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RESEARCH ARTICLE

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Activity budget and movement patterns of Brown Swiss and Alpine Grey lactating cows during summer grazing in alpine pastures

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ABSTRACT

We used GPS tracking to monitor the grazing patterns of Brown Swiss and Alpine grey lactating cows on an alpine summer pasture (2038 m a.s.l.; SD = 146) in the Dolomites. The pasture (171 ha) was managed with a continuous grazing system (0.52 LU/ha) with morning and evening milking in the barn, guided grazing during the 'day', and free grazing at 'night'. GPS positions were collected from 8 Brown Swiss multiparous and 9 Alpine Grey (4 primiparous and 5 multiparous) cows every two minutes. We inferred behaviours (grazing, resting, walking) from movement metrics, activity sensors and direct behavioural observations. After excluding milking periods, the cows grazed for 8 h/d, rested 10–11 h/d, and walked for 1.5/d. Grazing extended into late evening after milking, and resting prevailed throughout the 'night' until the morning milking. When grazing and resting, cows mainly used grasslands as the preferred habitat, but forest and sparse shrub were also used remarkably without consistent negative or positive selection. The pasture use was highly heterogeneous, with higher animal loads close to the barn, especially at night, and in areas with gentler slopes. Alpine Grey primiparous cows were less limited by slope and distance from the barn in their movement but were more selective in habitat use than multiparous cows. Differences between multiparous cows of the two breeds were less marked. Further studies should help understand the internal and external drivers of cattle grazing patterns to devise management practices combining animals' productivity and welfare with the conservation of the grassland ecosystem services.

HIGHLIGHTS

- Lactating cows in Alpine summer pastures spent daily 8 hours grazing, 10–11 hours resting, and 1.5 hours walking.
- The pasture was used unevenly. Grassland was the habitat most used and preferred by the cows, but forest and sparse forest were also used remarkably.
- Activity budget and pasture use differed more between primiparous and multiparous cows within breed than between multiparous cows of different breeds.

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Introduction

Alpine pastures are semi-natural ecosystems that play a crucial role in mountain livestock farming by providing forage for grazing herbivores. They may also deliver multiple non-provisioning ecosystem services, e.g. carbon stocking, soil erosion protection, water flow regulation, natural habitats and biodiversity conservation (Bunce et al. 2004; Schils et al. 2022). These pastures are managed through a variety of grazing systems (Probo et al. 2014; Pittarello et al. 2019), which aim at controlling livestock grazing patterns, to improve animal welfare and productivity, but also influence the ecosystem services associated with grasslands (Perotti et al. 2018; Schils et al. 2022). For example, high stocking rates may lead to over-grazing, which can transform grassland areas from sinks to carbon sources and modify soil conditions, microbial communities, and vegetation through animal trampling and excreta deposition (Bai and Cotrufo 2022).

In determining the actual grazing patterns, grazing systems interact with factors external and internal to animals (Rivero et al. 2021). Among the external factors,

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slope is known to limit movement (Kaufmann et al. 2013; Pittarello et al. 2021), and the availability and spatial distribution of shade, shelter, and water sources also influence that of animals in relation with climate conditions (Probo et al. 2014; Rivero et al. 2021). Additionally, vegetation is a very important factor determining the grazing patterns of animals. Cattle, if not prevented or limited by other factors, prefer patches of grasslands rich in highly palatable and digestible plants and tend to avoid less productive habitats such as dwarf shrub (Koch et al. 2018) and forest (Raniolo et al. 2022), except when resources in the grassland patches have been depleted (Schoenbaum et al. 2017). Less is known about differences in activity budgets between daytime and nightime. Although grazing predominates during the day and resting during the night, Kilgour (2012) found, in the studies he reviewed, an extensive variability in the proportion of time spent grazing between these two periods by cattle at pasture but did not attempt to explain it. Among the factors internal to the animal, cattle breeds may differ in the selection of slopes and altitudes (Pauler et al. 2020; Raniolo et al. 2022), activity budgets (Hessle et al. 2008; Spiegal et al. 2019), and plant species selection (Hessle et al. 2014; Koczura et al. 2019; Spiegal et al. 2019). Generally, local breeds are more suited to harsher areas than highly productive breeds, such as Holstein or Brown Swiss (Hessle et al. 2014; Zendri et al. 2016). Within breeds, younger individuals are smaller than mature individuals, which should favour them in moving over challenging terrain (Pauler et al. 2020).

