-related inaccuracies in GPS data (Buerkert & Schlecht., 2009). Furthermore, combining GPS with accelerometers enhances dead reckoning techniques, improving the accuracy of estimating animal paths and potentially reducing the frequency of GPS fixes required, thus extending the battery life of the devices (D'Eon et al., 2002).

3. STUDY AREA AND METHODOLOGY

3.1.Description of the Montesinho Natural Park

According to (ICNF, 2019), the park's description will be covered in the following sections:

3.1.1 Classification

The Montesinho-Coroa mountain range, known for its natural beauty and cultural heritage, was designated as a Natural Park by Decree-Law No. 355/79. This designation aims to protect the region's natural, scenic, and cultural values and promote socio-cultural activities.

Decree-Law No. 19/93 required the reclassification of the Montesinho Natural Park to align with new criteria for protected areas. Regulatory Decree No. 5-A/97 justified this reclassification due to the area's significant and relatively stable and European fauna population, including many threatened species, and essential natural vegetation. The low human impact allows natural ecological processes to continue, warranting protective measures for this valuable national and European heritage site.

3.1.2 Area and Location

The Montesinho Natural Park covers 74,229 hectares in northeastern Portugal, situated in a well-defined quadrilateral within the Sanabria region of Spain. It encompasses the Montesinho and Coroa mountain ranges, including the northern parts of Bragança and Vinhais municipalities. The park borders Spain to the north, east, and west. It is confined between longitudes 6º 30' 53" W and 7º 12' 9" W and latitudes 41º 43' 47" N and 41º 59' 24" N.

3.1.3 Geology and Geomorphology

The park is part of the complex geology of the Northwestern Iberian Peninsula. The region features polymetamorphic allochthonous complexes composed of stacked tectonic units overlying Paleozoic metasediments. The Bragança Massif, one of the five complexes in the Iberian Peninsula, contains exotic rocks from the Earth's crust and mantle, including granulites and metaperidotites, which resulted from a tectonic collision approximately 410 million years ago.

In the park’s eastern sector, the landscape evolution is heavily influenced by tectonics. The geomorphology north of Bragança is shaped by faults associated with the Bragança-Vilariça-Manteigas (BVM) fault line, oriented NNE-SSW. The Portelo fault, part of the BVM fault system, caused the uplift of a block to the west and the subsidence of a block to the east. This fault created a flat area at 850-900 meters elevation in the Espinhosela-Donai region and increased altitude towards the north in the Montesinho mountain range (1486 meters at the border). The subsided block features the Baçal surface to the south (600-700 meters) and the Aveleda surface to the north (800-900 meters), formed in late-Tertiary sediments and tilted southward. Additional faults in the east control the elevation of the Babe-Deilão plateau (800-900 meters), known locally as Alta Lombada.

3.1.4 Hydrology

The park’s hydrographic network is dense, comprising significant rivers, their tributaries, and numerous streams and torrential watercourses. It belongs to the Douro River basin, specifically the Tua and Sabor river basins, which include headwater sections of the main rivers and some medium and small tributaries.

Key rivers flowing through the park, from west to east, are the Mente, Rabaçal, Tuela, and Baceiro (part of the Tua basin), and the Sabor, Igrejas, Onor, and Maçãs (part of the Sabor basin). The Mente river joins the Rabaçal, which then merges with the Tuela near Mirandela to form the Tua river. The Igrejas river is a tributary of the Onor, which flows into the Sabor at Gimonde; the Sabor and Maçãs confluence occurs downstream at the borders of Bragança, Vimioso, and Mogadouro municipalities.

Most major watercourses originate in Spain, with some having substantial stretches there (e.g., 25 km of the Tuela, 19 km of the Maçãs, 18.5 km of the Mente, and 11 km of the Rabaçal). The Sabor river is predominantly Portuguese, with only a 2 km stretch in Spain. The Mente river flows along the border for 9.5 km of its 16.5 km within the park, and the Maçãs river flows entirely along the border for 21 km.

3.1.5 Climate

The climate in Trás-os-Montes is influenced by a mountain chain stretching from Alto Minho to Alvão-Marão, combined with other lower mountain ranges like the Montesinho, Coroa, and Nogueira. The region is shielded from maritime influences by these geographic barriers and further isolated by the Galaico-Duriense and Cantabrian mountains to the north and the Castilian-Leonese plateau and Beirão plateau to the south.

The area experiences a macroclimate with continental characteristics, summarized by the local saying, "nine months of winter and three months of hell," reflecting a Mediterranean climate with a pronounced summer drought. Annual mean temperatures range from 8.5ºC in the Montesinho mountain range to 12.8ºC in Baixa Lombada. Maximum and minimum temperatures vary between 5-7ºC and 14-17ºC, respectively. Temperature inversions frequently occur in winter and spring, leading to lower minimum temperatures in valleys compared to higher altitudes, resulting in greater diurnal and annual temperature ranges in deeply embedded valleys.

Annual precipitation follows a Mediterranean pattern, with 72% falling between October and March. The highest annual precipitation occurs in the highest altitudes (1215.6 mm in Moimenta and 1262.8 mm in Montesinho) and the western part (1075.1

mm in Vinhais), decreasing significantly towards the east (806 mm in Deilão) due to the Föhn effect as air masses lose moisture crossing the high terrain.

Wind speeds are highest from February to May, with the lowest values in winter, indicating more frequent stable conditions in winter compared to summer. The predominant wind direction is from the west throughout the year.

The eastern areas experience higher temperatures and lower precipitation, while the Montesinho and Coroa ranges have lower temperatures and higher precipitation. Consequently, soil moisture deficits last four months (June-September) in the east and three months (July-September) in the central and western areas. The well-defined winter affects the region's ecological and agricultural systems, with frost being a significant factor. The first frosts occur in early October and the last in late May, defining a frost-free period from mid-May to early October. Spring frosts limit primary productivity and affect crop yields, while autumn frosts mark the end of the growing season, with minimal impact on chestnut harvests.

3.1.6 Flora

The Montesinho Natural Park boasts a rich variety of vegetation observable within short distances. Key vegetation types include:

- Oak forests (dominated by *Quercus pyrenaica*)
- Chestnut groves
- Riparian woods
- Heathlands
- Meadows

The oak forests extend to the Serra da Nogueira, forming one of species most prominent and significant stands of this species. The diverse geology and climate further enhance plant life, with some species unique to the ultrabasic rock-derived soils.

3.1.7 Fauna

The park's varied habitats support a high level of biological diversity. Over 110 breeding bird species, including birds of prey like the golden eagle (*Aquila chrysaetus*), are found in these habitats, with 3-4 pairs representing about 10% of Portugal's population. Additionally, 70% of Portugal's terrestrial mammal species inhabit these forests, including significant populations of the Iberian wolf (*Canis lupus*). Around 10% of these species are listed as threatened in the Portuguese Red Book of Vertebrates. Furthermore, 50% of the Iberian endemic reptiles and amphibians found in mainland Portugal are also present in these oak forests.

3.1.8 Sociocultural Heritage

Montesinho Natural Park is rich in sociocultural heritage, maintaining traditional practices and festivities despite modern influences. Key aspects include:

- Traditional festivals like the "Festas dos Rapazes," held around Christmas or Epiphany, particularly in the Lombada area. These festivals are vital for community bonding and cultural preservation.
- Traditional music, especially bagpipes, is a staple of local celebrations.
- Remarkable examples of popular architecture, reflecting centuries of environmental adaptation. Noteworthy structures include dovecotes, mills, and forges, all built using locally sourced materials and traditional techniques.

3.2.Description of the study area

3.2.1 Location

The study site is Montesinho Natural Park a part of the Natura 2000 Site of Community Importance (SIC) Montesinho/Nogueira, in northeastern Portugal.

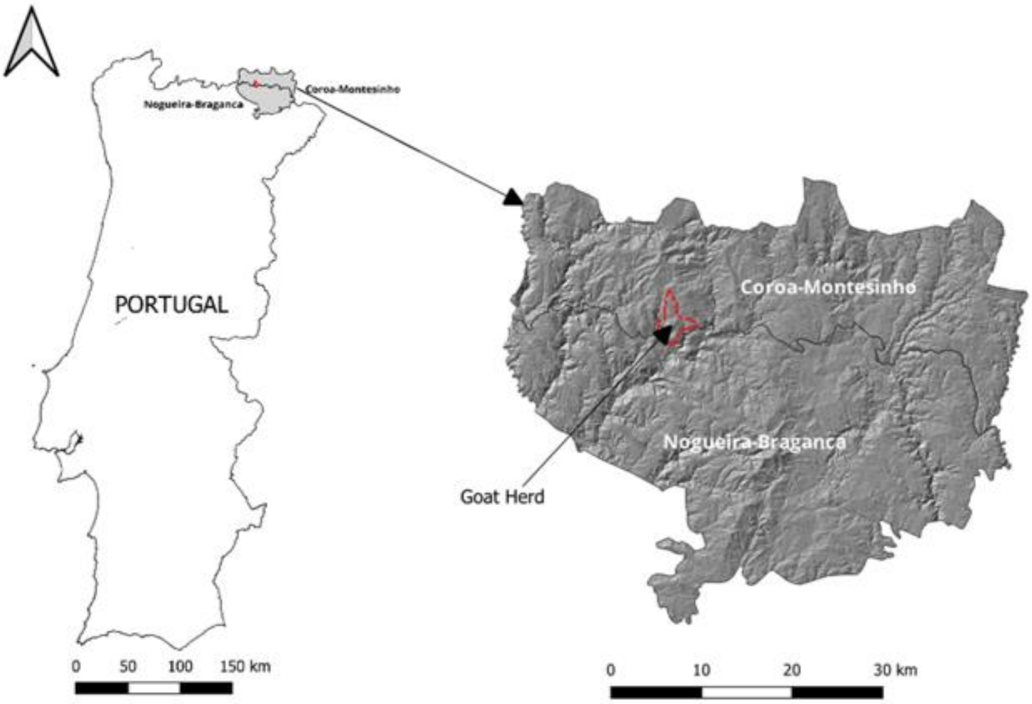


Figure 1-Location of the study area

The table below details the corral's location and elevation for the goat herd, indicating that it is positioned at coordinates 41.83761947N, -6.98525927E, at an elevation of 823 meters, and is used for the Preta de Montesinho breed.

Table 3-Location, altitude and breed and size of the experimental herd

Herd	Corral location (ESPG:4326-WGS 84)	Elevation at the corral (m)	breed
Goat	41.83761947N,-6.98525927E	823	Preta de Montesinho

3.2.2 Elevation and grazing itinerary

The elevation in the study area ranges from 574 to 1088 meters, with higher elevations in the north and lower elevations in the south. Goats traverse various elevations as they adapt to the different terrains.

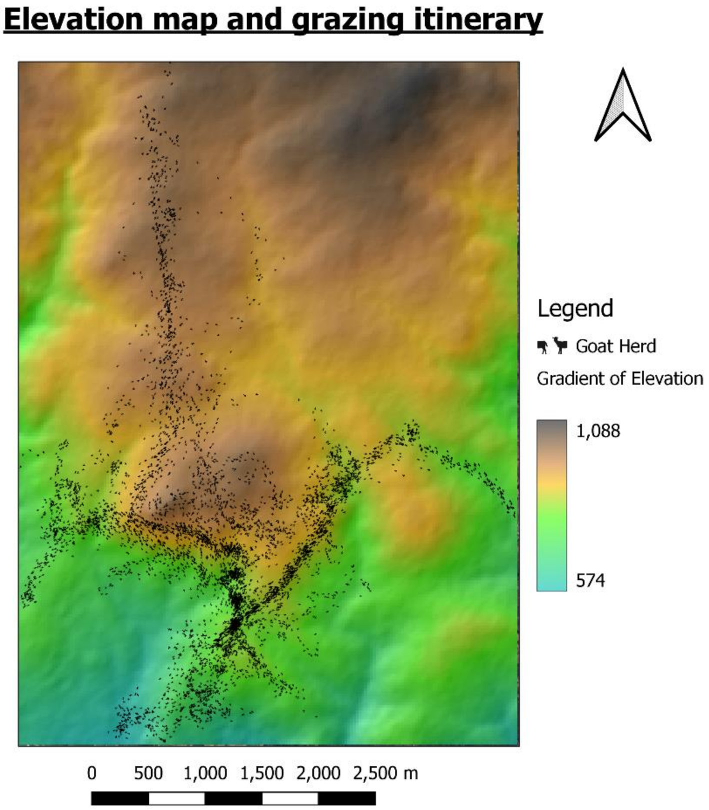


Figure 2-Elevation map and grazing itinerary in the study area

3.2.3 Topographic wetness index and grazing itinerary

The Topographic Wetness Index (TWI) is a widely used hydrological metric that characterizes the propensity of a landscape to accumulate water. It is instrumental in identifying wetland areas based on slope and contributing area factors. Areas with higher TWI values are indicative of higher wetness potential compared to areas with lower values (Deenik., 2021).

Our map results indicate that in our area, the TWI ranges from 3.7 to 19.38. This suggests that there are varying levels of wetness potential across the landscape.

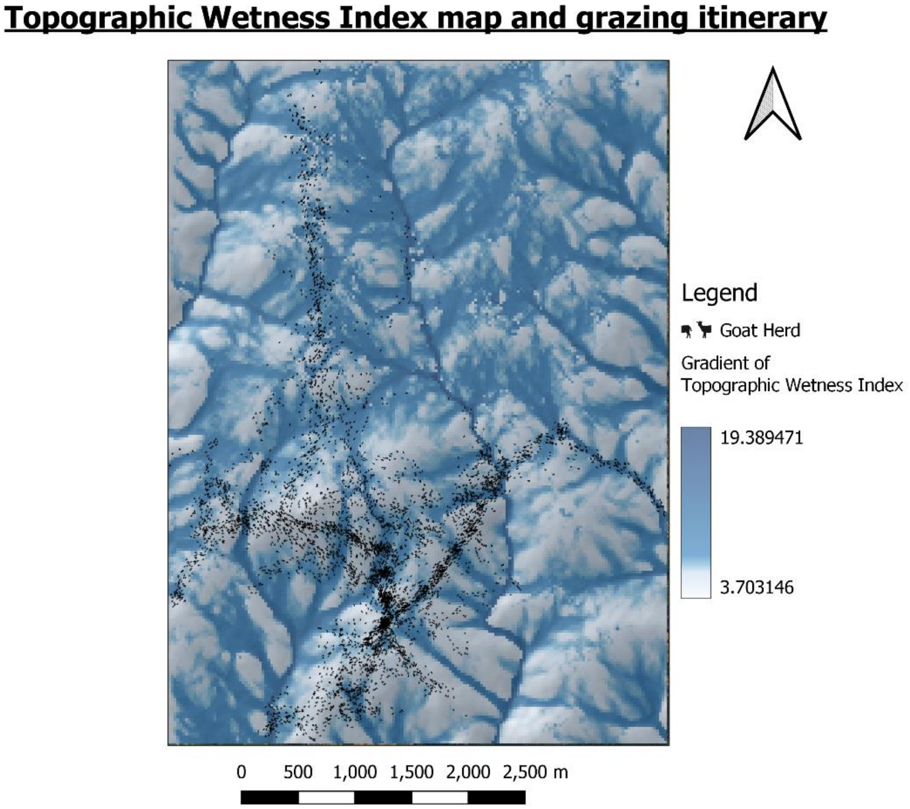


Figure 3-Topographic wetness index map and grazing itinerary in the study area

3.2.4 Relative Slope Position and grazing itinerary

Relative Slope Index (RSI) is a terrain parameter that synthesizes the elevation characteristics above channel lines and below ridges. It produces values ranging from 0 to 1, with 0 representing channel lines and 1 indicating terrain ridges (Bock & al., 2007).

