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Changes on the Climatic Edge: Adaptation of and Challenges to Pastoralism in Montesinho (Northern Portugal)

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Mountain areas are sensitive to changes in precipitation and temperature, which significantly impact traditional pastoralist communities, their economy, and their lifestyle. Alarming climate change scenarios justify the investigation of the ecological and socioeconomic vulnerabilities that characterize Portugal's mountain regions. This work explores how the traditional production systems of small ruminants—sheep and goats—could adapt in the Montesinho mountain range as it changes over the next 2 decades. Land use–land cover maps from 1995 and 2018 show how the pastoral landscape has changed and indicate trends for a future scenario. Documented landscape grazing patterns are used to determine sheep and goat landscape preferences under different climatic conditions. Finally, we identify the near-future constraints on traditional sheep and goat systems, contrasting landscape changes with sheep and goat preferences. Over coming decades, the balance between rangelands and cultivated lands will persist in the Montesinho mountain landscape, despite some trade-offs between both. Woodlands could emerge from scrublands colonizing rangelands, and permanent crops could significantly replace arable lands in agricultural areas. Therefore, it is likely that the agricultural areas preferred for sheep, and rangelands preferred for goats, may not be affected by the forecast landscape changes, but rather be favored by the expansion of permanent crops. However, pasture areas must expand, as they are key to pastoral landscape function in a warming climate scenario. Landscape decision makers and managers should implement a landscape-monitoring system to inform policies and strategies aimed at protecting and safeguarding mountain pastoralism and its vital ecosystem services.

Keywords: *landscape change; Mediterranean mountains; pastoral routes; Ivlev's selectivity index; sheep and goats.*

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Introduction

European pastoral regions have witnessed a general process of massive depopulation over several decades, and the northeast of Portugal is no exception (Lasanta et al 2017; Torres-Manso et al 2017; Dolton-Thornton 2021). The grazing of mountainous areas persists but is in decline, despite support from the European Common Agricultural Policy (CAP), which recognizes the value of local breeds and other agri-environmental practices (Plieninger et al 2012; EIP-AGRI Focus Group 2017; Nori 2017). Due to outmigration, shepherding is, in many cases, now conducted by low-skilled or marginalized shepherds (van Vliet et al 2015). Further, new influxes of small-scale artisanal producers and investment in tourism have not been enough to maintain the nature of local pastoralism (Whited 2018). In addition, inconsistencies in grants between traditional pastoralism and wildlife habitat creation continue to grow with new subsidy regimes promoting pristine land cover (Barnes et al 2016; Ribeiro et al 2016). Despite this, recent studies have shown positive synergies between livestock rearing and wildlife biodiversity, pointing to the value of integrated management of both components (Velado-Alonso, Morales-Castilla, Rebollo, et al 2020). However, there are fewer owners, unconsolidated flocks, and fewer shepherds due to a decline in the traditional mixed farming systems (Scoones 2020).

Throughout history, small ruminants have been fundamental to providing rural populations with crucial protein using local natural resources (Honrado et al 2017; Pulina et al 2017). Their adaptation to the intricate climate, relief, and high soil diversity of mountainous regions has also made them resilient to changes in the rural context (Gómez-Sal 2001; Hoffmann 2013; Velado-Alonso, Morales-Castilla, and Gómez-Sal 2020). Recognizing this marginal productive role, the CAP pays for each sheep and goat to compensate for economic losses and to preserve threatened breeds (Belanche et al 2021).

Shepherding practices also provide regulating services, such as fire risk control; cultural services, such as the maintenance of landscape heritage benefits; and supporting services, such as biodiversity and nutrient cycling (Tenerelli et al 2016; Hartel et al 2018; Marsoner et al 2018; Castro et al 2020; Múgica et al 2021). Nowadays, these ecosystem services are essential to confronting the threats posed by climate change (FAO 2016) and are well recognized by academics and researchers (Dumont et al 2019; Calle 2020). As a result, the Andalusian region administration agrees that financial support should be made available to safeguard them (Ruiz-Mirazo et al 2011).

Climate change is a major concern for current livestock systems worldwide (Salm et al 2020; Godde et al 2021) and has become a key issue for the Food and Agriculture Organization of the United Nations (see FAO nd). Climate change will not affect the world's different regions and the type of livestock production systems (industrial or landless, crop or livestock, and grazing or pastoral) in a uniform way (Nardone et al 2010). Due to their variable dependence on climatic and natural resources, pastoral systems will be the most affected by summer temperatures in southern Europe (Johannesen et al 2013). Therefore, adaptative responses to these climatic changes are key to ensuring the continuity of this important component of the biophysical and sociocultural fabric of the mountain regions.