Recently, the study of grazing patterns has greatly advanced with the rapid expansion of GPS tracking technology, which allows monitoring individual positions with a spatial accuracy of a few metres and a time frequency as low as minutes or even seconds (Tomkiewicz et al. 2010; Párraga Aguado et al. 2017). Additionally, sensors associated with GPS tracking devices enable to monitor the behaviour of animals in continuum and without observers' interference (Cagnacci et al. 2010; Semenzato et al. 2021), which has dramatically improved the understanding of the movement ecology of free-roaming animals (Nathan et al. 2022) and the grazing patterns of domestic livestock (Bailey et al. 2018; Rivero et al. 2021).

In this study, we aimed to compare the activity budgets and use of habitat and space of lactating cows during summer grazing in a high-elevation alpine pasture managed with a combination of loose rotational and continuous grazing. We compared time spent grazing, resting, and walking during 'day' and 'night' and in different habitats (grassland, forest, and sparse shrub). We also assessed the intensity of use of the pasture area in relation with day period, habitat type and land morphology (slope). In these comparisons, we included an assessment of the differences between Alpine Grey, a local dual-purpose breed of the eastern Alps (https://www.grigioalpina.it/), and Brown Swiss, a cosmopolitan dairy breed (http://www.anarb.it/en/home/). Raniolo et al. (2022) suggested that Alpine Grey might be more suitable for grazing in mountain pastures than Simmental, a larger and more productive dual-purpose breed (https://www.anapri.eu/it/), and we aimed to expand this finding by including a more specialised dairy breed as Brown Swiss. Additionally, we took advantage of the availability of different parity categories within the Alpine Grey breed to compare primiparous and multiparous cows.

Material and methods

Study area

The study was conducted during the summer of 2020 in the 'Vallazza' summer farm, located in the Natural Park 'Parco Naturale Paneveggio Pale di San Martino' in the Trento province, eastern Italian Alps (46°18′28″N, 11°44′38″E – Figure 1). Summer farms are temporary units traditionally used in the Alps for the seasonal transhumance of livestock that is moved from lowland permanent farms to graze alpine pastures (Zendri et al. 2016; Sturaro et al. 2013). The 'Vallazza' summer farm is at 2038 m a.s.l. (SD = 146) where the climate is alpine (Tattoni et al. 2010), with long and cold winters (mean October-April 2000 to 2021: precipitation = 132.8 mm ± 295.3 mm; temperature = −1.1° ± 5.5°) and fresh and rainy summers (mean June-September 2000–2021: precipitation = 147.5 mm ± 48.1 mm; temperature = 10.9° ± 3.9°).

The pasture area of the summer farm is partly delimited by natural barriers (steep slopes and rocky areas) and partly fenced with electrified wire, which is standard practice in the Italian Alps. Within this area, we identified the 'grazed area' (171 ha, Figure 1) as the surface enclosing, with a buffer of 50 m, all the retained GPS positions (see below for details on GPS positioning), in QGIS 3.22.7 (http://www.qgis.osgeo.org/), using the EPSG 4326 and 32632 coordinate systems. We then generated digital maps of the grazed area. We created a raster map of slope (mean = 15.3°; SD = 7.9°), with a resolution of 25 m, from the Digital Terrain Model (DTM) provided by the Natural Park 'Parco Naturale Paneveggio Pale di San Martino' (https://siat.provincia.tn.it/stem/). We digitised a vector map of the habitats on a fixed scale of 1:2500 from