Our goats excel on both steep and moderate slopes. They efficiently navigate challenging inclines and graze comfortably on gentler terrains, showcasing their adaptability and resilience across varied landscapes.

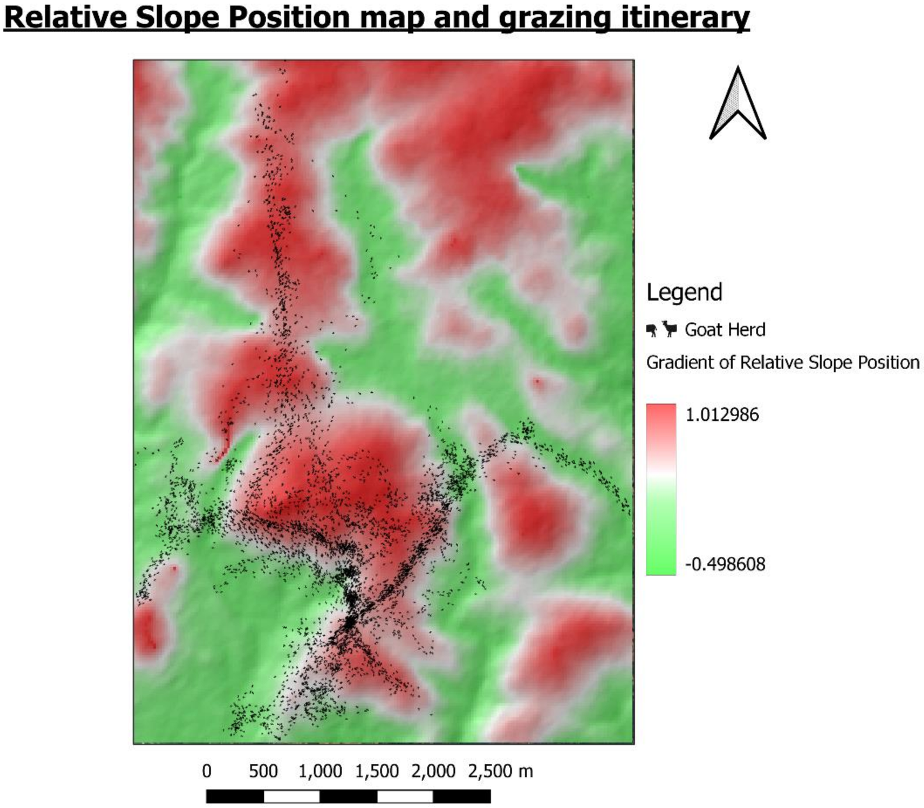


Figure 4-Relative slope position map and grazing itinerary in the study area

3.2.5 Land uses and grazing itinerary

Our study area is predominantly dominated by temporary rainfed and irrigated crops, which account for 36% of the land use. Oak forests make up the next most considerable portion at 31%. Orchards, which are expected to be chestnuts (*soutos*), comprise 15% of the area. This land-use is followed by the shrubs at 11% and Maritime pine forests at 4%. Chestnuts forests and improved pastures represent the most minor portions at 3%. Land uses with percentages less than 3% were excluded.

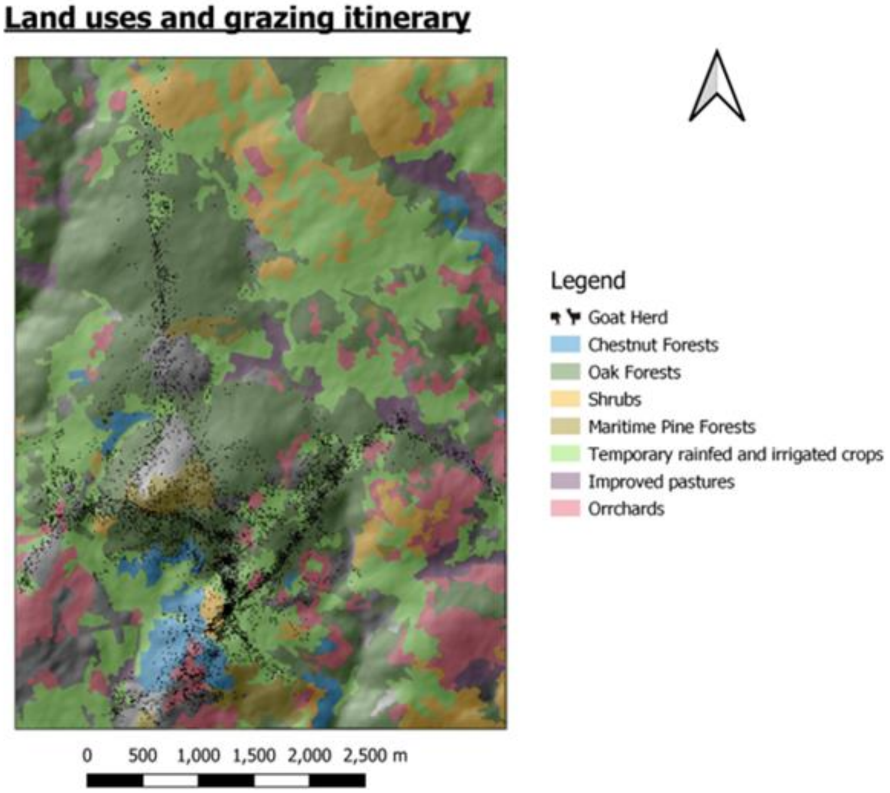


Figure 5-Map overlaying the experimental goat herd with land use and relief in the study area

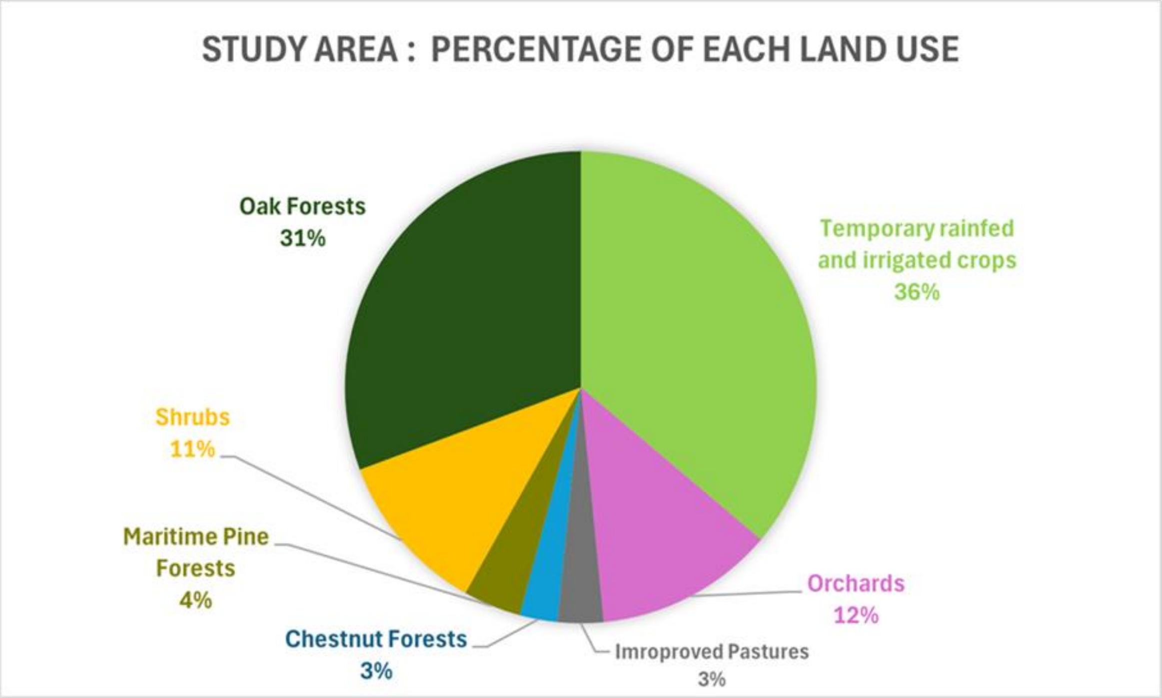


Figure 6-Pie chart showing the percentages of land uses in the study area

3.2.6 Description of the breed Preta de Montesinho

According to the General Food and Veterinary Directorate (Afonso et al., 2010), the breed is described in the following points.

Figure 6-Image of the Preta de Montesinho Breed

Source : https://ter-ra.pt/pt/racas/cabra-preta-de-montesinho/

3.2.6.1 Origins and Naming

The Black Goat of Montesinho, officially named "Cabra Preta de Montesinho," is associated with the Montesinho Natural Park in northeastern Portugal. Historically known as the Ancient Goat, Galega, Bragançana, or Black Goat, it is a significant symbol of the region.

3.2.6.2 Geographic Distribution

The breed is primarily found in the northeastern Portuguese municipalities of Bragança (15 breeders), Vinhais (4 breeders), and Vimioso (2 breeders). In the past, it was also prevalent in Macedo de Cavaleiros and Alfândega da Fé. Recently, interest in this breed has spread to other areas, including Amarante, Santa Marta de Penaguião, Mondim de Basto, Carrazeda de Ansiães, and Vila Velha do Rodão.

3.2.6.3 Recovery Efforts

Despite challenges, The Goat of Montesinho population has been slowly recovering. The establishment of the breed's genealogical book in January 1998 and recognition as an indigenous breed in 2009 have been crucial. This recognition allowed breeders to benefit from Agro-Environmental support measures, helping to prevent the breed's decline.

3.2.6.4 Morphological and Functional Characteristics

- General Appearance: Medium stature, with an average height of 69 cm in females and 77 cm in males. They have dark, short, and smooth hair.
- Head: Medium-sized, long, with a straight profile. Small horns when present, directed backward in a saber shape.
- Skin and Coat: Black to very dark brown, with short, smooth, often shiny hair.
- Body: Almost straight backline, well-developed udder with large teats.
- Limbs: Thin, strong, with small, hard hooves.

3.2.6.5 Breeding and Uses

The breed's prolificacy is 1.4, and the kids reach an average weight of 8.96 kg at 70 days. Milk production is diverse, with some farms producing 100-110 litres over 150 days.

3.2.6.6 Historical Challenges

A survey in 1999, supported by the Montesinho Natural Park and later by the Directorate-General for Veterinary in 2004, highlighted a significant decline in breeders and herd sizes due to desertification and population aging. The lack of milk collection and cheese production facilities further led to the abandonment of larger herds.

3.2.6.7 Traditional and Current Uses

Figure 7-Preta de Montisinho Goat Herd with their shepherd in a forest

Source : https://ter-ra.pt/pt/racas/cabra-preta-de-montesinho/

Traditionally, two main systems existed for raising these goats:

- Meat Production: Smaller goats in communal herds grazing in higher, poorer areas.
- Milk Production: Larger goats in more fertile areas with good milk yield.

Today, these goats are dual-purpose, raised for both meat and milk. The kid goat, known as "Cabrito Branco de Montesinho," is a gastronomic specialty due to its tender, light-coloured meat. Small herds still exist near homes, serving as a dairy source for the less affluent, often integrated with Churra Galega Bragançana sheep flocks.

3.2.6.8 Managing entity

ANCRAS, founded on May 28, 1990 – DR nº 20 of 24-01-1991.Since 1992, it was officially recognized as the managing entity of the Breed Genealogical Book Caprina Serrana at the national level. On January 21, 2010, he was granted the Registration Montesinho Black Goat (http://www.ancras.pt/).

3.3.Methodology

3.3.1 Data Acquisition

GNSS tagging was implemented on one animal per herd using DOMODIS collars, which utilize GPS technology for positioning and GLOBALSTAR technology for communication. The collars are powered by lithium-ion batteries (3.7 volts, 7.8 Ah) and have dimensions of 115 mm in length, 65 mm in width, and 40 mm in height, with a total weight of 750 g. The ratio of collar weight to animal weight is less than 1.5%, ensuring animal acceptance. Position data is collected every 5 minutes and transmitted via satellite to a web platform, except when the animal is stationary, in the corral, or experiencing technical issues. Battery failures are reported by shepherds approximately every two months, after which the batteries are recharged. However, occasional failures can lead to data loss. The positioning accuracy of these collars is estimated to range from 2 to 10 meters (Castro et al., 2022).

The use of one positioning collar per herd with a 5-minute data collection interval has been validated by prior research conducted by Castro et al. (2022), confirming its effectiveness for monitoring and data accuracy.

The data were acquired from the online platform "DOMODIS" in CSV format, including each point’s date and time, latitude, and longitude. The data is in two CSV files: one for the year 2022 and the other for 2023. The 2023 data spans from January 15 to June, while the 2022 data spans from January to November. We chose a one-year interval from April 2022 to March 2023 to include the maximum number of itineraries and records.

The total dataset includes the time, date, and geographical position of the animal, and the name of the shepherd. The GPS data was imported as a table into QGIS software, along with study area's land use map and the digital elevation model (DEM).

The land use map was sourced from the Land Use and Land Cover Map 2018 (COS2018v2.0), produced by the General Directorate of Territory of Portugal. This map provided detailed information on the land uses of Portugal in 2018 and was crucial for our study of land use by the goat herd.

The Digital Elevation Model (DEM) was acquired and projected into the Portuguese national map projection PT-TM06 of datum ETRS89 (EPSG:3763) using the GDAL command Gdalwarp, with a pixel size of 25 meters.

3.3.2 Data Cleaning and Preparation

To ensure the integrity of our dataset, we employed a comprehensive cleaning and visualization process using QGIS and Excel.

We started by displaying our data in QGIS, which allowed us to visualize the geographic distribution of data points and identify anomalies. By examining the data day by day and adding time labels, we could pinpoint and remove nighttime data, isolated points, and daily datasets with fewer than 20 positions. This meticulous approach ensured that only relevant and accurate data points were retained for further analysis.

Next, we used Excel to detect additional anomalies. We created a graph where the x-axis represented records and the y-axis represented recording times. This visualization technique allowed us to spot and address any remaining anomalies, enhancing the overall data accuracy.

Finally, we addressed the datetime information, which was initially in 'string' format. Using the QGIS Field Calculator, we converted these strings into 'datetimes' and further separated them into distinct date and time variables using the 'to_datetime', 'to_date', and 'to_time' functions. This step was crucial for accurate temporal analysis in subsequent phases.

3.3.3 Data Processing

3.3.3.1 Extracting and Calculating Variables

Following data cleaning and preparation, we extracted and calculated various physical, temporal, and land use variables. As well as the Sanon diversity index H’.

3.3.3.1.1 Extracting Land Use Information

To determine the type of land use for each GPS-recorded point, we used the "Join by Location" tool in QGIS. This process involved merging the GPS data with the land use map data, facilitating the identification of land use types for each point. We then exported the joined layer to an XML file for further analysis.

We created a pivot table in Excel to analyze the number of points per land use category for each date. The rows represented dates, while the columns represented land use categories. This arrangement provided a clear view of the points corresponding to each itinerary and land use category.

3.3.3.1.2 Calculating the Shannon Diversity Index (H')

The Shannon Diversity Index (H), also known as the Shannon-Wiener Index, quantifies species diversity within a community. It is calculated using the formula:

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

Figure 8-The Shannon-Wiener Diversity Index, or entropy, equation.

Σ: A Greek symbol meaning "sum"
***ln*:** Natural log
p $_i$**:** The proportion of the entire community composed of species *i*

Higher values of H indicate more species diversity, whereas lower values signify less diversity, with H = 0 indicating a community composed of a single species.

To calculate the SDI for each itinerary, we based the calculations on the number of records for each land use category for each daily itinerary. This calculation involved compiling the counts of land use records and applying the Shannon Diversity Index formula to derive the SDI.