Over the centuries, 5 sheep and 3 goat breeds have evolved in the northeast of Portugal (10,936 km^2), taking advantage of mixed farming remains (Rodrigues et al 2006; Bruno-de-Sousa et al 2011) afforded by grazing routes that traverse diverse land use types (Castro 2016). Their niche is constrained by the traditional landscape and principal crops of cereals and meadows for cattle (J. Castro 2004). Day after day, shepherds drive their flocks of no more than 200 head through a mosaic landscape around the farmstead over routes averaging 5 km. Sheep and goats benefit from a combination of agricultural byproducts and spontaneous vegetation: fallow and agroforestry patches, vegetable leftovers, orchard prunings, woods, and scrublands (M. Castro 2004). The different land use patches have distinct roles along these grazing routes (Baumont et al 2000). They represent valuable ecological knowledge vital for local livelihoods, and they will be essential to the policies and intervention strategies required for adaptation to climate change (Tamou et al 2018).

The authors have recorded and analyzed local herding routes for more than 30 years (Castro et al 2010). We have studied differences between sheep and goat routes, plant and vegetation type preferences, winter and summer diets, understory and fire risk reduction, grazing and browsing pressure, and vegetation regrowth and changes. Particularly relevant to this long-term research is the first detailed and systematic GPS recording of routes performed in the late 1990s (M. Castro 2004). The routes of 4 selected flocks—2 sheep and 2 goat—under different climatic conditions were monitored using a hand rover GPS for the first time. We registered preferred land uses of flocks while the shepherds' landscape preferences were ascertained and animals' plant preferences recorded. Records of these 54 long journeys over 1 year constitute the longest systematic geographical pastoral database for local sheep and goats. As a result, it is now possible to study the changes that have taken place over the last 2 decades in the small-ruminant–landscape relationship in the northeast of Portugal.

The diversity of climates and landscapes has made local breeds resilient to change over time, maintaining essential functions—productive economic, cultural, social, environmental, and landscape—particularly for its protected areas, such as the Montesinho Natural Park (PNM), the fourth-largest Portuguese protected area (74,203 hectares). The PNM is a well-preserved mountain landscape sharing Atlantic and Iberian central plateau influences, which bestow different bioclimatological zones: temperate (11%), Mediterranean humid (64%), and Mediterranean subhumid (25%). Changes in climates and landscapes will introduce uncertainties and generate challenges for PNM pastoralism.

The PNM has 2 helpful characteristics enabling the study of herbivore adaptive responses under extensive grazing management: small ruminant activity still based on local breeds and a marked edge between supra- and mesomediterranean conditions. Both underpin local ecological heritage and knowledge, which enable adaptation to different environments. These permit us to hypothesize that if the current climate and related landscape changes continue as forecast, the pastoral landscape patterns will need to change to adapt to climate change. Thus, this work's 2 objectives are (1) to compare the small-ruminant landscape use in different climatic situations with the changes taking place in the pastoral territory of PNM; and (2) to identify the PNM landscape management issues that are essential to adapt and enhance pastoralism in sustaining its ecosystem services, such as biodiversity and natural and cultural heritage. We use a landscape approach to envision PNM land use based on changes over the past 2 decades and assess its consequences for managing the sheep and goat pastoral routes in different climatic conditions.