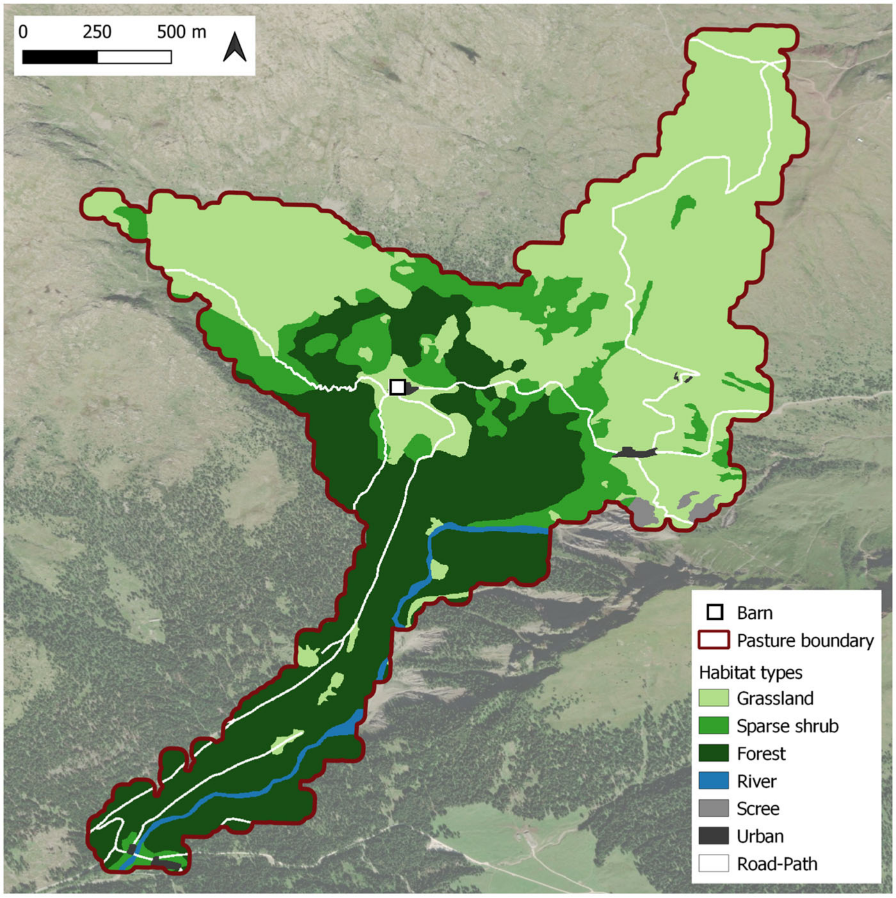

Figure 1. Grazed area with main habitat types. The external red line delimits a raster map (25 m resolution) encompassing all the GPS locations plus an external buffer of 50 m. The habitats are mapped as vectors at a fixed scale of 1:2500 (see main text for details).

the satellite images of the ArcGIS server (https://server.arcgisonline.com/ArcGIS/rest/services/World_Imagery/MapServer), with 7 'habitat types': 'grassland' (48% of the surface), 'forest' (*Picea abies* and/or *Larix decidua* stands, 34%), 'sparse shrub' (grassland mixed with shrub – mostly *Rhododendron* spp., 12.6), 'road-path' (paved roads or forest paths, 3.3%); 'stream' (stream beds, 1.3%), 'scree' (areas covered by loose stone with little vegetation, 0.3%), 'barn' and 'urban' (0.5% altogether).

Summer farm management and animals sampled

This summer farm has a long history of continuous grazing (Zanella et al. 2010), and during the study period hosted a herd of dairy cattle (89 livestock units – LU) of mixed breeds (Brown Swiss, Alpine Grey), with a low stocking rate (0.52 Livestock LU/ha). Lactating cows were milked twice daily in the barn, starting at approximately 6 am and 5 pm. Each day, after the morning milking, they were conducted by the shepherds to graze in a different section of the pasture area, where they were then left free until they returned to the barn for the evening milking, after which they were again released free to spend the night outdoor. During the milking, all cows received a concentrate supplement (composition: crude protein: 14.7%; crude fibre: 6.1%; crude fat: 3.4%; total ash: 5.2%. Amount: Alpine Grey = 4 Kg head/d; Brown Swiss = 6 Kg/d), which is a common practice in these grazing systems (Zendri et al. 2016).

We monitored 9 Alpine Grey (4 primiparous and 5 multiparous) and 8 multiparous Brown Swiss cows from 5 July to 5 September 2020. We selected individuals that were expected to maintain lactation throughout the whole study period. Due to the herd composition, we could not match the parity distribution of the two breeds. We considered the imbalance between groups in the statistical analysis (see below). Individual milk yields were obtained from the monthly milk recordings (excluding August, when controls are suspended) collected by the Breeders Association of Trento and averaged for each cow. Individual live body weight was recorded at the beginning and at the end of the grazing season, using a mobile scale for livestock (TW1 Weigh Scale, Gallagher, Hamilton, New Zealand) with 100 g precision, and averaged for each cow. We classified cows for 'breed-parity' as 'Brown Swiss multiparous', 'Alpine Grey primiparous' and 'Alpine Grey multiparous' and compared milk yields and live body weight of the three categories with a simple one-way ANOVA.