3.3.3.1.3 Calculating Temporal Variables

To calculate the temporal variables, we followed the steps outlined below.

3.3.3.1.3.1 Converting Points to Paths

We utilized the "Point to Paths" tool in QGIS to convert the cleaned GPS points into daily itineraries. This new layer provided a comprehensive view of the daily paths, including the start and return times to the corral.

3.3.3.1.3.2 Calculating Durations and Lengths

Using the QGIS Field Calculator, we calculated the duration of each itinerary by applying specific field expressions. Additionally, we calculated the length of the paths using the '$length' expression due to its straightforward calculation.

3.3.3.1.3.3 Exporting and Further Calculations

We exported the processed data to an XML file and performed additional time-related calculations in Excel. It included determining the Absolute value of differences between itinerary and standard times (e.g., 6 AM, 12 PM). Furthermore, we calculated the days between the itinerary dates and the equinoxes/solstices of the previous, current, and following years, selecting the minimum difference to the nearest solstice or equinox.

3.3.3.1.4 Extracting Physical Variables

We first clipped the Digital Elevation Model (DEM) to the area of interest to extract physical variables. Using the 'Basic Terrain Analysis' tool in SAGA GIS, integrated within QGIS, we extracted variables such as altitude, Topographic Position Index (TPI), and Relative Slope Position (RSP).

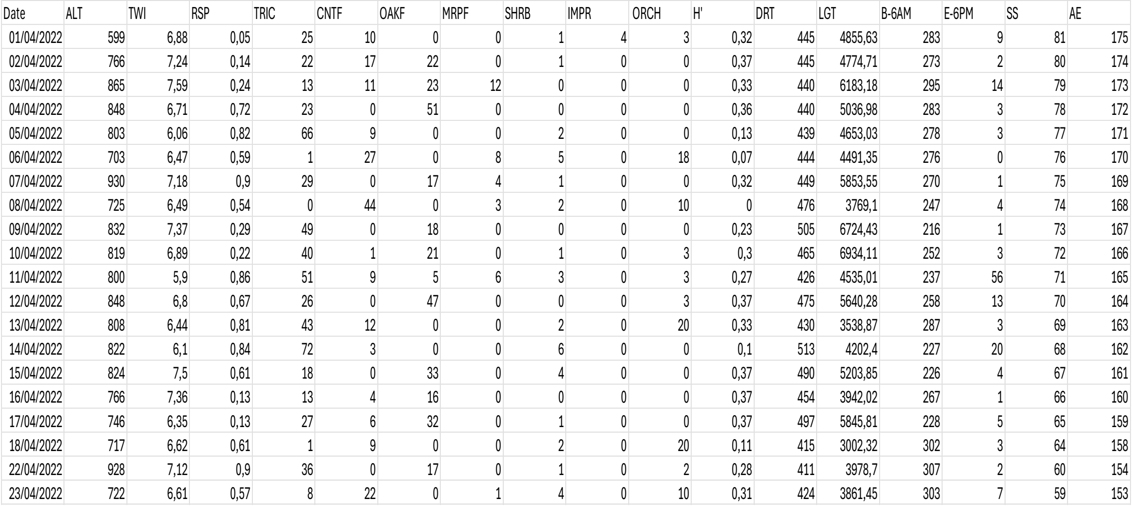
SAGA GIS (System for Automated Geoscientific Analyses) is a comprehensive open-source geographic information system for geospatial analysis and data processing. It offers a wide range of tools for terrain analysis, hydrological modeling, and other geoscientific applications. When integrated within QGIS, SAGA GIS enhances QGIS's capabilities by providing additional functionalities for advanced spatial analysis.

Using the 'Sample Raster Value' tool in QGIS, we assigned the extracted physical variables (altitude, TPI, and RSP) to the corresponding GPS points. Subsequently, using the ‘GroupStats’ plugin in QGIS, we calculated the daily median values of each variable for the grazing itineraries.

This process ensured that every GPS point had the essential physical attributes required for subsequent analysis.

3.3.3.1.5 Final Data Preparation

We prepared a comprehensive dataset containing all the variables for each itinerary, treating each itinerary as an individual record. This dataset was structured to facilitate a Principal Component Analysis (PCA) uncover underlying patterns and relationships within the data.



Date	ALT	TWI	RSP	TRIC	CNTF	OAKF	MRPF	SHRB	IMPR	ORCH	H'	DRT	LGT	B-6AM	E-6PM	SS	AE
01/04/2022	599	6,88	0,05	25	10	0	0	1	4	3	0,32	445	4855,63	283	9	81	175
02/04/2022	766	7,24	0,14	22	17	22	0	1	0	0	0,37	445	4774,71	273	2	80	174
03/04/2022	865	7,59	0,24	13	11	23	12	0	0	0	0,33	440	6183,18	295	14	79	173
04/04/2022	848	6,71	0,72	23	0	51	0	0	0	0	0,36	440	5036,98	283	3	78	172
05/04/2022	803	6,06	0,82	66	9	0	0	2	0	0	0,13	439	4653,03	278	3	77	171
06/04/2022	703	6,47	0,59	1	27	0	8	5	0	18	0,07	444	4491,35	276	0	76	170
07/04/2022	930	7,18	0,9	29	0	17	4	1	0	0	0,32	449	5853,55	270	1	75	169
08/04/2022	725	6,49	0,54	0	44	0	3	2	0	10	0	476	3769,1	247	4	74	168
09/04/2022	832	7,37	0,29	49	0	18	0	0	0	0	0,23	505	6724,43	216	1	73	167
10/04/2022	819	6,89	0,22	40	1	21	0	1	0	3	0,3	465	6934,11	252	3	72	166
11/04/2022	800	5,9	0,86	51	9	5	6	3	0	3	0,27	426	4535,01	237	56	71	165
12/04/2022	848	6,8	0,67	26	0	47	0	0	0	3	0,37	475	5640,28	258	13	70	164
13/04/2022	808	6,44	0,81	43	12	0	0	2	0	20	0,33	430	3538,87	287	3	69	163
14/04/2022	822	6,1	0,84	72	3	0	0	6	0	0	0,1	513	4202,4	227	20	68	162
15/04/2022	824	7,5	0,61	18	0	33	0	4	0	0	0,37	490	5203,85	226	4	67	161
16/04/2022	766	7,36	0,13	13	4	16	0	0	0	0	0,37	454	3942,02	267	1	66	160
17/04/2022	746	6,35	0,13	27	6	32	0	1	0	0	0,37	497	5845,81	228	5	65	159
18/04/2022	717	6,62	0,61	1	9	0	0	2	0	20	0,11	415	3002,32	302	3	64	158
22/04/2022	928	7,12	0,9	36	0	17	0	1	0	2	0,28	411	3978,7	307	2	60	154
23/04/2022	722	6,61	0,57	8	22	0	1	4	0	10	0,31	424	3861,45	303	7	59	153

Figure 9-Overview of the prepared Data for computing the PCA

3.3.4 Statistical Analyses

3.3.4.1 Statistic descriptive:

In our analysis, we calculated various descriptive statistics such as the mean elevation, Topographic Position Index (TPI), Shannon Diversity Index (H'), and Relative Slope Position.

3.3.4.2 Inferential statistics

3.3.4.2.1 R/RStudio Overview and Packages

R is an open-source software environment known for statistical computing and graphics. It is widely used by statisticians, data analysts, and researchers due to its extensive support for statistical techniques and graphical methods. It was operating on

UNIX, Windows, and MacOS, R benefits from a rich ecosystem of packages developed by a global community.

RStudio is an integrated development environment (IDE) tailored for R, enhancing productivity with features like an intuitive interface, code debugging, package management, and integration with version control systems. It simplifies data analysis workflows across operating systems, offering efficient script organization and output management.

R's functionality is extended through packages containing functions, datasets, and documentation for various analytical tasks. These packages range from basic statistics to advanced machine-learning algorithms and visualization techniques. Users can expand R's capabilities by installing packages from repositories like CRAN, ensuring adaptability to diverse analytical needs.
(Grolemund., 2014).

3.3.4.2.2 Correlation study

Before computing PCA, we analyse the correlations between variables to detect strong correlations, which can lead to redundancy in the data. Identifying strong correlations is crucial because highly correlated variables provide redundant information, potentially skewing the principal components' ability to accurately capture unique variance across the dataset accurately.

High correlations between variables indicate that they share similar information, which might inflate the importance of specific dimensions in PCA. It can result in principal components that do not adequately represent the proper underlying structure of the data, as they may be dominated by redundant information rather than capturing distinct patterns or relationships.

3.3.4.2.3 Preliminary Tests Before PCA

Before computing the Principal Component Analysis (PCA), two preliminary tests were conducted to assess the suitability of our data: the Kaiser-Meyer-Olkin (KMO) Test and Bartlett's Test of Sphericity.

3.3.4.2.4 Performing PCA

Principal Component Analysis (PCA) was conducted to uncover relationships among variables and individuals within our dataset. This analytical process was carried out using R and RStudio, starting with meticulous data preparation and quality assurance to ensure data integrity throughout importation.

Several key R packages were utilized to facilitate the PCA implementation and enhance the analysis:

- Psych: Used for conducting the Bartlett and KMO tests, which assess the adequacy of the data for PCA by examining the correlation matrix and sampling adequacy.
- readr: Employed efficient reading and importing rectangular text data into R, ensuring smooth data handling from the initial stages.
- FactoMineR: Facilitated multivariate exploratory data analysis and mining, essential for extracting patterns and relationships from complex datasets through PCA.
- Factoextra: Enhanced the visualization and interpretation of multivariate analysis results, providing clear and insightful representations of PCA outcomes.
- ggcorrplot: Utilized 'ggplot2' for creating visually appealing correlation matrix plots, aiding in the visualization of variable relationships and strengths of associations.

These packages collectively enabled comprehensive data manipulation, visualization, and interpretation of PCA results.

3.3.5 Limitations

The methodology employed in this study, while robust in its approach to understanding goat herd grazing patterns and environmental interactions, is not without limitations that must be acknowledged and addressed to ensure the reliability and validity of our findings.

One significant limitation is potential data interruptions inherent in GPS technology used for tracking goat movements. These interruptions, whether due to battery failures or technical issues, can introduce gaps or inaccuracies in the dataset. Furthermore, rigorous data cleaning procedures were applied during the analysis phase using QGIS and Excel for the identification and removal of unreliable data points. This meticulous approach aimed to preserve data integrity and minimize the impact of interruptions on the overall findings.

Another challenge involves the interpretation of land use categories, particularly those with high percentages of grazing by goats, such as temporary rainfed and irrigated crops. Despite their substantial presence in the study area, these categories may contribute minimally to the Principal Component Analysis (PCA). This discrepancy could potentially skew interpretations of grazing patterns.

Furthermore, the representation of grazing day itineraries in the PCA poses another limitation. Some itineraries may be underrepresented or centrally located in the PCA plot, indicating minimal variance contribution. Despite this, these itineraries were retained in the analysis to maintain a balanced representation across seasons and ensure comprehensive insights into seasonal grazing patterns. Sensitivity analyses and robust statistical methods in RStudio were employed to mitigate biases introduced by uneven seasonal representation, thus enhancing the reliability of our findings.

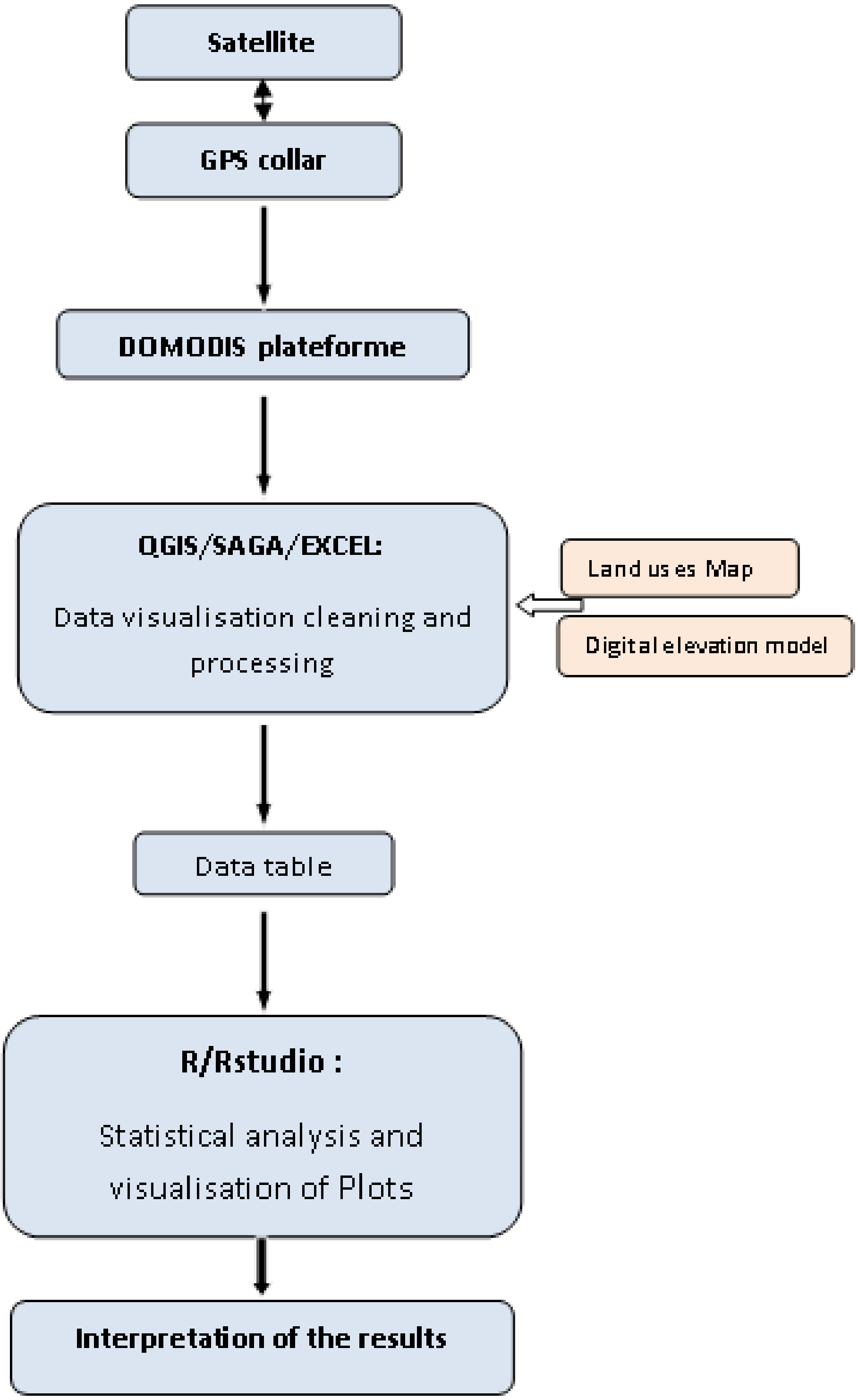


Figure 10-Diagram summarizing the methodology

4. RESULTS AND DISCUSSION:

4.1.Descriptive statistics

The table Below summarizes data on goats, showing a total of 16,389 records initially collected. After database cleaning, 14,929 records remained, indicating that 1,460 records were removed. The goats undertook 232 grazing journeys, and the highest number of records in a single day was 90, occurring on September 18.

Table 4-locations records, number of grazing journeys, and maximum daily record for the experimental goat herd

Herd	Total records	Records after data base cleaning	Grazing journeys	Daily maximum records
Goat	16389	14929(1460)	232	18 September (90)

The scatter plot illustrates the temporal distribution of location data over a year. The data spans from March to April of the following year, revealing patterns in data coverage and variability across months and seasons. Records are consistently captured between 07:00 and 18:00, with fewer observations during early mornings and evenings.