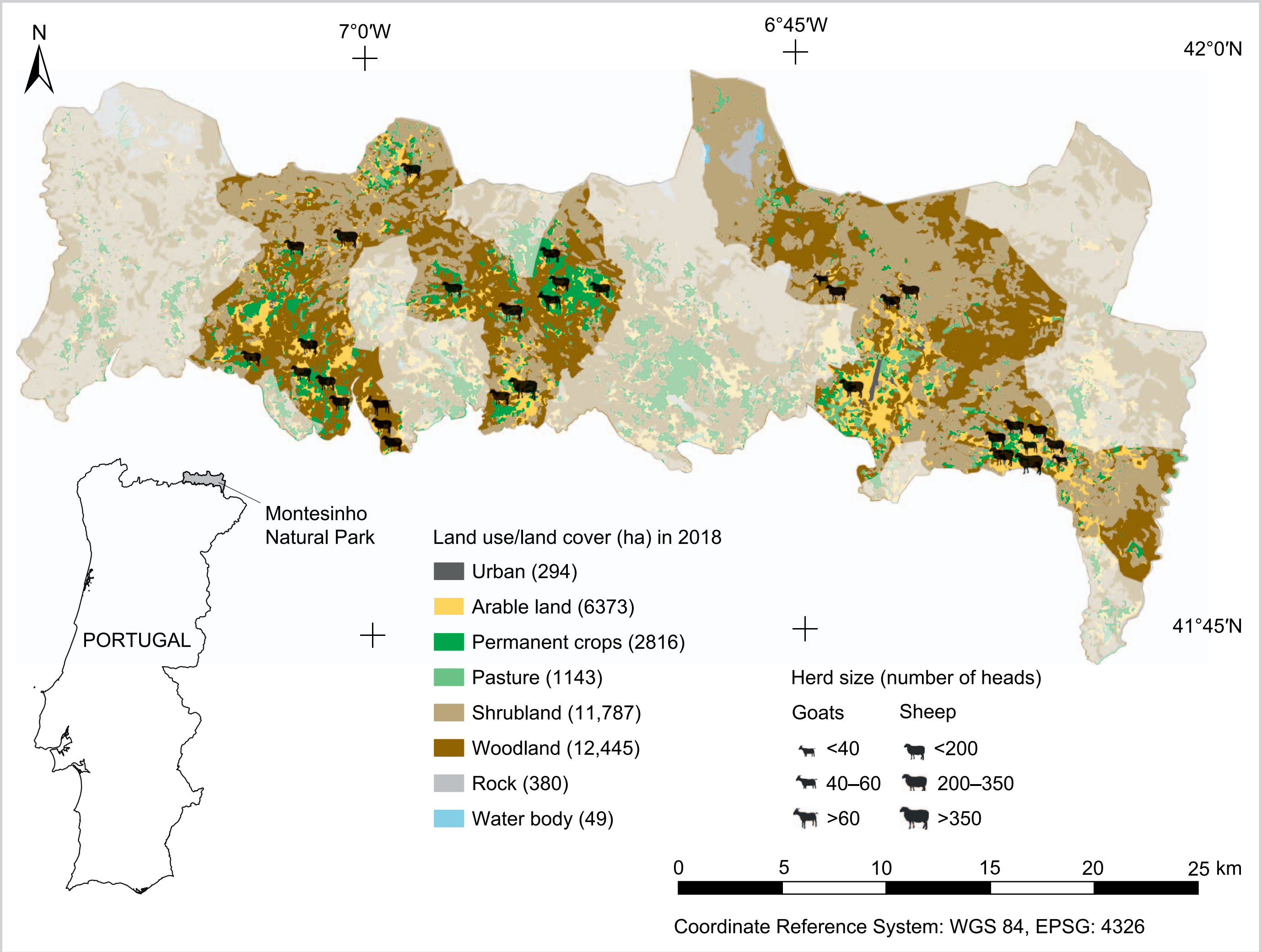
Study area and methodology

Study area

The study area corresponds to the pastoral territory of PNM (Figure 1): 35,296 hectares that currently sustain 40 herds of sheep (4042 head) and 7 herds of goats (248 head). These are based on rangelands (34.8% shrublands and 35.6% woodlands) and cultivated areas (18.2% arable lands, 8.1% permanent crops, and 3.3% pastures) distributed across 23 rural communities. All the sheep and goats are threatened local breeds—Churra Galega Bragança sheep and Preta de Montesinho goats—both under 10,000 head in total. They are protected and subsidized under the CAP agri-environmental measures.

The territory has a heterogeneous relief, with a plateau cut by deep valleys and some mountains consisting of flat to very steep slopes. The elevation ranges from 438 (Mente River) to 1486 masl (Montesinho peak). The average annual rainfall varies from 1262 (Montesinho mountain range) to 806 mm (Lombada plateau). The average annual temperature varies from 8.5 to 12.8°C (same locations; INMG 1991). Climatic predictions indicate that the temperatures in the Montesinho mountain range will progressively rise by 4°C by the end of this century, reducing the humid temperate and supramediterranean zones with

FIGURE 1 Land use and land cover of Montesinho Natural Park, pastoral territory (study area), and sheep and goat flock distribution. (Source: data from breeder organizations and DGT 2019)



corresponding expansion of subhumid mesomediterranean environments (Andrade and Contente 2020).