Movement data collection

We monitored the movement patterns of the cows with GPS collars (Vertex Plus model, Vectronic Aerospace GmbH) scheduled to record a position every 2 min. Since we had only 9 collars available, we divided the cows into 2 groups of 9 and 8 individuals, distributed across breed-parity categories, sequentially monitored for one month each. One GPS collar failed to acquire positions after August 1. We obtained 362,157 positions out of the 372,803 scheduled (position acquisition rate: 97,1%). With this high acquisition rate, we assumed the median position error to be within 6 m (Párraga Aguado et al. 2017). We pre-processed acquired positions data in PostgreSQL 14 (https://www.postgresql.org/docs/14/index.html) with the plugin PostGIS 3.1.5 (http://postgis.net/2022/02/01/postgis-3.1.5/). We first eliminated all impossible positions (e.g. peaks of mountains, etc.) and then excluded the remaining outlier positions with the procedure used by Raniolo et al. (2022). Briefly, this procedure identifies the outlier positions as those associated with unreliable movement speed and/or abnormal deviations from the movement trajectory (e.g. the spatial-temporal sequence of locations). Since our schedule of position collecting covered the whole day, we needed to exclude the periods spent in the barn by each cow during milking. For this purpose, we used a procedure like that of Raniolo et al. (2022). We first identified the potential milking periods that included the locations collected between 5:00 to 8:00 am and 4:00 to 7:00 pm inside a 50 m buffer surrounding the barn. Within these periods, we then identified the actual individual milking periods as the sequences of 10 min time intervals having more than 3 missed locations (when GPS are inside buildings, the probability of acquiring locations drops because of the physical obstruction to the satellites' signal) and average acceleration values of the x and y activity sensors (see below) lower than 35 (which indicates inactivity). We excluded the positions recorded during the actual individual milking periods and checked visually for consistency of the resulting individual cows' outdoor daily movement trajectories.

The GPS collars were equipped with a tri-axial activity sensor set by the manufacturer to store acceleration values (0–255) as averages over five-minute intervals. We used accelerometer data combined with metrics of movement steps (e.g. the segments linking consecutive pairs of locations) to classify positions according to three 'behaviour categories': 'grazing' (i.e. bouts of biting, chewing, and swallowing, also if interrupted by relocation movements between clusters of plants; Owen-Smith et al. 2010); 'resting' (standing without leg movements or lying); 'walking' (with a clear directionality, without interruptions for grazing). The classification and validation procedures are described in detail in Supplementary Appendix S.1. Briefly, we trained a random forest classifier (Liaw and Wiener 2002; Homburger et al. 2015) by matching the known behaviour associated with 2,237 positions to the corresponding accelerometer values and movement metrics. The final geodatabase contained 269,963 outdoor locations, which we classified into two 'day-periods': 'day' (between the morning and evening milking) and 'night' (between the evening and morning milking) and associated with the corresponding individual cows' features ('individual', 'breed-parity'), temporal variables ('Julian date', 'hour'), linear distance from the barn ('barn distance'), movement features ('slope' and 'speed', calculated as the distance in m between each consecutive pair of locations divided by the time in seconds separating their acquisition – Urbano and Cagnacci 2014), 'habitat' (the habitat type corresponding to the position), and behaviour.

Daily activity budget of cows

For each day of monitoring, we computed the hours spent in each behaviour category ('grazing time', 'resting time', 'walking time') by each cow during each day-period as $NB_i/30$, where NB_i is the number of locations (collected every 2 min) assigned to each behaviour. We analysed grazing time, resting time and walking time separately for each day-period, because their values across the whole day had a bimodal distribution. We used linear mixed models with the 'lmer4' function of the 'lme4' library (Bates et al. 2015) in R 4.2.0 (R Core Team 2016) to test the effects of breed-parity as a fixed factor and of the individual cow nested into breed-parity as a random factor (Table S.2.1). We assessed the model's marginal R^2, due to fixed factors only, and the conditional R^2, due to fixed plus random factors (Nakagawa and Schielzeth 2013) with the Performance package (Lüdecke et al. 2021). We verified that the larger sample size of the 'Brown Swiss multiparous' group did not influence the results by applying a stratified bootstrap (Nigam and Rao 1996; Pons 2007) with 1000 replications, using breed-parity to define strata. This procedure uses a resampling weighted on the class numerosity and is suitable for analysing data classes with variable sample sizes. We checked that the bootstrapping results were consistent with those of the simple model. For the sake of simplicity, we showed in the main text the results of this model and reported in supplementary material (Table S.2.2) the outputs of the stratified bootstrap.