During spring (March to May), there is continuous and dense data collection throughout the day, while summer (June to August) shows a similarly high density of records primarily during daylight hours. Fall (September to November) exhibits steady data collection until mid-October, where a significant gap suggests interruptions. Winter months (December to February) show sparse data, particularly in December, possibly due to weather conditions or holidays. Data collection resumes in January and February, resembling the pattern observed in spring and summer.

Overall, the plot suggests that data collection is more consistent in warmer months, possibly influenced by seasonal factors. The gaps in October and December indicate paused or interrupted data collection. This pattern reflects the daily activity rhythms of the goat herd and highlights potential influences such as weather or logistical factors affecting data continuity throughout the year.

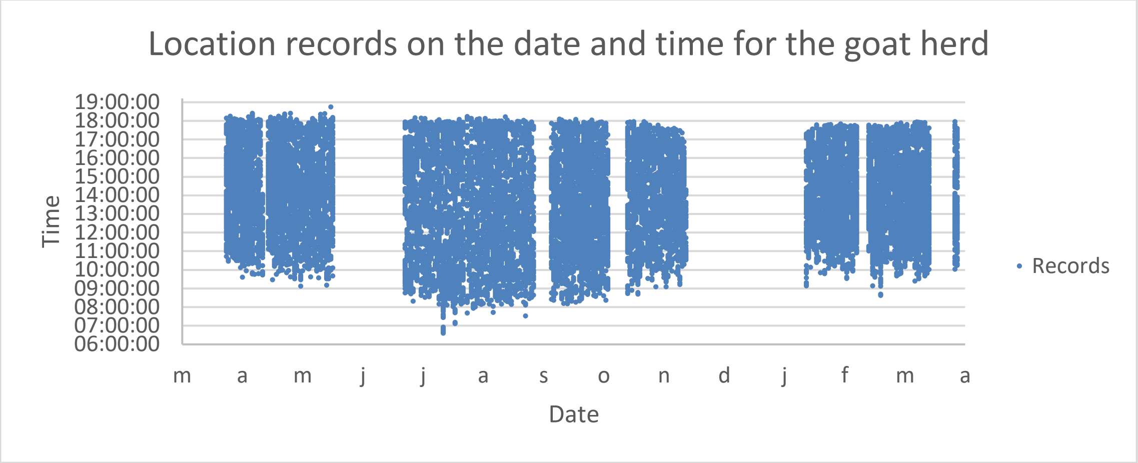


Figure 11-Location records on the date and time for the experimental goat herd

The graph displaying monthly records collected reveals notable seasonal and monthly patterns. June has the lowest number of records, with only 135 entries, indicating data collection interruptions due to equipment failure or environmental conditions. November follows with a relatively low count of 878 records, possibly due to reduced data collection activities or specific seasonal influences.

Moderate record months include January, with 1023 records, suggesting resumed data collection after a sparse December. March shows 1332 records, indicating increasing data collection as spring begins. May, with 1417 records, reflects consistent data collection typical of spring. October has 1396 records, with a slight decline likely due to mid-October interruptions. With 1535 records, September represents steady data collection during the fall season. With 1575 records, February shows a stable collection pattern as winter transitions to spring.

The highest record months are April, July, and August. April has 1883 records, indicating dense data collection during spring. July records total 1904, reflecting peak activity in summer. With 1951 records, August marks the highest data collection, indicating peak summer activity.

The graph shows a higher and more consistent data collection during warmer months (April to August) due to favourable conditions. Significant drops in June and relatively lower counts in November and January suggest potential interruptions or unfavourable conditions. Spring and fall months exhibit steady data collection with slight variations.

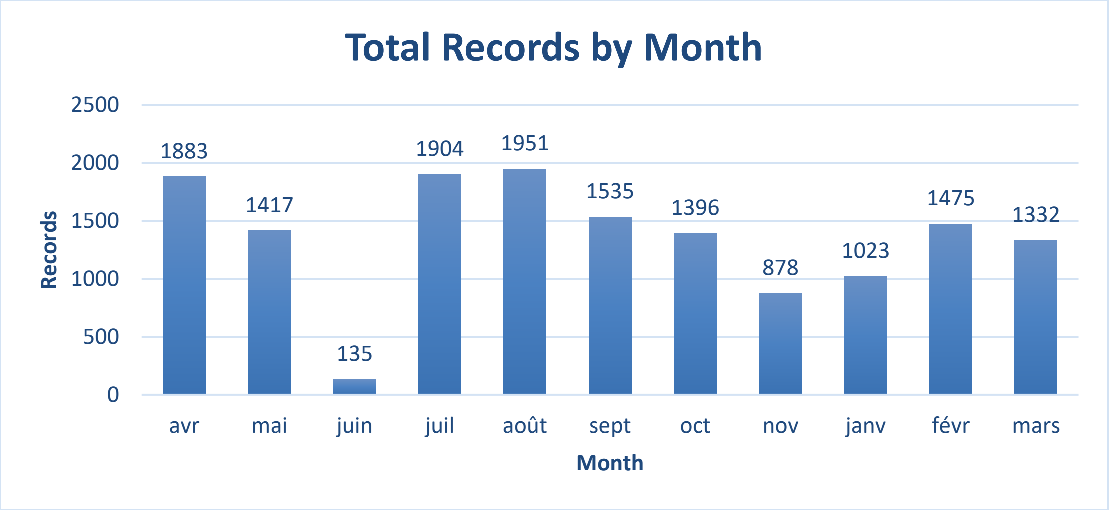


Figure 12-total of monthly records

The grazing land use by goat herds varies significantly across seasons, with Temporary rainfed and irrigated crops (TRIC) and oak forests (OAKF) occupying the largest percentages throughout the year. However, from spring to winter, there is a noticeable decrease in the dominance of Temporary rainfed and irrigated crops in favour of oak forests. Temporary rainfed and irrigated crops peak at 53.11% in spring but decrease steadily to 35.13% in winter, while oak forests increase from 19.70% in spring to 34.54% in winter, reflecting a shift in seasonal preference for browsing and shelter. Chestnut forests (CNTF) and Orchards (ORCH) show a higher percentage during spring and winter compared to autumn and summer, indicating a seasonal preference possibly influenced by flowering and grazing patterns. Improved pastures (IMPR) exhibit higher usage in winter and autumn, followed by summer but not in spring, suggesting seasonal growth patterns and management practices. Maritime Pine forests (MRPF) show a pattern of higher use in winter and autumn, followed by spring and then summer, reflecting seasonal availability and nutritional content. Shrubs (SHRB) display greater variability in autumn and winter compared to summer and spring, likely due to changes in growth and accessibility throughout the year. Overall, these seasonal variations highlight the goats' adaptive grazing patterns in response to changing vegetation types and availability across the seasons.

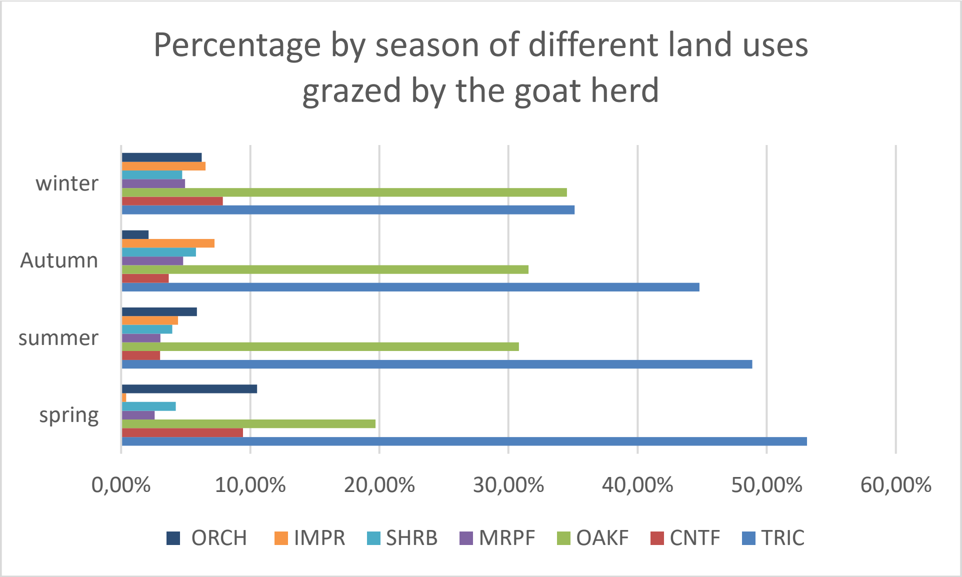


Figure 13-Percentage by season of different land uses grazed by the goat herd

The table below presents the average values of various variables. The average path length is approximately 6 km, with a mean duration of 8 hours and 9 minutes. The average elevation is 833 meters, indicating that goats are moderately grazing in high terrain. The Topographic Wetness Index (TWI) of 7.3 suggests relatively high moisture or wetness, while the Relative Slope Position (RSP) of 0.52 indicates a moderate slope.

Table 5-Mean of relative slope position, Topographic wetness index, elevation, duration and length.

Variables	RSP	TWI	Elevation(m)	Duration (minutes)	Length(m)
Mean	0,52	7,37	833	489	5925

4.2.Inferential statistics

4.2.1 Correlation analysis

Based on the correlation matrix analysis before conducting my PCA, here is the interpretation:

B-12AM has a high correlation with duration, B12PM, and B6PM. E-6AM has a high correlation with E12PM, E12AM, and E6PM. We keep the variables E6PM and B6AM.

B indicates the hour when the herd starts their grazing journey and E indicates the hour when the herd returns to the corral.

We calculated the difference between these two variables at 12PM, 12AM, 6AM, and 6PM. Since some of these variables are correlated with the duration or with each other, we have decided to keep only the two variables, E6PM and B6AM, for further analysis.

For the differences between the grazing day and equinoxes and solstices they are correlated in pairs like WS/SS and VE/AE we keep SS and AE to avoid redundancy.

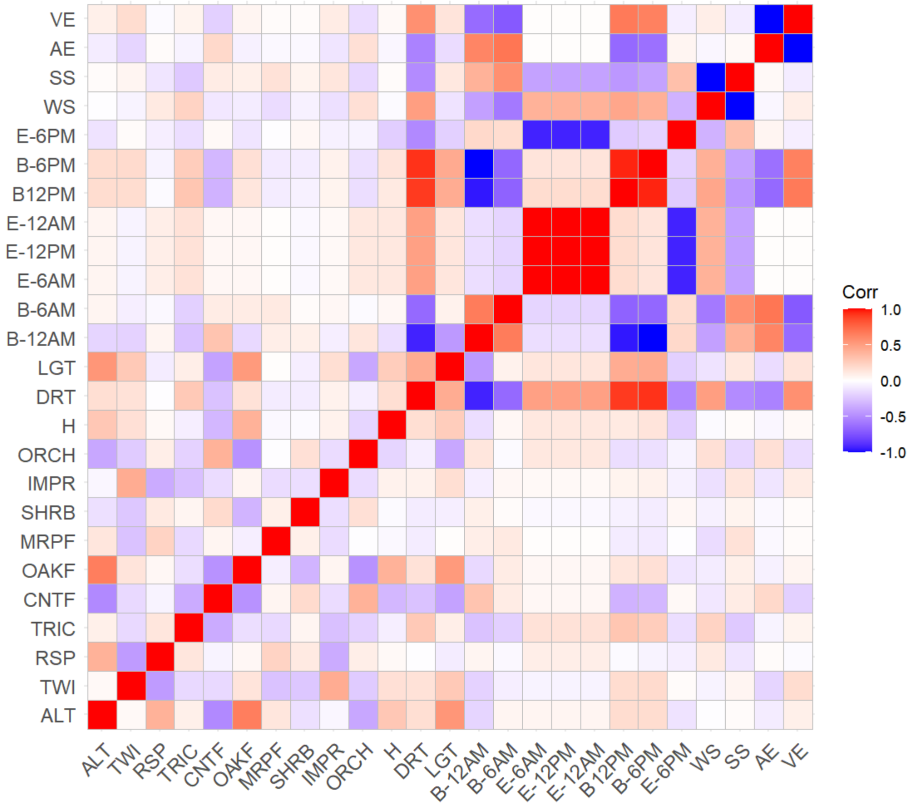


Figure 14-Correlation Matrix

4.2.2 Kaiser–Meyer–Olkin test

The overall MSA of 0.59 indicates moderate variability across the dataset's variables. It supports the application of PCA to effectively reduce dimensionality while preserving significant patterns and relationships within the data.

Each variable's MSA quantifies how much its values deviate or vary from their mean across the dataset. Here are key observations based on the provided MSA values:

- Variables with higher MSAs (e.g., ALT, H', E-6PM) exhibit more significant variability or dispersion in their values across the dataset. For instance, ALT (0.69), H' (0.71), and E-6PM (0.71) indicate that these variables have relatively higher dispersion compared to the average.
- MSA values around the overall MSA (0.59) indicate average variability. Variables such as OAKF (0.59), LGT (0.64), and B-6AM (0.63) fall close to this average, suggesting moderate variability in their values.
- Variables with lower MSAs (e.g., TRIC, MRPF, SS) show less variability in their values. For example, TRIC (0.32), MRPF (0.33), and SS (0.50) suggest that these variables have relatively more consistent or stable values across the dataset.

Table 6-MSA value for each variable

Variables	MSA
H'	0,71
E-6PM	0,71
ALT	0,69
ORCH	0,68
TWI	0,67
DRT	0,67
CNTF	0,64
LGT	0,64
B-6AM	0,63
OAKF	0,59
RSP	0,57
SHRB	0,54
IMPR	0,5
SS	0,5
AE	0,48
MRPF	0,33
TRIC	0,32

4.2.3 Bartlett's Test

Null Hypothesis (H0): The variances across the groups are equal.

Alternative Hypothesis (H1): At least one group's variance is different from the others.

Table 7-Results of Bartlett's Test

Statistic	Value
$\chi 2$	1776.179
p-value	$2.12 \times 10{-}283$
Degrees of Freedom	136

Chi-Square Statistic: The high chi-square statistic of 1776,179 indicates substantial differences in variances among our groups. In Bartlett's test, a higher chi-square value suggests more significant discrepancies in variances.

p-value: The p-value of $2.12 \times 10{-}283$ indicates an extremely low probability that the observed differences in variances are due to random chance. It strongly confirms that the differences are highly significant.

Given the extremely small p-value (much smaller than 0.05), there is strong evidence to reject the null hypothesis. It means that the correlation matrix of variables is significantly different from an identity matrix, indicating that the data is suitable for factor analysis or PCA. In practical terms, this means that meaningful relationships among the variables that can be explored and interpreted through these statistical methods.