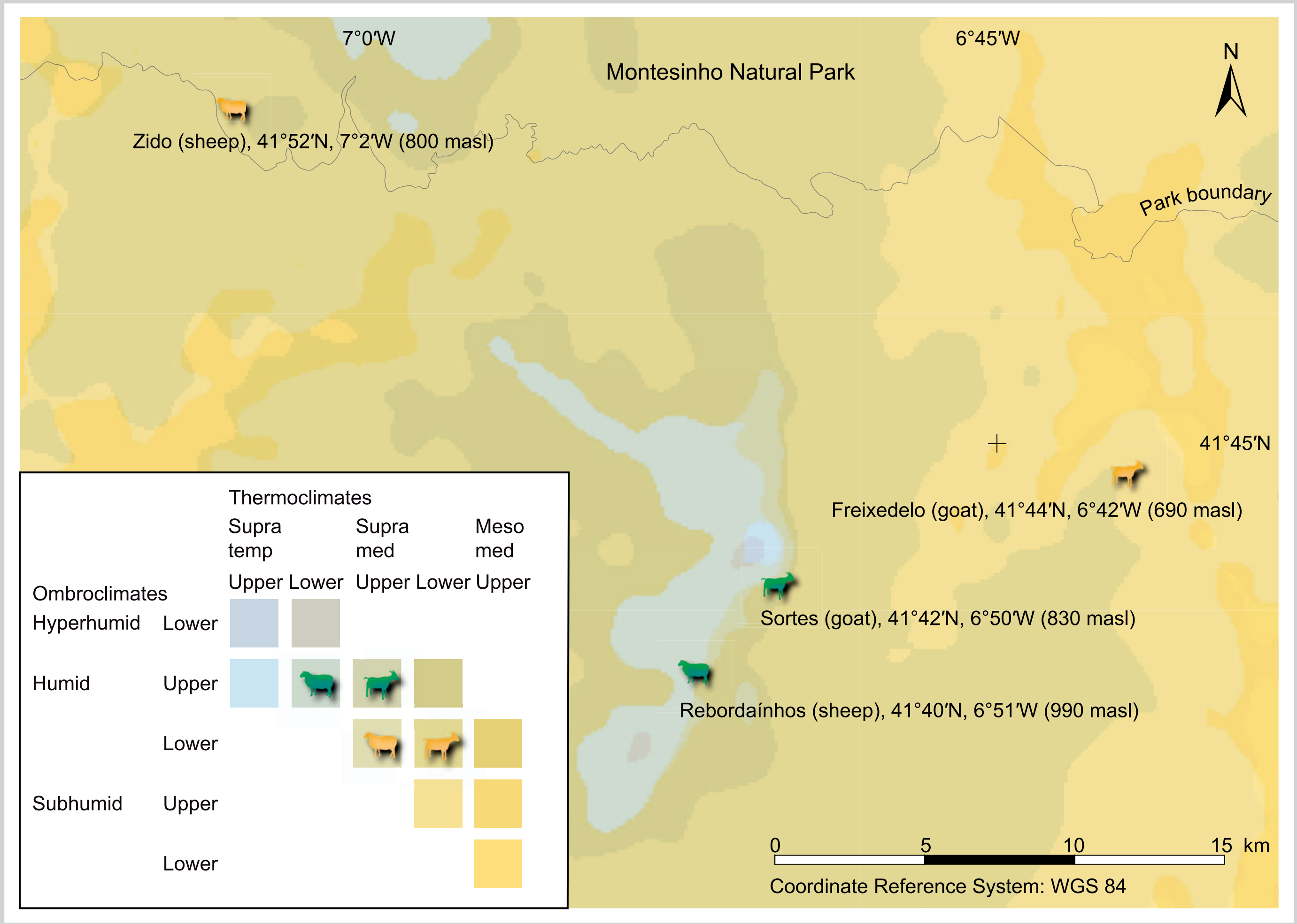
The landscape heterogeneity is due to the high diversity of land cover and uses. It includes annual crops (cereals 16.0, vegetables 0.8%) and permanent crops (*Castanea sativa* 8.4%, *Olea europaea* 0.3%), pastures (2.7%), natural woodlands (*Quercus pyrenaica* 11.1%, *Q. rotundifolia* 0.6%), riparian forests (5.7%), pine woods (*Pinus pinaster*, 13.9%), and seminatural shrublands (35.2%). These support a high floral and faunal species richness (Sil et al 2016; DGT 2019). Soils are mainly Leptosols (77.1%) and Cambisols (20.1%); Luvisols and Alisols cover only 2% of the territory (Agroconsultores e Coba 1991).

As in other European regions, the PNM has witnessed a rapid decrease in rural populations, which has brought fundamental land use changes during the last 2½ decades. This includes an increase in woodlands due to the lack of human and livestock removal of biomass and an increase in perennial crops because of a lack of workforce (Lasanta et al 2016; Maharjan et al 2020; Dolton-Thornton 2021). Considering its marked temperate–Mediterranean transition and landscape heterogeneity, the PNM provides a unique global change laboratory, providing insights into how climate change challenges the most remote mountain areas in the Mediterranean basin.