Movement and use of pasture

We evaluated how behaviour, breed-parity, day-period and land morphology influenced the cows' movement patterns and use of pasture with three approaches. First, we examined the probability of using different habitats; second, we assessed the fine-scale spatial use of pasture; third, we compared the size of the areas that individual cows used daily. For the analyses of habitat use and daily areas used by cows, we verified the absence of interference by sample size as above described with a stratified bootstrap (see Table S.2.4 and Table S.2.7). For the analysis of fine-scale intensity of use of pasture we used total data, instead than individual data. In addition, we normalised frequencies of locations before mapping and scaled variances for comparing models with different sample size (see below for details).

Habitat use

We excluded the habitats seldom used (road-path, stream, scree, farm, urban). We used a multinomial model in the function 'multinomial' of the 'nnet' library (Venables and Ripley 2002) to assess the probability of a cow to be using forest, sparse shrub, or grassland as a function of the 2-way interactions between breed-parity and day-period, behaviour and day-period, breed-parity and slope, day-period, and barn distance (Table S.2.3).

Fine-scale intensity of use of pasture

We examined how spatially structured effects affected the fine-scale use of the grazed area based on the frequency distribution of cows' positions discretised within a grid of 25 × 25 m cells aligned with the DTM. We classified each cell for the summed number of positions of each breed-parity category during each day-period of the study duration. We first mapped the intensity of use to compare the total use of pasture with those during the 'day' and 'night' and the use of pasture when grazing, resting, and walking. For this purpose, we normalised the intensity of use as proportion of the maximum use (number of locations per pixel) recorded for each day-period and behaviour. To analyse spatially structured factors influencing space use we then assigned to each cell the 'prevalent habitat', which we defined as 'grassland', 'sparse shrub', and 'forest' when their percent cover was higher than 50% of the cell, the slope, and the linear distance (m) from the cell's centre to the barn. We analysed the positions' frequency with the INLA (Integrated Nested Laplace Approximation) approach, which works on a Bayesian framework using the SPDE (Stochastic Partial Differential Equations) methodology and allows to manage error covariance due to spatial autocorrelation (Rue et al. 2009; Homburger et al. 2015). We used the 'INLA' function of the INLA library (Rue et al. 2009) in R 4.2.0 (R Core Team 2016) to compare breed-parities and day-periods with six models (Table S.2.3), one for each combination of breed-parity and day-period, using six corresponding sub-datasets. We set the option 'scale.model = TRUE' in the INLA models to standardise the variance to 1, enabling the comparison of the models' results (Freni-Sterrantino et al. 2018). The models assumed a zero-inflated negative binomial distribution due to the high frequency of 0 values. They included the random spatial effect of the single cell (to account for the autocorrelation of neighbouring cells) and the fixed effects of habitat prevalence ('grassland', 'sparse forest', 'forest', each one expressed as a separate binomial variable yes/no), slope, and barn distance (log-transformed). For hyperparameter specification, we set the parameters and the diffuse prior distribution as in Homburger et al. 2015 (spatial structured effect (τ_s): Gamma distribution with shape 1 and rate 0.00025; unstructured effect (τ_ε): Gamma distribution with shape 0.5 and rate 0.00149). We computed the approximations of model posterior marginals with the empirical Bayes approach and the Gaussian method to balance between accuracy and computational cost. We compared the models with a forest plot to highlight possible differences in terms of statistical relevance (Anzures-Cabrera and Higgins 2010).