4.2.4 PCA Results and interpretation

4.2.4.1 Percentage of variance explained:

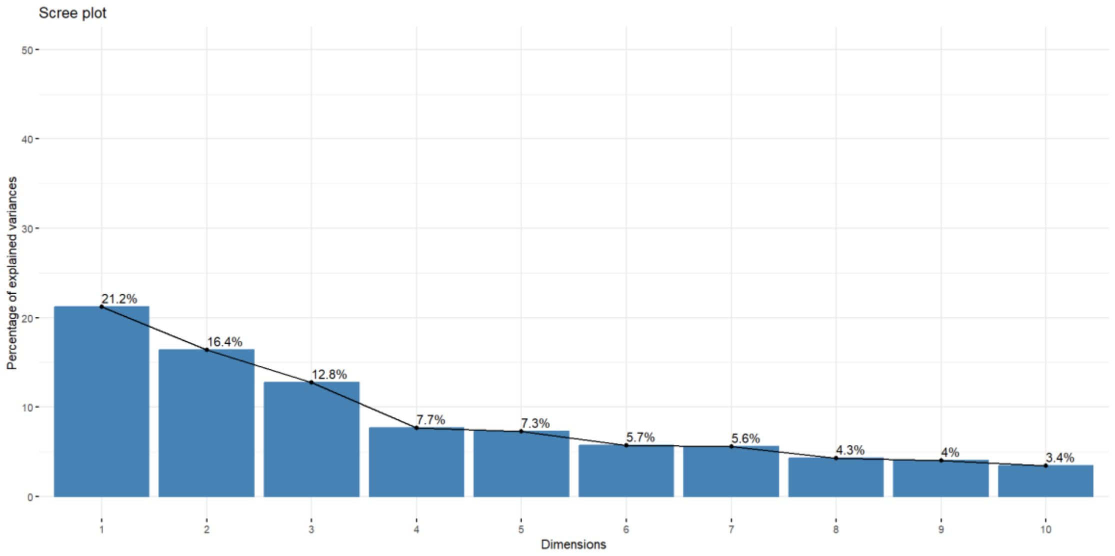


Figure 15-Variance Explained by PCA Axes

For our analysis we will keep the first three axes which explains 50.39% of the total variance.

Table 8-eigenvalues, variance percentage and cumulative variance percentage for the three first dimensions

Dimension	Eigenvalue	Variance (%)	Cumulative Variance (%)
Dim.1	3.61	21.23	21.23
Dim.2	2.78	16.37	37.61
Dim.3	2.17	12.78	50.39

4.2.4.2 Study of Variables

4.2.4.2.1 Contribution Study

Our analysis will focus on the variables that significantly contribute to forming the principal components (axes). Only the variables with high contributions are considered.

4.2.4.2.1.1Axe 1 (Dim1 - 21.2%)

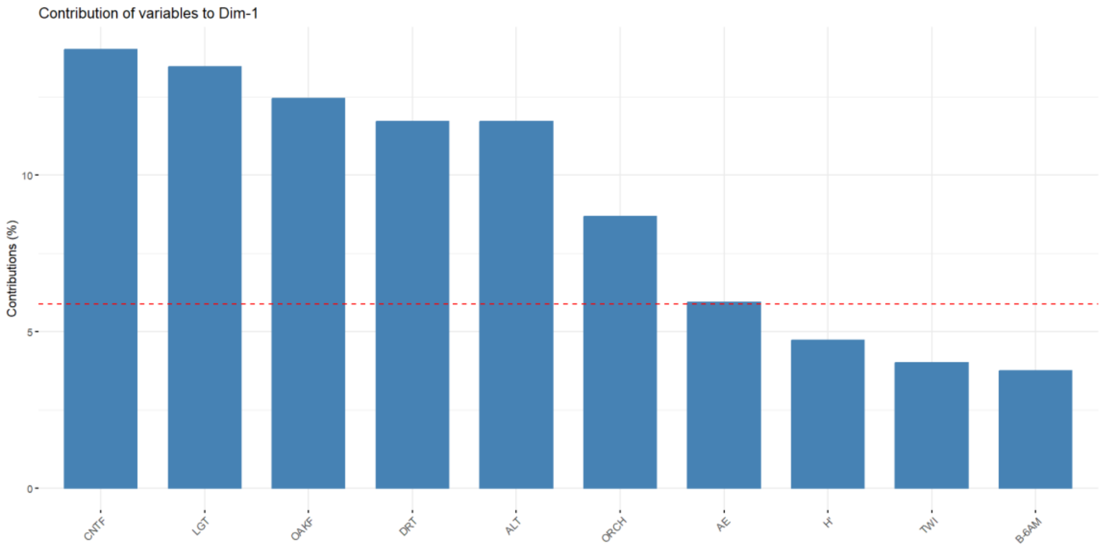


Figure 16-Contribution of variables to Dim 1

The variables that contribute the most to the formation of the first axis are shown in the tables below:

Table 9-Variables Contributing most to Axis 1 formation

Category	Variables
Physical	LGT, ALT
Land Use	CNTF, OAKF, ORCH, H'
Temporal	DRT
Seasonal	AE

4.2.4.2.1.2Axe 2 (Dim2 - 15.6%)

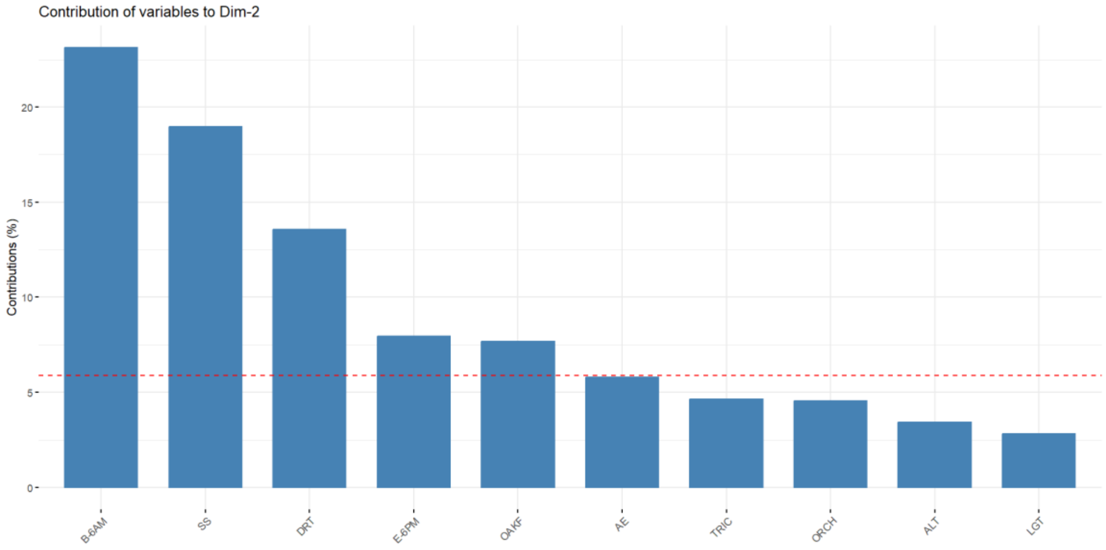


Figure 17-Contribution of variables to Dim 2

The variables that contribute the most to the formation of the second axis are presented in the table below:

Table 10-Variables Contributing most to Axis 2 formation

Category	Variables
Temporal	B-6AM, DRT, E-6PM
Seasonal	SS, AE
Land Use	OAKF

4.2.4.2.1.3Axe 3 (Dim3 - 12,8%)

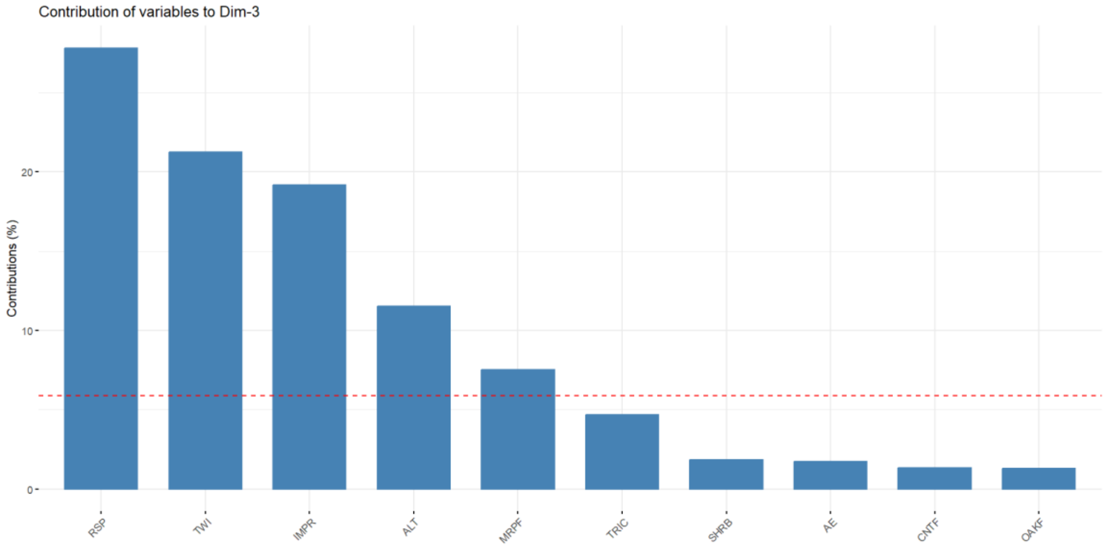


Figure 18-Contribution of variables to Dim 3

The variables that contribute the most to the formation of the third axis are represented in the following table:

Table 11-Variables Contributing most to Axis 3 formation

Category	Variables
Land Use	IMPR, MRPF
Physical	RSP, ALT, TWI

4.2.4.2.2 Studying the correlation between variables and axes:

Table 12-Correlations of variables with the first three principal components

Variables	Dim1	Dim2	Dim3
ALT	0,65	0,31	0,50
TWI	0,38	0,17	-0,68
RSP	-0,01	-0,12	0,78
TRIC	0,22	-0,36	0,32
CNTF	-0,71	-0,13	-0,17

OAKF	0,67	0,46	0,17
MRPF	-0,11	0,10	0,40
SHRB	-0,30	-0,14	0,20
IMPR	0,22	0,21	-0,65
ORCH	-0,56	-0,36	-0,02
H'	0,41	0,27	0,06
DRT	0,65	-0,61	-0,09
LGT	0,70	0,28	0,02
B-6AM	-0,37	0,80	0,13
E-6PM	-0,32	0,47	-0,05
SS	-0,21	0,73	-0,07
AE	-0,46	0,40	0,19

Table 13-Important positive and negative correlations of variables with the three first axis

Axis	Positive Correlations	Negative Correlations
Axis 1	Land Use : OAKF, H'	Land Use : CNTF, ORCH
	Physical : ALT, LGT	Seasonal: AE
	Temporal : DRT	
Axis 2	Temporal: B-6AM, E-6PM	Temporal : DRT
	Seasonal: SS, AE	
	Land Use : OAKF	
Axis 3	Physical : ALT, RSP,	Physical : TWI
	Land use : MRPF	Land use : IMPR

4.2.4.2.2.1Axis 1

Variables such as OAKF (Oak Forest), ALT (Altitude), LGT (Length), H' (Shannon diversity index), and DRT (Duration) are positively correlated with Axis 1, indicating their significant influence in defining the variability captured by this axis. Specifically, OAKF suggests more significant presence of oak forests, ALT reflects higher altitude, LGT denotes more extended ecological features, H' represents higher ecological diversity or complexity, and DRT indicates a longer duration of some temporal event or phenomenon. Conversely, CNTF (Chestnut Forest) and ORCH (Orchard) are negatively correlated with Axis 1. This implies that as the presence of chestnut forests and orchards decreases, other positively correlated variables (OAKF, ALT, LGT, H', DRT) tend to increase along Axis 1. This inverse relationship suggests that areas with chestnut forests or orchards may have lower values in terms of altitude, length, and Shannon diversity index compared to areas dominated by oak forests or diverse ecological settings.

Thus, we can say that grazing itineraries within oak forests (OAKF) are characterized by higher diversity, greater altitude, longer length, and extended duration. This makes sense because a longer length corresponds to a longer duration, indicating a long route. In contrast, grazing itineraries within chestnut forests and orchards, predominantly chestnut, are characterized by reduced altitude, shorter length, and lower Shannon diversity (H').

Therefore, Axis 1 contrasts grazing itineraries with higher duration, length, altitude, and Shannon diversity (H'), typically found in oak forests, against those with lower values for these parameters, typically found in chestnut forests and orchards. This distinction highlights how oak forests support more diverse and extended grazing routes, while chestnut forests and orchards are associated with shorter, less diverse routes.

4.2.4.2.2.2Axis 2

Variables such as B-6AM, E-6PM, SS, AE, and OAKF are positively correlated with Axis 2, indicating their significant influence on the variability explained by this axis. B-6AM and E-6PM represent differences in activities at 6 AM and 6 PM, respectively. Higher values of B-6AM, E-6PM, SS (Summer Solstice), and AE (Autumn Equinox) suggest shorter grazing durations, as these variables are negatively correlated with grazing duration. SS and AE indicate the temporal distance from the summer solstice and autumnal equinox. OAKF reflects the presence or characteristics of oak forests.

Conversely, DRT (grazing duration) is negatively correlated with Axis 2, indicating that as values of other seasonal and temporal variables (B-6AM, E-6PM, SS, AE) increase, grazing duration tends to decrease. This implies that grazing duration is longer during periods with minimal differences in activities at 6 AM and minimal difference between the grazing day and the summer solstice.

Therefore, Axis 2 distinguishes grazing patterns characterized by high differences (B-6AM, E-6PM) and seasonal influences (SS, AE), typically associated with shorter grazing durations, from patterns with lower values for these variables, which tend to correlate with longer grazing durations. Interestingly, WS (Winter

Solstice) and VE (Vernal Equinox) show negative correlations with SS and AE in the correlation matrix, suggesting that grazing activities during these periods may exhibit shorter durations compared to periods with less difference between the day and SS, and activities at specific times like 6 AM and 6 PM (B-6AM, E-6PM), which tend to correlate with longer grazing durations. Additionally, the presence of oak forests (OAKF) positively influences Axis 2, highlighting their role in shaping grazing patterns during these temporal and seasonal periods.

4.2.4.2.2.3Axis 3

Variables such as ALT (Altitude), RSP (Relative Slope Position), and MRPF (Maritime Pine Forest) are positively correlated with Axis 3, indicating their significant influence in defining the variability captured by this axis. ALT reflects higher elevation, RSP denotes a higher relative slope position, and MRPF suggests a positive association with Axis 3. Conversely, TWI (Topographic Wetness Index) is negatively correlated with Axis 3. As the topographic wetness index decreases, other positively correlated variables (ALT, RSP, MRPF) increase along Axis 3. This relationship suggests that areas with higher altitudes, steeper slopes (RSP), and maritime pine forests (MRPF) may have lower topographic wetness values than other areas.

MRPF shows a positive correlation with Axis 3, indicating its significant influence in defining the variability captured by this axis. Conversely, IMPR (Improved Pasture and Irrigated Crops) is negatively correlated with Axis 3. This distinction highlights how MRPF tends to be associated with higher values in this context, while IMPR is associated with lower values.

Therefore, Axis 3 highlights how grazing patterns are shaped by physical attributes like altitude and terrain characteristics, and specific land uses such as maritime pine forests and improved pastures.

4.2.4.2.3 Studying the Circle of correlation

4.2.4.2.3.1Axes 1 and 2

The integration of Axis 1 and Axis 2 offers insights into how land uses such as oak forests, chestnut forests, orchards, altitude, temporal variables, and seasonal transitions, shape grazing patterns in the study area. OAKF (oak forests), positively correlated with both axes, tends to be situated at higher altitudes, facilitating longer grazing routes and durations. This grazing pattern is particularly pronounced in summer because the difference between the grazing day and SS (Summer Solstice) is low, characterized by minimal differences in start times (B-6AM) that allow for earlier grazing onset. Autumn similar to summer in timing and duration, albeit less prominently.

Interestingly, our correlation analysis reveals a negative correlation between the Autumn Equinox (AE) and Vernal Equinox (VE), similar to the inverse relationship observed between SS and the Winter Solstice (WS). It a seasonal reversal between summer and winter, with autumn contrasting with spring.

Therefore, it can be deduced that areas dominated by CNTF (Chestnut Forest) and orchards (ORCH) are associated with winter and spring. The combined insights from Axis 1 and Axis 2 offer a holistic understanding of how land use variables, temporal factors, and seasonal transitions collectively influence regional grazing patterns.