Landscape change

The study first assumed a baseline for land use evolution according to the trends of the last 2 decades. We used the land use–land cover (LULC) maps published for 1995 (DGT 2010) and 2018 (DGT 2019). They constitute the first and the last available systematic LULC mappings officially published. This long time interval also allows us to predict a scenario based on global landscape changes, including climate effects, well into the future. The LULC gains, losses, persistence, and swap changes by category were analyzed. This was done by overlaying the 1995 and 2018 maps to produce a matrix that provided the LULC transitions occurring between the 2 dates. On-diagonal entries represented areas where the LULC did not change over time, and off-diagonal entries showed how each LULC changed to a different category. LULC totals in 1995 were the row totals in the right column; those of 2018 were the column totals in the last row of the matrix. The transition probability matrix allowed us to predict LULC area changes. It showed the change proportions of the 1995–2018 matrix and, multiplying those

FIGURE 2 Distribution, thermoclimates, and ombroclimates of sheep and goat landscape preference reference sites (cooler and wetter sites in green, warmer and drier sites in yellow; temp, temperate; med, Mediterranean).



change proportions by each 2018 LULC total, it gave us the expected transitions between each LULC category pair. This assumes that the past LULC transition processes and magnitudes (1995 to 2018) can be used as the basis for projecting to an equal future period (Logsdon et al 1996).

LULC selectivity

This study's second main assumption is the climate as a driver of landscape selection by sheep and goat herds. According to Lechowicz (1982), "Electivity indices measure the utilization of food types (r) in relation to their abundance or availability in the environment (p)." They are used mainly for estimating forage or habitat preferences in the context of wildlife. Our study applies the concept to LULC classes grazed by small ruminants in pastoral routes across the landscape.

Fifty-two pastoral routes for grazing sheep and goats were recorded in the PNM vicinity by M. Castro (2004) across diverse environmental situations (see Figure 2). Using these, we determined the sheep and goat usage of the major LULC classes: arable lands, permanent crops, pastures, shrublands, and woodlands, grouped as in Table 1.

For each LULC class, selectivity was determined based on Ivlev's electivity ratio E_i (Ivlev 1961). This considers the proportion of flock time spent in each LULC to the route's entire time (r_i) and the proportion of the area of each LULC to the entire community territory (p_i), as follows:

$$E_i = (r_i - p_i)/(r_i + p_i)$$

We excluded roads, urban and industrial areas, and water bodies not relevant to the pastoral routes. The values of the index E_i range between 1 (highly preferred) and -1 (completely avoided). They are 0 when the proportion of time spent on the LULC equals the proportion of LULC area, which indicates random use of it.

Results and discussion

Changes and projections for the PNM pastoral landscape

The PNM pastoral landscape analysis explains how the LULC changes could impact the rural economic, social, and environmental dynamics of the area. The results presented in Table 2 were obtained through GIS analysis, and their validity depends on the published maps' overall reliability.

The land use pattern is changing, raising concerns about the region's ecosystem services and functions (Castro 2010; Azevedo et al 2011; Sil et al 2016). The LULC distribution for 1995 and 2018 shows that rangelands—shrublands and woodlands—have strengthened as the dominant land cover category over 23 years. Based on the transition matrix

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TABLE 1 The 5 major land use land cover types.

Land use–land cover class	Description
Arable land	Nonirrigated arable land, complex cultivation patterns, annual crops associated with permanent crops, fallows, or stubble surfaces
Permanent crop	Olive or chestnut groves, vineyards, fruit trees, agroforestry areas
Pasture	Meadows, upland acid grasslands and rush pasture, floodplain pastures
Shrubland	Sparsely vegetated areas, sclerophyllous vegetation, transitional woodland–shrub
Woodland	Broadleaved woods, coniferous and mixed forests

(Table 3), we estimated the expected LULC areas by the end of an equal period into the future (2041), should the changing trends prevail. The woodland and permanent crop areas show an overall increasing trend, while the arable crop areas and shrublands show a decreasing trend.