Daily areas used by cows

We used a utilisation distribution (UD) method to calculate the surface (in ha) of the areas used daily by individual cows during 'day' and 'night' with the function 'kernelUD' of the adehabitatHR library (Calenge 2011) in R 4.2.0 (R Core Team 2016), using 90% and 50% of the locations with the smoothing parameter set at 25 m. This is a common approach to estimate the total area used (90%,' total area', excluding the 10% most peripheric and occasional locations) and, within that, the portion used most intensively (50%, 'core area') by free-roaming animals (Viana et al. 2018; Floyd et al. 2022). We analysed the size of total areas and core areas with a generalised linear mixed model using the 'glmer' function of the 'lme4' library (Bates et al. 2015) based on a Gamma distribution and a log link function. The model (Table S.2.4) included the fixed effects of the 2-way interaction between breed-parity and day-period and of Julian date as a linear covariate, plus the random effect of individual cows nested into breed-parity. We assessed the model's marginal R^2, due to fixed factors only, and the conditional R^2, due to fixed plus random factors (Nakagawa and Schielzeth 2013) with the Performance package (Lüdecke et al. 2021).

Results

Milk production and live body weight

Live body weight differed markedly between breed-parities ($p < 0.001$) with the expected ranking order, being lowest for Alpine Grey primiparous, intermediate for Alpine Grey multiparous, and highest for Brown Swiss multiparous (GLM least square means: 565.6 kg, SE = 18.7; 603.8 kg, SE = 20.8; 689 kg, SE = 13.9; respectively). Milk yield also varied significantly ($p < 0.05$) between breed-parities, but with a different ranking order: it was again lowest for Alpine Grey primiparous, slightly higher for Brown Swiss multiparous, and clearly highest for Alpine Grey multiparous (GLM least square means: 15.1 kg/day, SE = 1.7; 17.1 kg/day; SE = 1.2, 22.2 kg/day, SE = 1.8; respectively).

Activity budgets

The hours spent grazing were influenced by breed-parity ($p < 0.01$) during the 'day' but not during the 'night' (Table S.2.1). During the 'day' (Figure 2A), Alpine Grey primiparous cows grazed on average for 4:30 h (SE = 0:12), Alpine Grey multiparous for 5:02 h (SE: 0:14), and Brown Swiss multiparous for 5:23 h (SE: 0:10). During the 'night' (Figure 2B), cows of all breed-parity categories grazed for 2:36–2:54 h (SE = 0:07–0:10). The hours spent resting were also influenced by breed-parity during the 'day', but, again, not during the 'night' (Table S.2.1). During the 'day' (Figure 2C), Alpine Grey primiparous cows rested longer (3:15 h, SE = 0:11) than Brown Swiss and Alpine Grey multiparous cows (2:37–2:54 h; SE = 0:07–0:12). During the 'night' (Figure 2D), resting time varied between 7:39 and 7:57 h (SE = 0:08–0:11) among breed-parity categories. Finally, time spent walking was unaffected by breed-parity during both 'day' and 'night' (Table S.2.1; Figure 2.E and 2.F, respectively). During the 'day', cows walked for 1:20–1:30 h (SE = 0:08–0:11), and during the 'night' for 0:22–0:28 h (SE = 0:03–0:04).

The random effect of the individual cow (Table S.2.1) explained around 60% of the total pseudo R^2 of the models analysing grazing and resting times, and almost all of that of the model analysing walking times.

Habitat use

After accounting for the effects of slope and barn distance (Figure S.2.1), which substantially reflected the spatial distribution of the habitats (Table S.2.3), the habitat use was significantly affected by the 2-way interactions of behaviour with day-period and behaviour with breed-parity (Table S.2.3 and Figure 3).

When grazing and resting during the day, the cows used predominantly grassland (probability of use, grazing: 0.531, SE = 0.002; resting: 0.678, SE = 0.003) followed by sparse shrub (probability of use, grazing: 0.289, SE = 0.002; resting: 0.196, SE = 0.002) and forest (probability of use, grazing: 0.179, SE = 0.002; resting: 0.126, SE = 0.002). When grazing and resting during the 'night', the cows used grassland more (probability of use, grazing: 0.557, SE = 0.003; resting: 0.609, SE = 0.002) than sparse shrub (probability of use, grazing: 0.234, SE = 0.002; resting: 0.272, SE = 0.001) and forest (probability of use, grazing: 0.209, SE = 0.002; resting: 0.119, SE = 0.001). When walking during the 'day', cows used grassland (probability of use: 0.379, SE = 0.004) and sparse shrubs (probability of use: 0.396, SE =0.004) similarly and more than forest (probability of use: 0.225, SE= 0.003). During the 'night', they used grassland (probability of use: 0.460, SE = 0.006) more than sparse shrub (probability of use: 0.298, SE = 0.006) and forest (probability of use: 0.242, SE = 0.003).