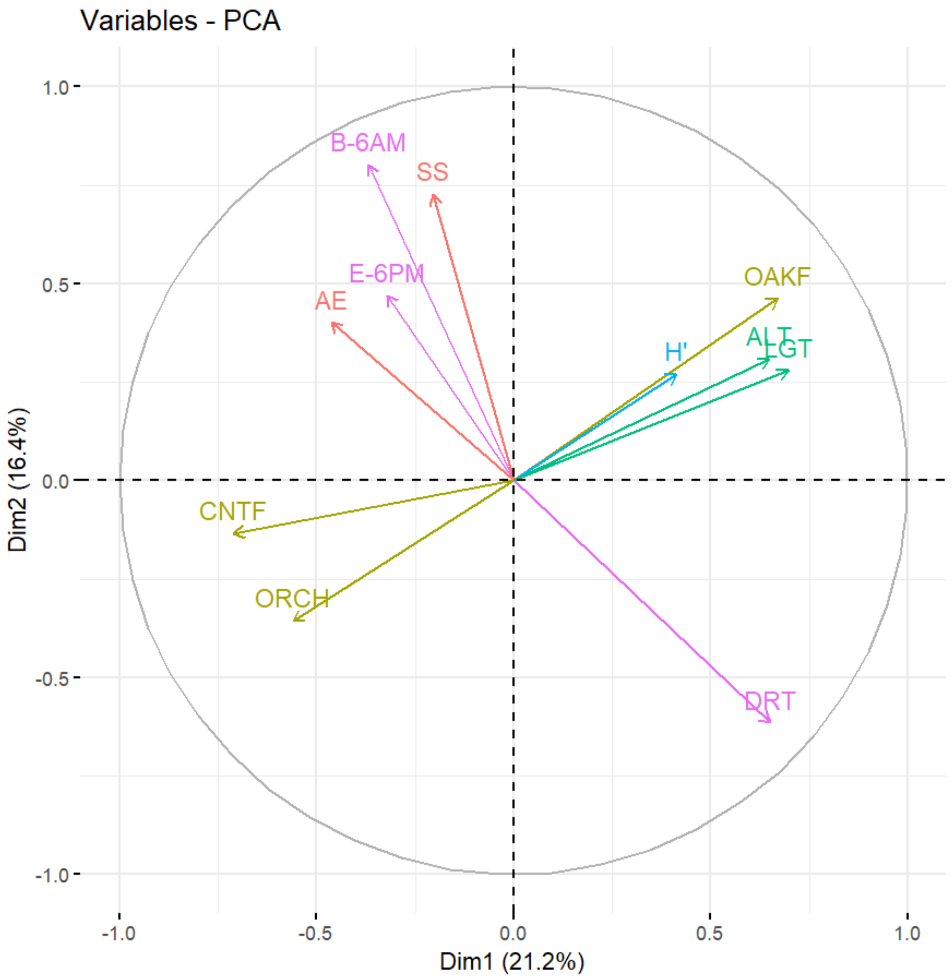


Figure 19-Correlation Circle for Principal Components 1 and 2

4.2.4.2.3.2Axis 1 and 3

The integration of Axis 1 and Axis 3 offers a comprehensive understanding of how physical variables and land uses influence grazing patterns in the study area. By examining the correlations with these axes, we gain valuable insights into the environmental and land use characteristics that shape grazing patterns.

OAKF (oak forests), positively correlated with Axis 1, is typically found at higher altitudes, facilitating longer grazing routes and durations. It indicates that areas dominated by oak forests support more extensive and diverse grazing patterns due to their greater altitude, length, and duration.

Conversely, Axis 3 highlights the influence of physical attributes such as ALT (Altitude), RSP (Relative Slope Position), and TWI (Topographic Wetness Index) on grazing patterns. Specifically, ALT and RSP positively correlate with Axis 3, indicating that areas with higher altitudes and steeper slopes tend to exhibit distinct grazing patterns. MRPF (Maritime Pine Forest) is also positively associated with Axis 3, suggesting that these forests are typically found in higher and steeper terrains.

On the other hand, TWI is negatively correlated with Axis 3, implying that areas with higher topographic wetness tend to be found in lower and flatter terrains. This relationship suggests that regions with higher slopes and altitudes have lower moisture levels, which can significantly influence grazing dynamics.

For land uses, IMPR (Improved Pasture and Irrigated Crops) is negatively correlated with Axis 3, indicating that these areas are typically associated with higher wetness and lower altitudes, contrasting with the drier and more elevated maritime pine forests.

Therefore, the combined analysis of Axis 1 and Axis 3 elucidates how different physical variables and land uses interact to shape grazing patterns. The insights reveal that oak forests, characterized by higher altitudes and longer grazing routes, support more diverse and extensive grazing activities. Meanwhile, maritime pine forests are associated with higher and steeper terrains but lower wetness levels, affecting their grazing dynamics. In contrast, improved pastures with higher wetness and lower elevation, exhibit different grazing patterns.

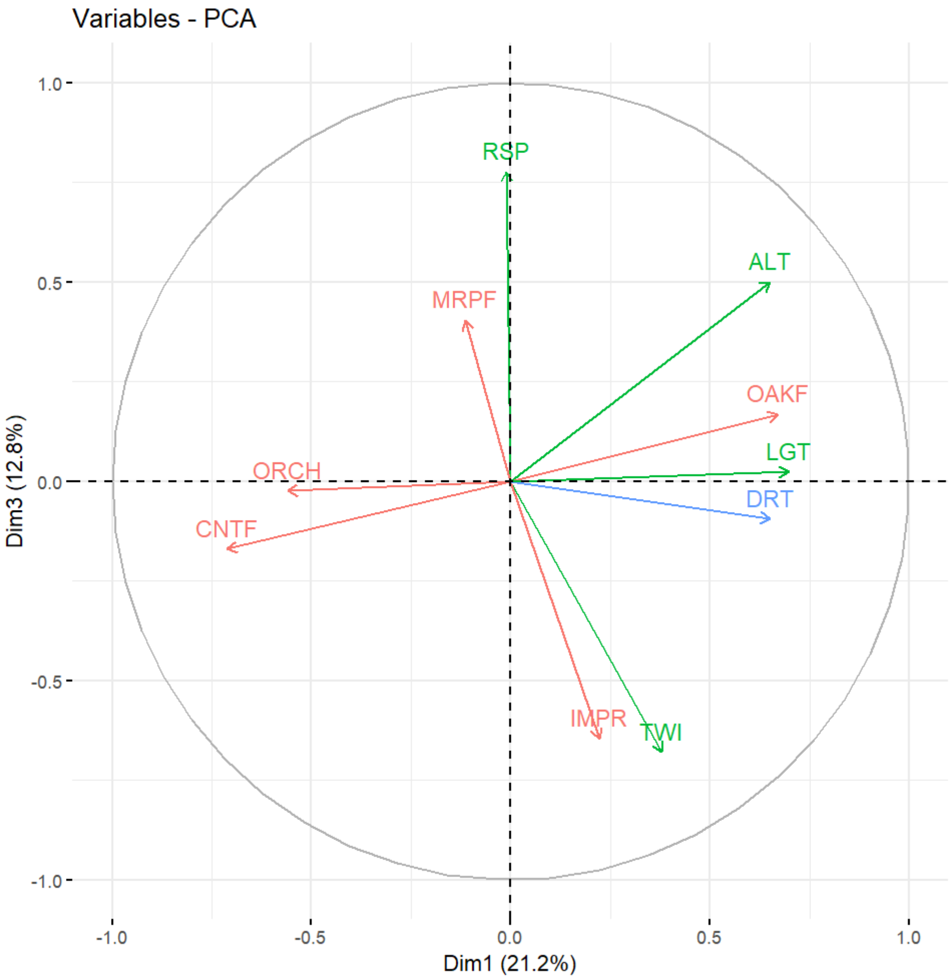


Figure 20-Correlation Circle for Principal Components 1 and 3

4.2.4.2.3.3Axis 2 and 3

Axes 2 and 3 provide a comprehensive view of how temporal, seasonal, and physical variables interact to influence grazing patterns in the studied region. The analysis reveals that oak and maritime pine forests, typically located at higher altitudes and steeper slopes, exhibit distinct grazing patterns compared to improved pastures and irrigated crops, which are found on wetter and lower terrains.

Oak forests correlate positively with Axis 2 and are usually situated on steeper slopes and at higher altitudes, as also indicated by their positive correlation with Axis 3. These areas are less grazed during winter and spring, reflecting their negative correlation with grazing duration and positive correlation with the summer solstice (SS) and autumnal equinox (AE). This suggests significant grazing differences compared to the summer and autumn seasons.

Maritime Pine Forests (MRPF) correlate positively with Axis 3, indicating their presence at steeper slopes and higher altitudes. They are more utilized during spring, as both MRPF and AE (which indicates a high difference between the grazing day and the autumn equinox, suggesting spring) correlate with Axis 3.

Improved Pasture (IMPR) and irrigated crops, negatively correlated with Axis 3, are associated with higher topographic wetness (TWI) and are generally found at lower altitudes. This contrasts with maritime pine forests and oak forests, which are located at higher altitudes and on drier terrains. IMPR exhibits distinct seasonal grazing patterns, with higher utilization in winter and autumn. AE correlate positively with Axis 3 further emphasizes increased grazing activity on IMPR during autumn compared to the spring months. Areas of IMPR with high TWI are less used in summer and spring, indicating a preference for autumn and winter grazing.

Both Improved Pastures (IMPR) and Maritime Pine Forests (MRPF) are categorized under medium duration grazing patterns. This classification reflects their temporal characteristics, indicating they are neither strictly aligned with short nor long durations. The seasonal dynamics, influenced by AE and TWI, create distinct grazing patterns for MRPF and IMPR, driven by environmental factors and seasonal changes.

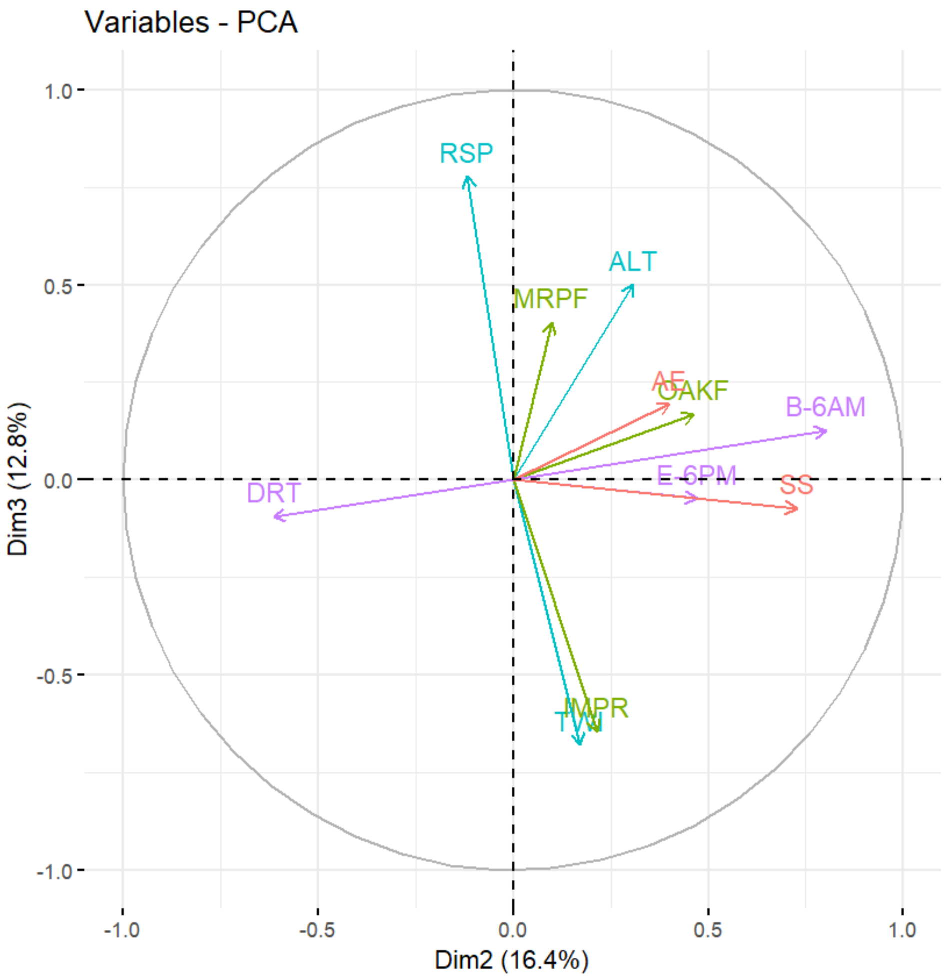


Figure 21-Correlation Circle for Principal Components 2 and 3

4.2.4.3 Study of individuals

For the study of individuals, they are categorized by season in order to be able to understand the variation induced by the seasons

4.2.4.3.1 Axis 1 et 2

Many individuals are clustered near the centre of the plot, indicating that they are not strongly represented by either of the first two principal components. These grazing paths may have characteristics that are not well captured by the dominant patterns identified in Dim1 and Dim2.

The second principal component (Dim2) separates summer (in red) from winter (in blue). This suggests that the variables associated with Dim2 (such as specific temporal and seasonal factors) differentiate summer grazing patterns from winter ones.

Both autumn (in brown) and spring (in green) are positioned close to each other and to the centre along Dim2. This means that grazing patterns in autumn and spring are more similar compared to those in summer and winter.

Positive Correlation (Right Side): Grazing itineraries during summer and autumn tend towards the plot's right side (positive values of Dim1). This indicates that these seasons are positively correlated with the variables defining Dim1. Variables positively correlated with Dim1 likely include altitude (ALT), length (LGT), and diversity (H'), suggesting that summer and autumn grazing paths might be longer, at higher altitudes, and more diverse.

Negative Correlation (Left Side): Grazing itineraries during spring and winter tend towards the left side of the plot (negative values of Dim1). This indicates a negative correlation with the variables defining Dim1. These seasons might be associated with lower altitudes, shorter paths, and less diversity.

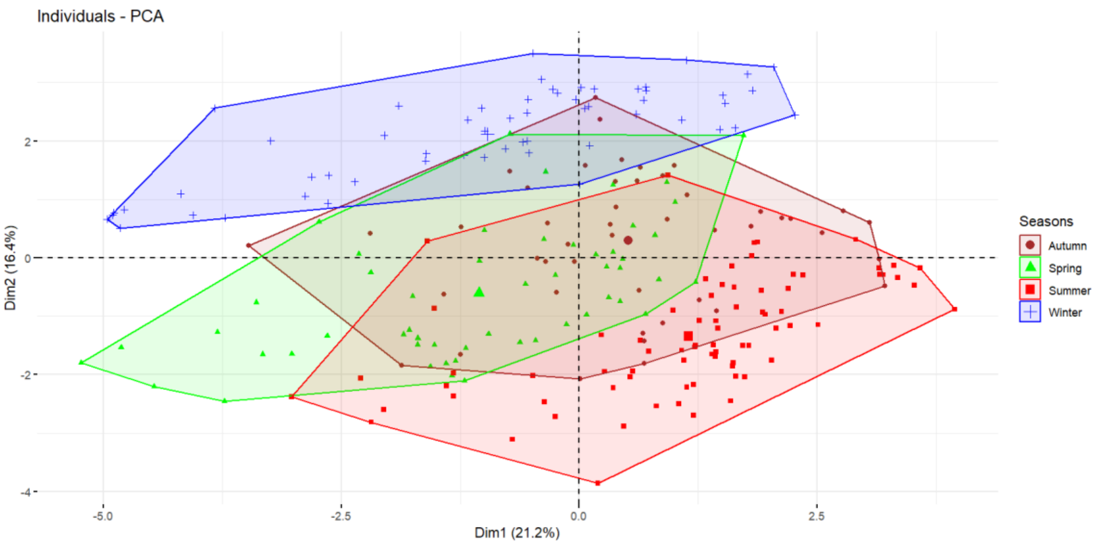


Figure 22-Visualization of Individuals by Season on axis 1 and 2

4.2.4.3.2 Axis 1 et 3

Many grazing itineraries are clustered near the centre of the plot, indicating that they are not strongly represented by either of the first and third principal components. These itineraries likely have characteristics that are not well captured by the dominant patterns identified in Dim1 and Dim3.