Specifically, the area of permanent crops, mainly chestnut orchards, has increased by more than half, at the expense of 10% of the arable lands, reducing rural labor requirements. As in other regions of Europe, this change probably took place due to population migration, to the district capital Bragança or the main cities of Porto and Lisbon, which offer better education, business, and job opportunities (Cocca et al 2012; Corbelle-Rico and Crecente-Maseda 2014; Lasanta et al 2016; Šťastná and Vaishar 2017; Barnes et al 2020). This process explains the changes in arable land, one fourth less today than before. In total, the cultivatable land area—arable lands and permanent crops—decreased by more than 10%. Land abandonment and some afforestation have expanded the rangelands, mainly the woodlands, by 5%. The lack of wood gathering and grazing has permitted the development and evolution of vegetation, which, together with some afforestation, could explain the significant expansion of woodlands (Debussche et al 1999; Lasanta et al 2017). A new dam to supply freshwater to the district capital increased the water body class. Based on the 1995 and 2018 land cover maps, the LULC transition probability matrix analysis predicts the LULC areas for an equal period into the future (2041; Table 3). The changes are depicted through the 8 × 8 LULC class matrix table, in which rows represent the earlier land cover categories (1995), while columns represent the later land cover categories (2018). These data are essential to predict LULC areas in the future. Similarly, rows represent the year 2018, and the columns represent the year 2041.

The transition probability matrix (Table 3) indicates that water bodies (100%), woodlands (95.7%), built-up areas (93.7%), and permanent crops (90.5%) could change the least by the end of the projection period. According to the model, the shrubland (25.2%) and rock (32.7%) classes will be major contributors to woodland expansion. This dynamic corresponds to the vegetation's natural development and will obviously be influenced by any unpredictable forest fires (Lasanta-Martínez et al 2005; Zakkak et al 2018; Heydari et al 2020).

The cultivatable land shows significant adjustments. Only about two thirds of the cultivated area remains as arable land, which means an important part of it is transformed into other classes, such as permanent crops, woodlands through afforestation, pastures, and shrublands through land abandonment. Similarly, the pasture class shows instability: less than half remains. This has transitioned to arable land or has been abandoned to shrubland, which is attributed to intensifying agriculture on the better soils and abandonment on the worst. The rock class associated with burned areas also shows a natural instability due to vegetation recovering as shrublands and woodlands or being

TABLE 2 Land use and land cover change, 1995–2018 (ha).

1995	2018								
	Urban	Arable land	Permanent crop	Pasture	Woodland	Shrubland	Rock	Water	Total
Urban	**246**	0	2	0	1	13	0	0	262
Arable land	25	**5911**	831	608	745	537	0	0	8673
Permanent crop	2	23	**1652**	0	125	24	0	0	1826
Pasture	2	227	59	**458**	95	229	1	0	1071
Woodland	0	23	27	4	**7544**	284	0	0	7883
Shrubland	2	185	236	72	3830	**10,577**	280	22	15,205
Rock	0	3	10	0	114	122	**99**	0	348
Water	0	0	0	0	0	0	0	**27**	27
Total	294	6373	2816	1143	12,455	11,787	380	49	35,296

Note: Bold values indicate the area of a given land cover that did not change.

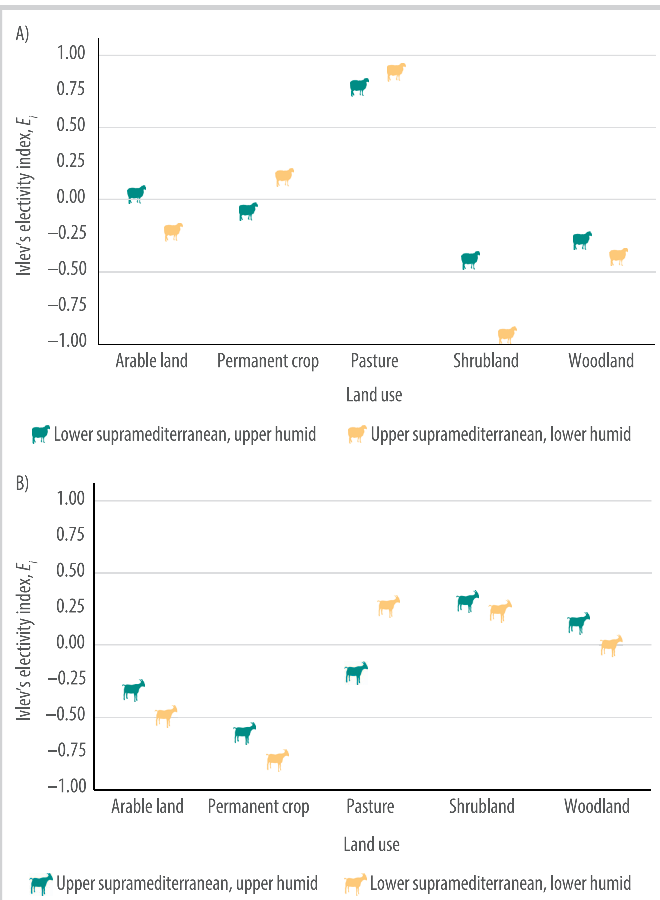
TABLE 3 Transition probability matrix for land cover classes (%; total in ha).