When grazing, Brown Swiss multiparous cows used grassland less (probability of use: 0.508, SE = 0.002) than Alpine Grey primiparous (probability of use: 0.573, SE = 0.003) and Alpine Grey multiparous cows (0.584, SE = 0.003), but used forest more (probability of use, Brown Swiss multiparous: 0.240, SE = 0.002;

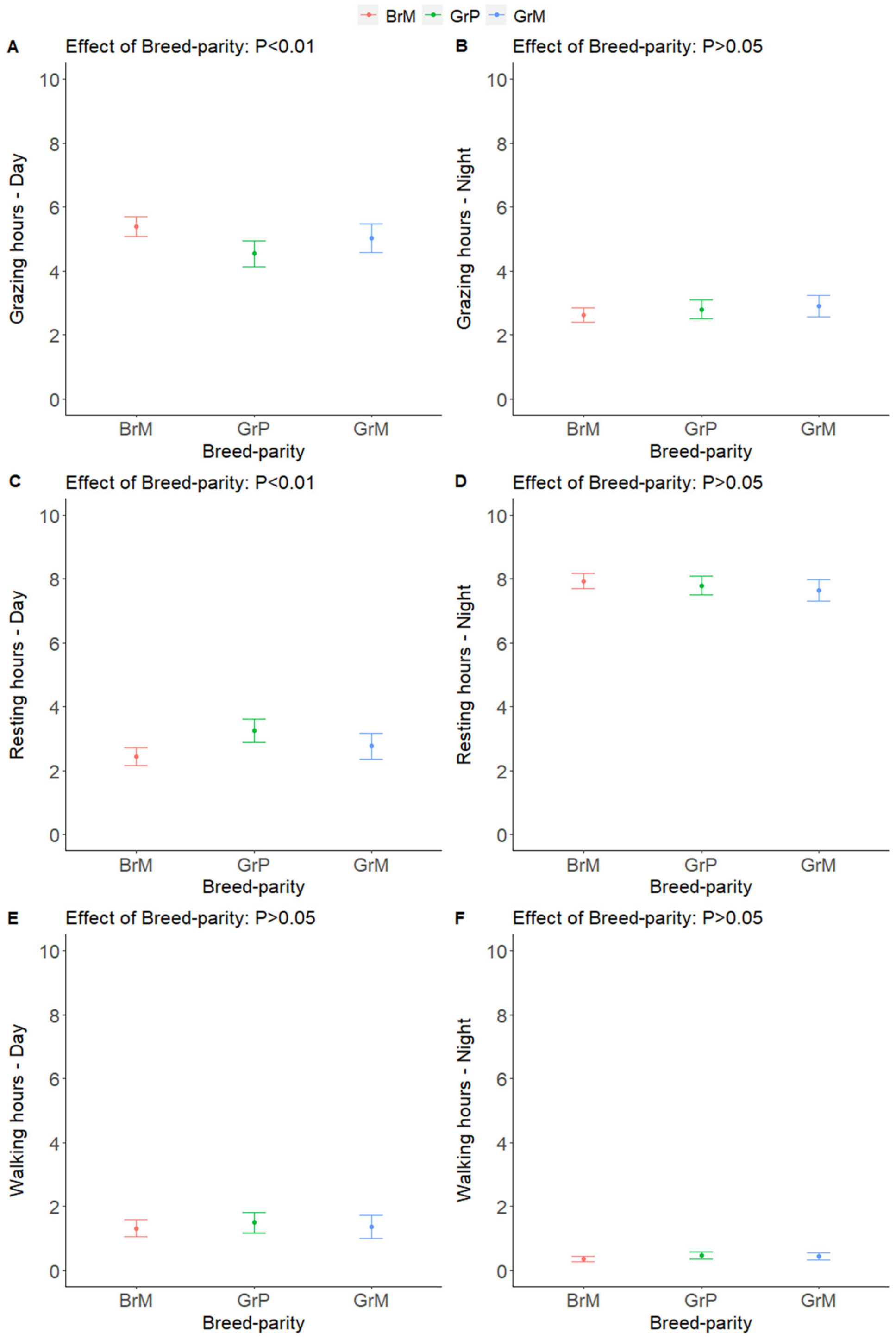

Figure 2. Effects of breed-parity on the hours spent grazing (A and B panels), resting (C and D panels) and walking (E and F panels) during 'day' and 'night'. 'BrM': Brown Swiss multiparous; GrM: Alpine Grey multiparous; GrP: Alpine Grey primiparous. Whiskers indicate 95% confidence intervals. For details of the parametric coefficients of the statistical models see Supplementary Table S.2.1.