Grazing itineraries situated at higher altitudes and steeper slopes are represented by positive values along Dim3. These are likely to be associated with maritime pine forests (MRPF).

Grazing itineraries associated with lower altitudes and higher topographic wetness (IMPR) are represented by negative values along Dim3. These areas tend to have distinct grazing patterns compared to higher, drier terrains.

Grazing itineraries during summer and autumn align positively on Dim1, indicating a connection to longer and more diverse routes in higher altitude areas. These seasons also show positive values on Dim3, reinforcing the association with higher altitudes and steeper slopes.

Grazing itineraries during spring and winter align negatively on Dim1, suggesting shorter routes and different grazing patterns in lower altitude areas.

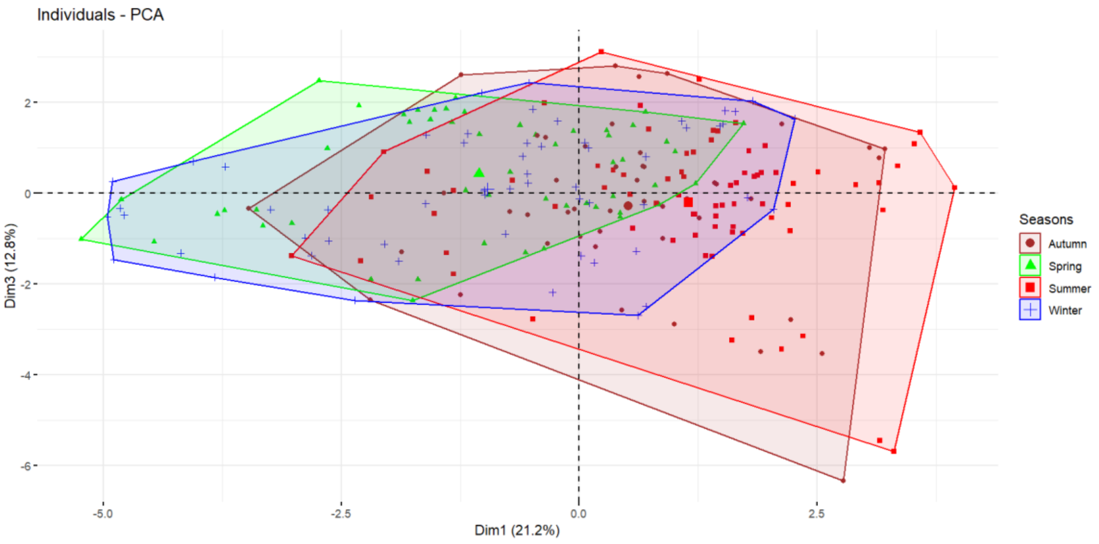


Figure 23-Visualization of Individuals by Season on axis 1 and 3

4.2.4.3.3 Axis 2 et 3

The second principal component (Dim2) separates winter (blue) from summer (red) grazing itineraries. Winter paths cluster separately from summer paths, indicating distinct grazing patterns between these two seasons.

Autumn (brown) and spring (green) grazing paths are more concentrated near the centre of the plot. This indicates that these seasons have grazing patterns that are similar to each other and are not as distinct as winter and summer. These itineraries are less represented by Dim2, suggesting they share characteristics that Dim2 does not capture well.

Some grazing itineraries, particularly in autumn and summer, are positioned far from the centre, indicating unique characteristics that differ significantly from the majority of the paths.

Grazing itineraries during summer and autumn tend to overlap with both positive and negative correlations along Dim3. This indicates that these seasons share certain characteristics, possibly related to higher altitudes and steeper slopes, but also have distinct differences.

Winter grazing paths generally correlate negatively with Dim3, indicating they are associated with conditions different from summer and autumn paths. However, some winter itineraries have positive correlations, suggesting variability within the winter grazing patterns.

Spring grazing paths are more distributed towards the lower part of Dim3, indicating a stronger negative correlation. This suggests that spring grazing patterns are more aligned with lower altitudes and wetter conditions, similar to specific winter paths, and are less associated with the characteristics represented by positive Dim3 values.

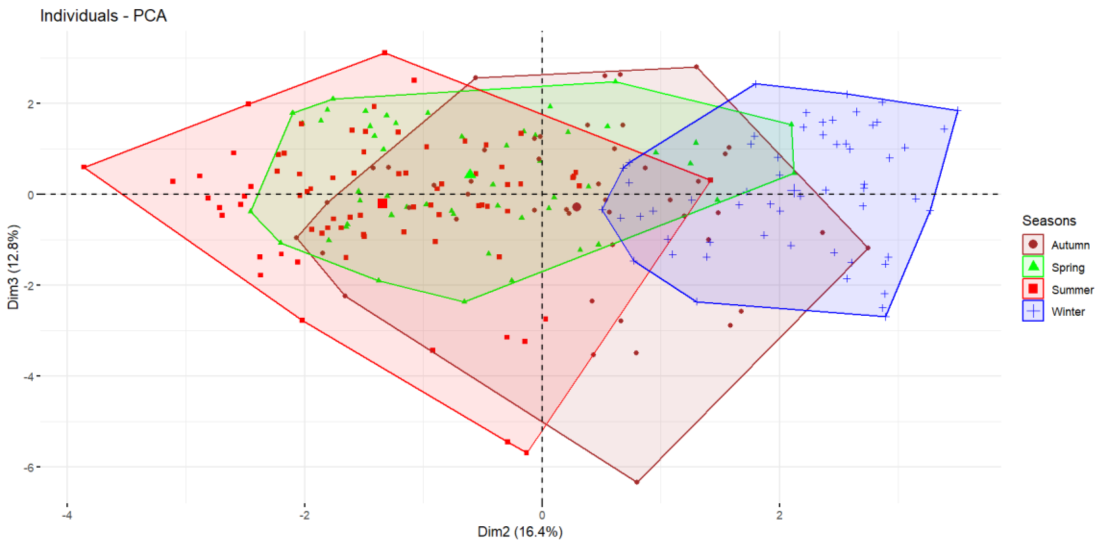


Figure 24-Visualization of Individuals by Season on axis 2 and 3

4.2.4.4 Study of individuals and variables

4.2.4.4.1 Axis 1 and 2

The biplot analysis integrating Axis 1 and Axis 2 offers a nuanced understanding of how land use types such as oak forests (OAKF), chestnut forests (CNTF), and orchards (ORCH), alongside altitude and seasonal transitions, shape grazing patterns in the study area. Oak forests, positively correlated with axes and typically found at higher altitudes, facilitate longer and more diverse grazing routes, particularly noticeable in summer when grazing activities start early due to minimal differences between the grazing day and the summer solstice (SS). Autumn exhibits similar characteristics to summer, albeit less prominently. Conversely, areas dominated by chestnut forests and orchards are associated with winter and spring, marked by distinct seasonal differences such as the negative correlation between the autumn equinox (AE) and the vernal equinox (VE), echoing the inverse relationship observed between SS and Winter Solstice (WS).

The biplot also reveals the clustering of individuals around the plot centre, indicating grazing paths that deviate from the dominant seasonal patterns captured by the principal components. This suggests that these paths possess unique characteristics that are not fully represented by the principal axes. Dim2 effectively distinguishes grazing patterns between seasons, with summer distinctly separated from winter, and autumn and spring positioned closely together, indicating similarities in their grazing patterns. Seasonal contrasts are further highlighted by Dim1, where summer and autumn grazing paths correlate positively with variables like altitude, route length, and diversity, suggesting longer and more varied grazing activities. In contrast, winter and spring grazing tends towards lower altitudes, shorter routes, and less diversity. This comprehensive analysis underscores how a combination of land use variables, seasonal transitions, and temporal factors collectively shape the ecological dynamics in the region, offering valuable insights into the management and conservation of grazing landscapes.

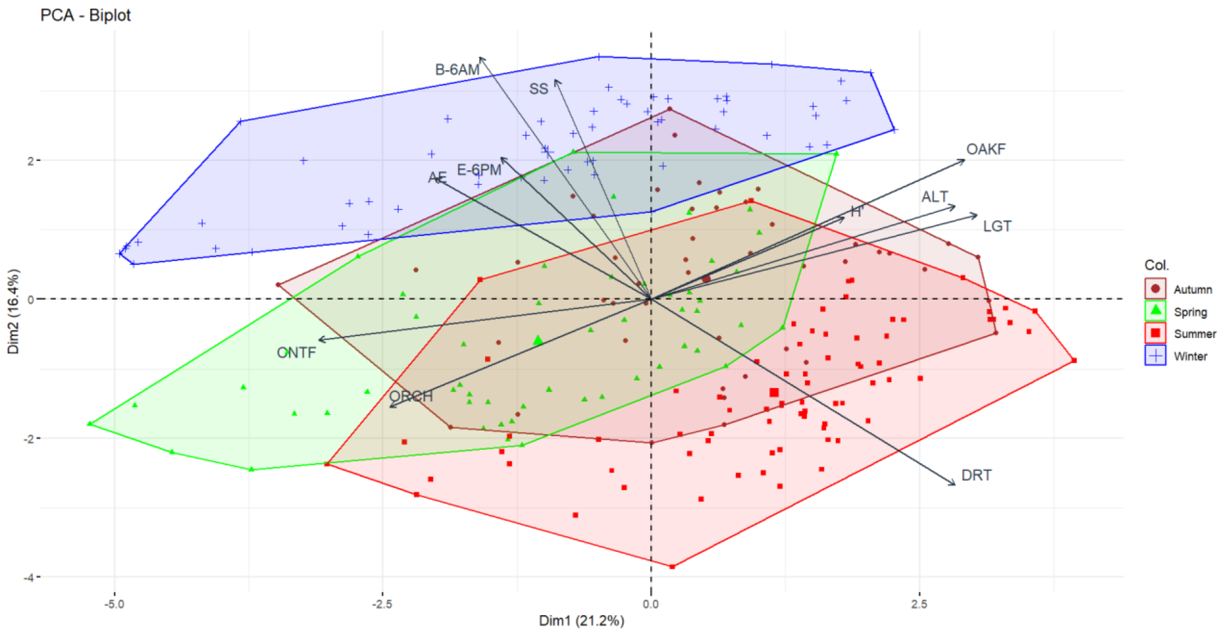


Figure 25-Visualization of variables and Individuals by Season on axis 1 and 2

4.2.4.4.2 Axis 1 and 3

Axes 1 and 3 provide a comprehensive view of how physical variables and land use influence grazing patterns in the study area. Oak forests (OAKF), positively correlated with Axis 1, are found at higher altitudes, facilitating longer and more diverse grazing routes and durations during the summer and autumn. This suggests that areas dominated by oak forests support extensive grazing activities due to their elevated and varied terrain.

Conversely, Axis 3 highlights the influence of physical attributes such as altitude (ALT), relative slope position (RSP), and topographic wetness index (TWI) on grazing patterns. ALT and RSP positively correlate with Axis 3, indicating that higher altitudes and steeper slopes influence grazing patterns, particularly in maritime pine forests (MRPF) during spring, winter, and autumn, but not in summer. In contrast, TWI negatively correlates with Axis 3, indicating lower altitudes and higher moisture levels, which affect grazing dynamics differently, as seen in improved pastures and irrigated crops (IMPR) during summer and autumn.

The biplot shows the clustering of grazing itineraries around the plot centre, suggesting they possess unique characteristics not well captured by the principal axes. Itineraries associated with higher altitudes and steeper slopes are represented by positive values on Dim3. Conversely, grazing itineraries linked to lower altitudes and higher topographic wetness are represented by negative values on Dim3, showcasing distinct grazing patterns observed in lower, wetter terrains such as improved pastures and irrigated crops.

Overall, Axes 1 and 3 together provide insights into how different physical variables and land uses interact to shape grazing patterns across seasons.

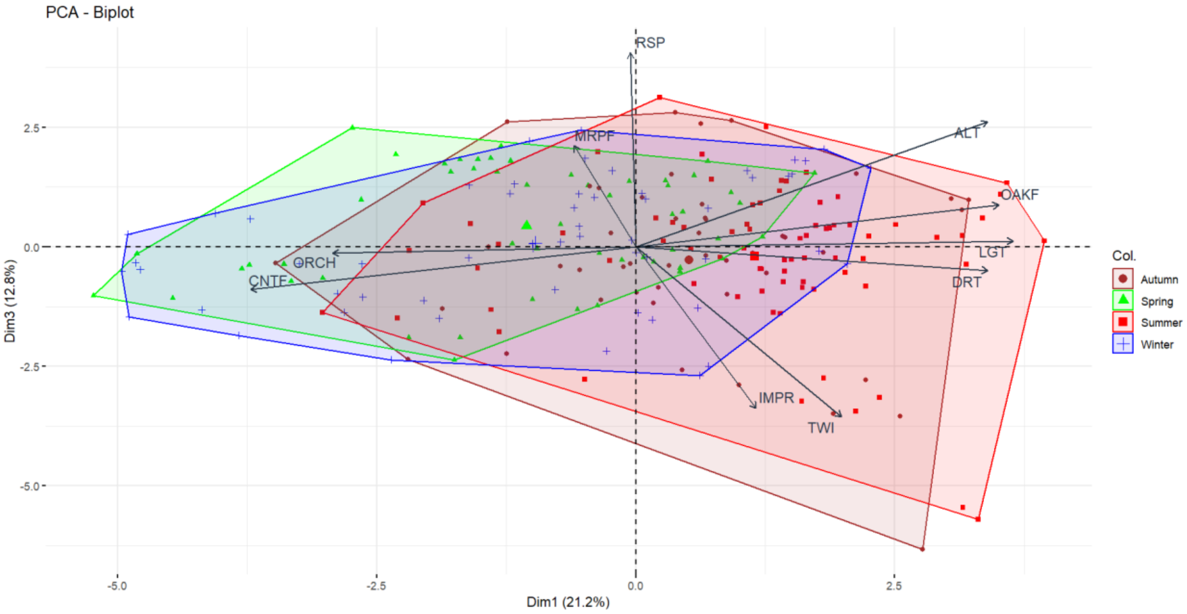


Figure 26-Visualization of Individuals by Season on axis 1 and 3

4.2.4.4.3 Axis 2 and 3

Axis 2 and Axis 3 together provide a comprehensive view of how temporal, seasonal, and physical variables interact to shape grazing patterns in the study area. Oak forests (OAKF), positively correlated with Dim 2, are typically found at higher altitudes and exhibit shorter durations, particularly noticeable during winter and spring due to their negative correlation with duration. This pattern is characterized by differences in start times (B-6AM) and a higher contrast between the grazing day and Summer Solstice (SS), which facilitate later grazing onset.

Maritime pine forests (MRPF), positively correlated with Axis 3, are situated at higher altitudes and steeper slopes. During spring and winter, MRPF occupies areas that correlate with Axis 3, emphasizing their unique seasonal occupancy patterns. In contrast, improved pastures and irrigated crops (IMPR), negatively correlated with Axis 3, are associated with higher topographic wetness and lower altitudes, showcasing distinct grazing patterns compared to drier, higher-altitude forests. IMPR predominates during winter and autumn, as indicated by its correlation with Axis 3 during these seasons.