2018	2041								
	Urban	Arable land	Permanent crop	Pasture	Woodland	Shrubland	Rock	Water	Total
Urban	**93.7**	0.0	0.8	0.0	0.5	5.0	0.0	0.0	294
Arable land	0.3	**68.2**	9.6	7.0	8.6	6.2	0.0	0.0	6373
Permanent crop	0.0	1.3	**90.5**	0.0	6.9	1.3	0.0	0.0	2816
Pasture	0.1	***21.2***	5.5	**42.7**	8.9	***21.4***	0.1	0.0	1143
Woodland	0.0	0.3	0.3	0.1	**95.7**	3.6	0.0	0.0	12,455
Shrubland	0.0	1.2	1.6	0.5	***25.2***	**69.6**	1.8	0.1	11,787
Rock	0.0	1.0	2.8	0.0	***32.7***	***35.1***	**28.5**	0.0	380
Water	0.0	0.0	0.0	0.0	0.0	0.0	0.0	**100.0**	49
Total	299	4805	3459	998	15,856	9472	326	66	35,296

Note: Bold values indicate the percentage of given land cover that did not change; bold and italic values indicate significant changes.

restored by afforestation. The analysis indicates that transforming the different rangeland classes into agriculture classes is less likely than the opposite transformation, due to the shrinking of rural communities and the attractiveness of industries in the region. In Europe more generally, it is believed that 120 million ha of cropland has been abandoned since 1990 (Levers et al 2018), and these processes are not expected to be reversed in the future. Further, 11% of the European Utilized Agricultural Area is estimated to be under risk of abandonment in the period between 2015 and 2030 (Perpina Castillo et al 2018).

FIGURE 3 Sheep and goat land use and land cover preferences for reference sites (see Figure 2).



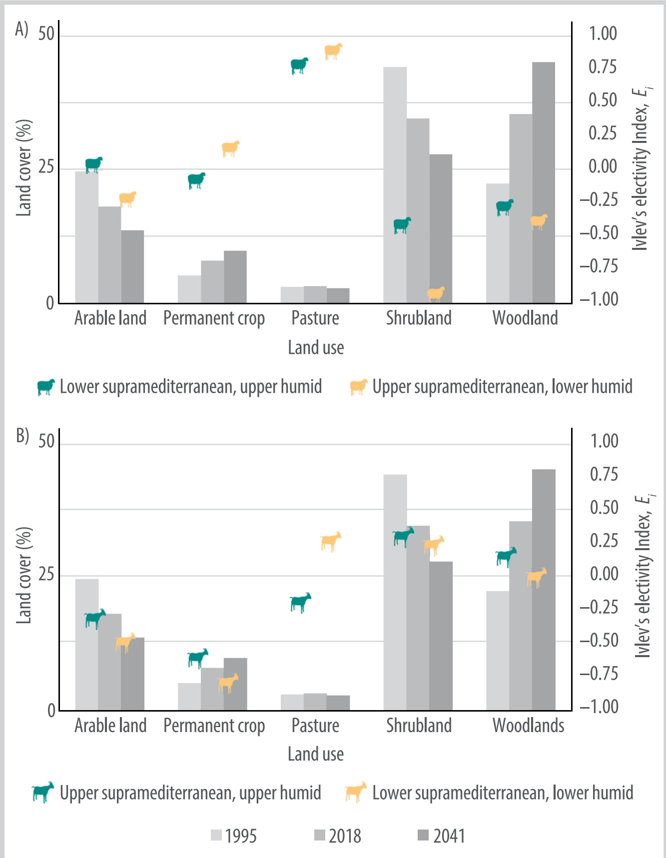
The model shows the particular evolution of the pasture class after a slight increase over recent decades, gaining from arable lands (7.0%). However, it will diminish over the next few years, as this class area shows important losses and a high rate of reverse transfers (21.2%) and transitions to shrublands (21.4%). As we will see later, this observed fact could be an important constraint to PNM pastoralism.

Preferences and alternatives for sheep and goats

Flock LULC selectivity markedly diverged between sheep and goats when comparing their pastoral routes (Figure 3). The Ivlev electivity index (E_i) shows that sheep preferred cultivated patches—pastures, arable lands, and permanent crops—more than the rangeland areas such as shrublands and woodlands, with E_i values positive for the first and negative for the latter. Goats showed an opposite trend, preferring shrublands and woodlands to agricultural areas. Previous studies have also described these patterns (Castro et al 2017; Ramalhosa et al 2018). Pastoral routes depend on both species' behavior and grazing opportunities (Baumont 2014; Bailey et al 2015; Meuret and Provenza 2015). The weather and fodder sensibilities of sheep suggest that pastoral routes and schedules are carefully chosen, especially during the hottest days of summer (Savini et al 2014). Ideally, sheep find forage near to the village in the pastures and among the byproducts of agriculture: fallow lands, orchard prunings, and foliage. They utilize more distant rangelands only when access to cultivated fields is not allowed during growing and harvest periods. In contrast, goat flocks cover longer routes and journeys without weather constraints and far away from shelter. They take advantage of cultivated patches only in especially abundant periods, such as harvest time: E_i values are positive for shrublands and woodlands and negative for arable lands and permanent crops.

LULC usage by sheep and goats also showed distinct changes between the studied sites (Figure 3). Pastures increase notably in warmer and drier situations for both

FIGURE 4 Changes in the Montesinho Natural Park pastoral landscape and sheep and goat landscape preference references.



species, but particularly for goats. The reduction of the forage quality of rangelands and agricultural byproducts in warmer and drier seasons (Dickhoefer et al 2011) could explain the decrease in electivity. Thus, even though they are usually limited to goats in the landscape, pastures can compensate for these changes. In the case of sheep, the permanent crop leftovers, mainly olive grove prunings in fall and winter, could also compensate for them.

Figure 4 overlays PNM pastoral landscape tendencies and sheep and goat selectivity in the referenced situations. Goat preferences for rangelands seem to vary according to their availability in the landscape; shrublands and woodlands have dominated and will still dominate the PNM pastoral landscape. This is not the case for sheep preferences, and limits in the preferred agricultural LULC classes could constrain sheep pastoralism in the PNM. However, adjustments favoring permanent crops, such as olive groves and chestnut orchards, could rebalance this. In both cases, pastures will play a key role in developing PNM pastoralism. On the other hand, animal preferences occur via a complex process that balances nutritional needs and resource availability (Papachristou et al 2005; Provenza et al 2015; Vilalba et al 2015). Therefore, their ability to adapt is more limited by their marked sensitivity to high temperatures than by availability of food resources.

Depending on circumstances, the PNM LULC trends could either meet or deviate away from sheep and goat preference trends in warming circumstances. The decrease in arable land and shrubland areas is likely to influence species selectivity in an environmentally changing context, despite arable lands being more challenging for sheep. In contrast, woodland enlargement is unlikely to meet both sheep and goat requirements in a changing context. Nevertheless, new permanent crop areas could help sheep to adapt to new environmental circumstances. Finally, limited pastures will always be the most restrictive factor to the development of pastoralism in the PNM. In all considered situations, the biggest challenge expected in future climate change projections for Mediterranean pastoral systems is decreased pasture productivity (Sebastià 2007; Nardone et al 2010).

Conclusions, limitations, and development needs

Global changes related to climate, migration, and policies have influenced the PNM landscape in terms of LULC patterns and dynamics. The pastoral routes are the shepherds' interpretation of the landscape opportunities and grazing availabilities for sheep and goats. The 2 species have similar overall relationships with vegetation cover, but the LULC composition of pastoral routes indicates different landscape use by both: sheep herds are always nearer to hamlets than are goats. The time perspective and the comparative approach we used allow us to infer and elucidate the relationships between the selectivity of sheep and goats and landscape change. The results highlight that the low level of pasture will remain, impacting grazing routes for sheep and goats in warming circumstances. Also, the expected expansion of permanent crops and forest areas could disrupt the goats' routes. Our results will help PNM pastoral landscape management, guiding livestock agricultural and environmental policies to consider the relationships between grazing and landscape changes. The study informs shepherds and farmers on the likely effects on their pastoral routes and informs national and local administrations on the likely effects of altering pastoral landscapes.

In the future, a closer understanding of the social context of local pastoralism is needed to outline possible LULC scenarios that differ from those deduced from the previous 2 decades of changes. Local practices by indigenous peoples reflect day-to-day adaptation. It is necessary to monitor those practices and changes in the pastoral landscape that have influenced sheep and goat LULC selectivity. Future developments must also include an ethnographic analysis to understand how traditional practices have adapted to global changes based on local knowledge. These should consider the knowledge of indigenous peoples as a major resource for adaptation to change.

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