The biplot analysis reveals clustering of grazing itineraries around the centre, indicating diverse characteristics not fully explained by the main axes. Paths associated with higher altitudes and steeper slopes align positively along Dim 3. Conversely, paths linked to lower altitudes and higher wetness exhibit negative values on Dim 3, highlighting unique grazing dynamics in areas dominated by improved pastures and irrigated crops.

Seasonal distinctions are also evident, with winter paths clearly separated from summer paths along Dim 2. Autumn and spring grazing patterns show greater overlap near the plot centre on Dim 2, suggesting similarities in grazing patterns between these seasons.

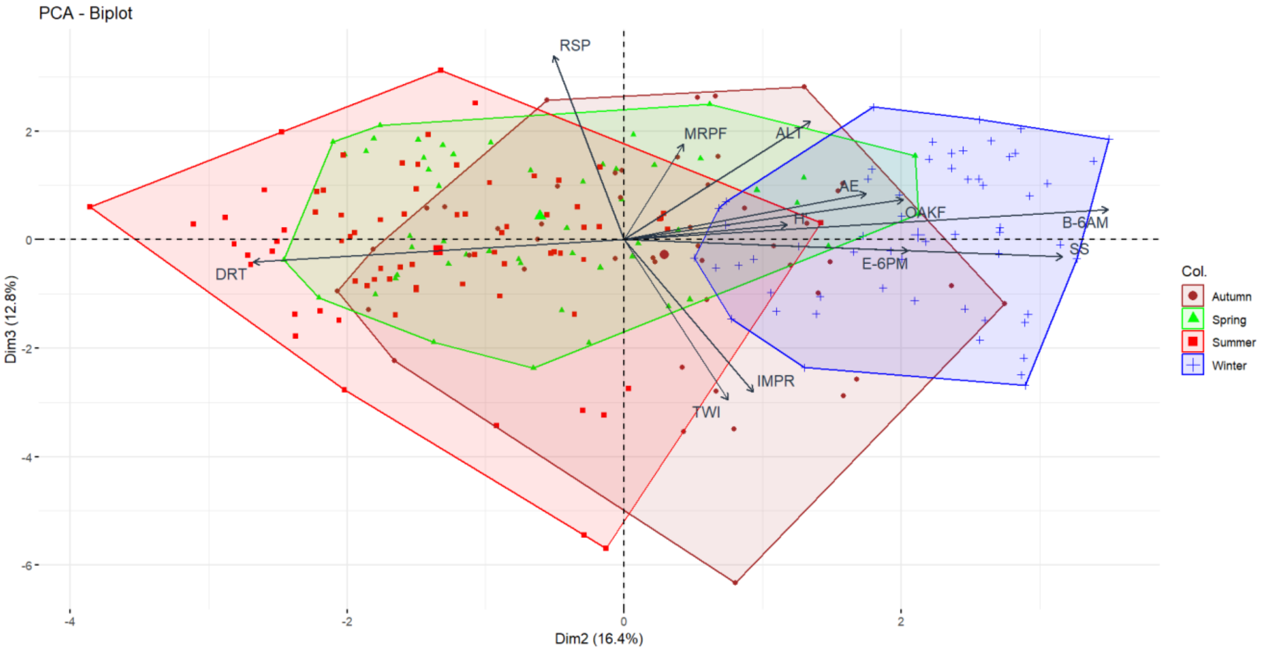


Figure 27-Visualization of Individuals by Season on axis 2 and 3

4.2.5 Discussion

This study delved into the grazing patterns of a goat herd within Montesinho National Park, revealing distinct patterns. Our findings indicate that goats exhibit peak grazing activity from 07:00 to 18:00 uninterrupted, with heightened activity in summer and autumn, and reduced activity in spring and winter. This aligns with existing research suggesting that goat herds embark on extensive journeys across varied terrain, unaffected by weather conditions and often far from immediate shelter (Castro., 2020).

In our study, goats primarily grazed in temporary rainfed and irrigated crops (TRIC), which consist of cereal and other forage crops, and oak forests (OAKF). The seasonal dynamics show that TRIC areas peak in spring but decrease in winter, while OAKF usage increases from spring to winter. During summer and autumn, goats exhibit a preference for oak forests characterized by varying altitudes, lengths, durations, and diversity. This preference is supported by earlier research indicating heavy consumption of foliage, particularly in August and September, with acorns becoming a significant dietary component from September to November (Castro, 2008). Furthermore, according to Hassidou (2016), in Trás-os-Montes, Northeastern Portugal, specifically in the parishes of Rebordainhos and Freixedelo within the Bragança municipality, goats primarily utilize forests (mainly oak and pine species) and rainfed crops as their main feeding resources. This supports the grazing patterns observed in our study.

Orchards and chestnut forests are primarily utilized during winter and spring, as their lower altitudes and shorter vegetation lengths provide supplementary forage opportunities post-harvest (Castro, 2008). These land uses exhibit usage during these seasons likely due to flowering, however their overall usage is lower compared to other types of land. The limited use can be explained by the fact that owners often prohibit access to prevent damage to the trees' bark (Castro., 2008; Hassidou., 2016).

Improved pastures (IMPR) are utilized more in winter and autumn, followed by summer, but not in spring. This pattern may be related to seasonal growth cycles and management practices enhancing pasture availability in colder months. Similarly, Maritime Pine forests (MRPF) are used more in winter and autumn, reflecting seasonal availability and nutritional content. Shrubs (SHRB) show greater variability in usage during autumn and winter, likely due to changes in growth and accessibility.

Higher altitudes and steeper slopes in oak forests facilitate extended grazing routes during summer, reflecting adaptive behaviours in response to seasonal resource availability (Castro et al., 2010). Furthermore, goats cover longer distances at a quicker pace during grazing, demonstrating their adaptation to forage across dispersed resources including forested areas (Castro et al., 2004).

This study contributes significantly to understanding the grazing systems of goats in Montesinho natural park, illustrating how goats navigate diverse landscapes throughout the year. By integrating empirical data with existing knowledge, we emphasize the importance of sustainable land management practices that balance agricultural productivity with ecological conservation.

5. CONCLUSION

The study of grazing patterns in Montesinho Natural Park provides invaluable insights into the intricate interplay among terrain variables, seasonal dynamics, and land use types, all crucial elements for the sustainable management of pastoral communities. By leveraging GPS tracking data, this research unveils the nuanced ways in which terrain, forest composition and seasonal transitions exert influence over the grazing patterns of goat herds across varying climatic conditions. The study investigates the grazing patterns of a goat herd across seasons and landscapes using multiple analyses.

Location data reveals distinct daily and seasonal trends, with peak activity observed from 07:00 to 18:00, more pronounced in spring and summer, and reduced in winter, especially in December. Monthly records highlight peaks in data collection in April, July, and August, contrasting with lower counts in June and November, possibly due to interruptions.

Grazing preferences across different land uses show that temporary rainfed and irrigated crops (TRIC) and oak forests (OAKF) are primary grazing areas, with TRIC peaking in spring and declining in winter, while OAKF usage increases from spring to winter. Chestnut forests (CNTF) exhibit peaks in spring and winter, reflecting adaptive foraging strategies.

Principal Component Analysis (PCA) provides insights into how land use types, terrain, and seasonal transitions shape grazing patterns. Oak forests at higher altitudes facilitate longer and more diverse grazing routes, particularly noticeable in summer. Chestnut forests and orchards are associated with winter and spring, characterized by shorter routes and less diversity.

Terrain attributes such as altitude, relative slope position, and topographic wetness index influence grazing patterns differently across seasons and landscapes. Higher altitudes and steeper slopes influence grazing patterns in maritime pine forests during spring, winter, and autumn, while lower altitudes and higher moisture levels affect grazing dynamics in improved pastures and irrigated crops during summer and autumn.

Future research should prioritize longitudinal studies to track grazing patterns over multiple years, assessing long-term trends in response to climatic variability and land use changes. Understanding the ecological impacts of grazing across different land use types is crucial for managing vegetation dynamics and promoting biodiversity conservation. It is also essential to investigate how pastoral communities can adapt to climate change and extreme weather events. Comparative studies among regions with similar landscapes but different management practices can reveal universal principles and region-specific factors. Additionally, analysing the socio-economic impacts of grazing on local communities will provide insights into traditional knowledge, economic viability, and cultural heritage.

Practical applications should focus on implementing precision livestock management through GPS tracking and remote sensing technologies. These tools can optimize grazing strategies in real-time, improving animal welfare and resource efficiency. Developing adaptive management frameworks that integrate seasonal grazing preferences with land use planning will maximize productivity while maintaining ecological integrity. Providing evidence-based recommendations to policymakers on sustainable land management practices will support conservation goals and preserve traditional knowledge systems. Educational initiatives should disseminate research findings to stakeholders, promoting sustainable grazing management practices.

Overall, these recommendations aim to enhance biodiversity conservation, climate resilience, economic viability, and policy development in extensive pastoral systems. They advocate for sustainable practices that balance livestock production with conservation objectives, ensuring long-term benefits for both ecosystems and communities.

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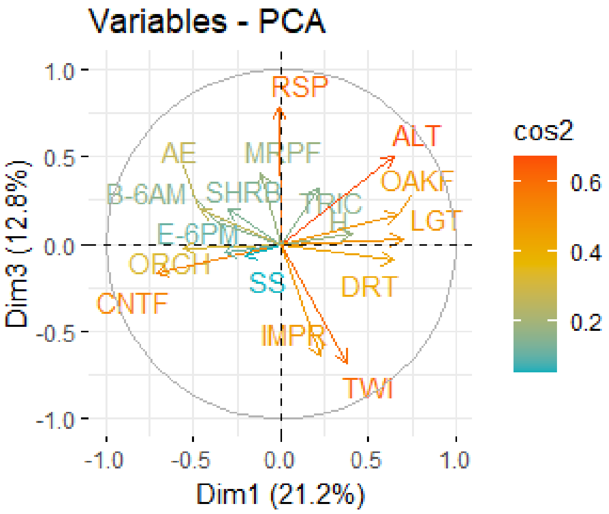
ANNEXES



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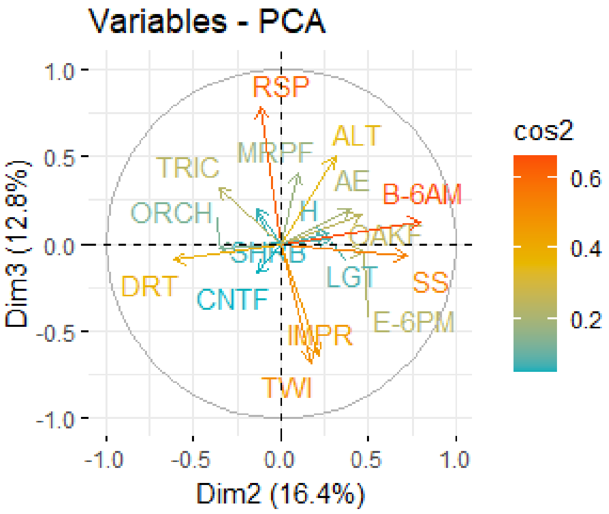

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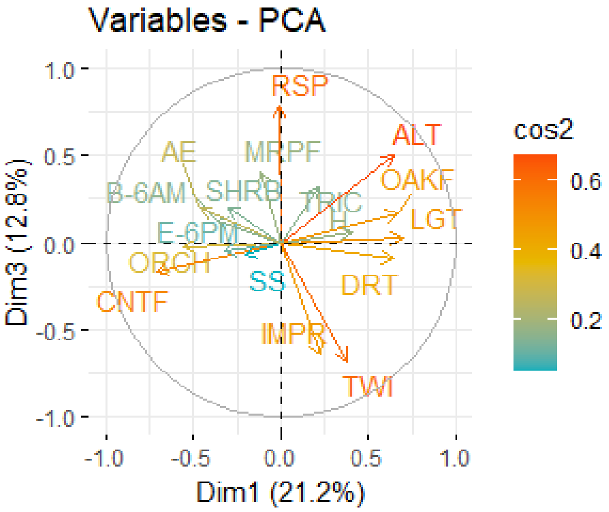

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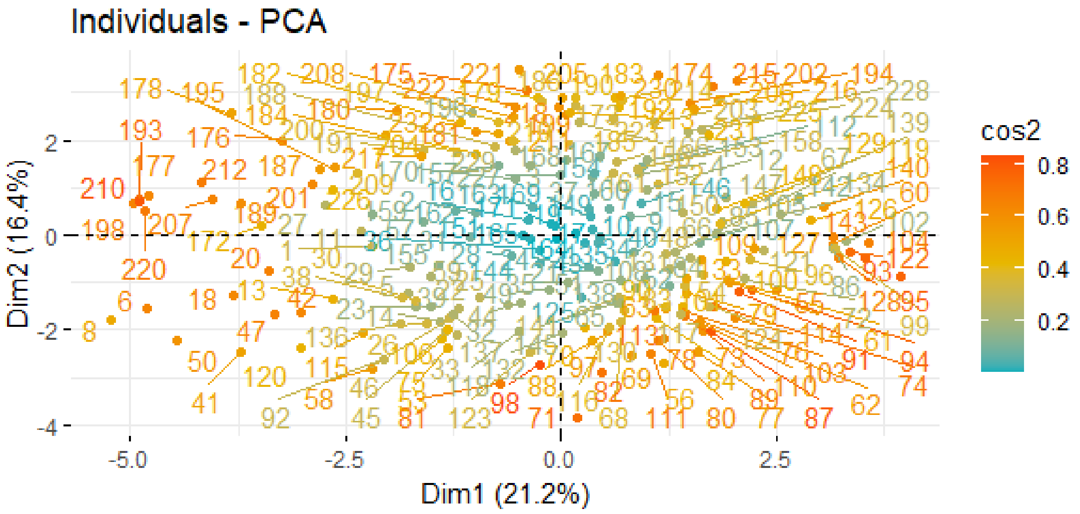

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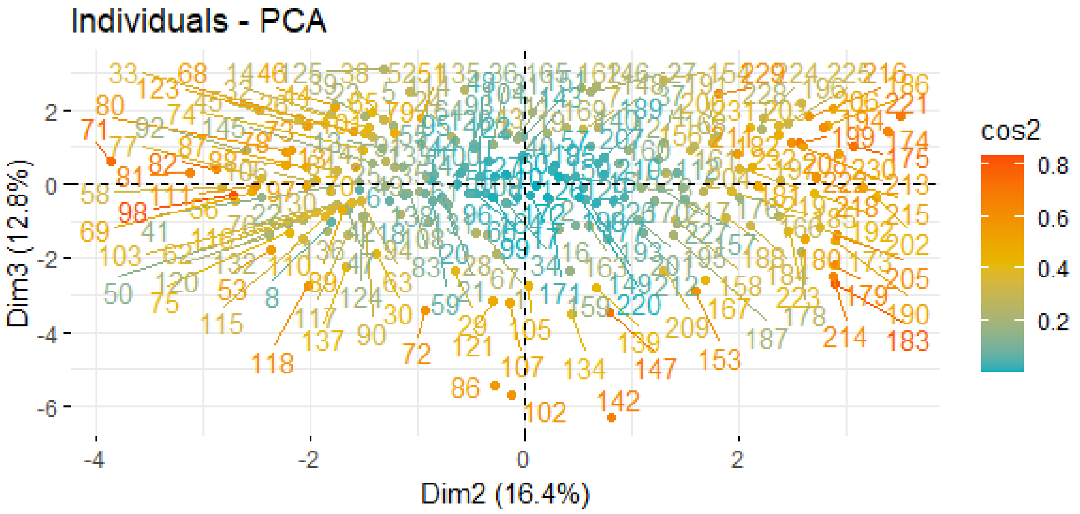

Annex 5-quality of representation of individuals, axis 2 and 3