Alpine Grey primiparous: 0.155, SE = 0.002; Alpine Grey multiparous: 0.166, SE = 0.002). The use of sparse shrub did not differ between breed-parities (probability of use: 0.250–0.270, SE: 0.002–0.003). When resting, Brown Swiss multiparous cows used grassland less (probability of use: 0.601, SE = 0.002) than Alpine Grey primiparous (probability of use: 0.667, SE = 0.002) and Alpine Grey multiparous (probability of use: 0.663, SE = 0.003), while used forest more (probability of use, Brown Swiss multiparous: 0.152, SE = 0.001; Alpine Grey primiparous: 0.121, SE = 0.002; Alpine Grey multiparous: 0.079, SE = 0.001).

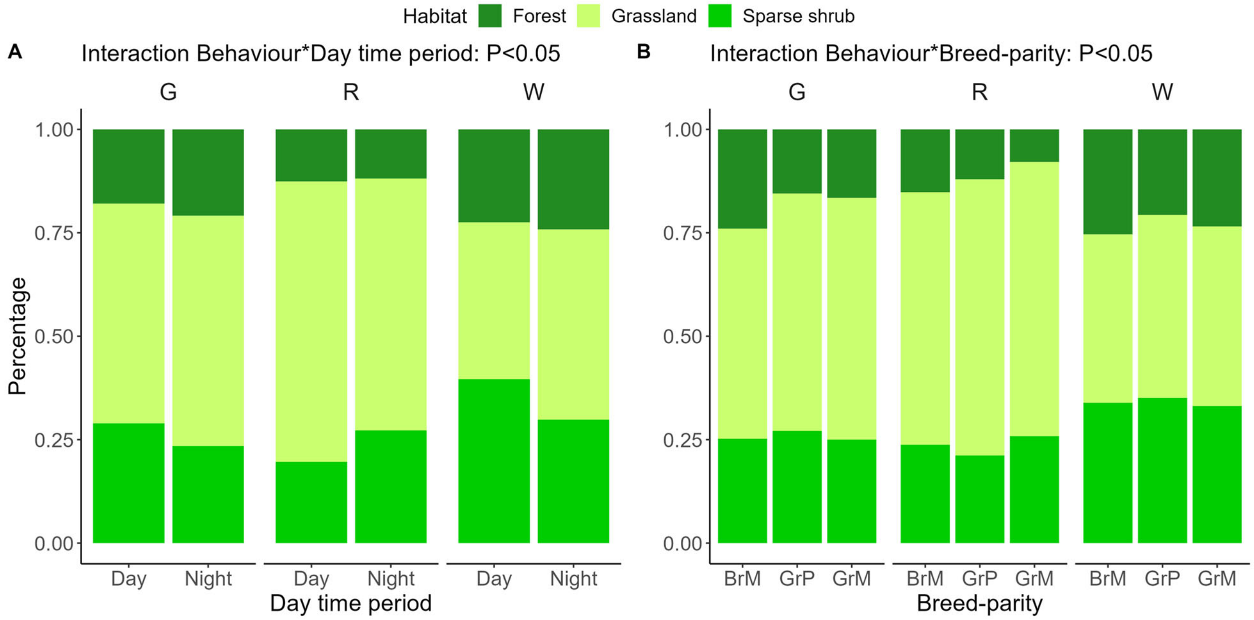

Figure 3. Estimated probability of using different habitats as a function of the interactions between behaviour and day time period (panel A) and behaviour and breed-parity (panel B). G: grazing; R: resting; W: walking. G: grazing; R: resting; W: walking. BrM: Brown Swiss multiparous; GrP: Alpine Grey primiparous; GrM: Alpine Grey multiparous. See Table S.2.2 for the model's parameters.

Use of sparse shrub was lower for Alpine Grey primiparous (probability of use: 0.212, SE = 0.002) than for Alpine Grey multiparous (probability of use: 0.259, SE = 0.002) and Brown Swiss multiparous (probability of use: 0.238, SE = 0.002). When walking, Alpine Grey primiparous cows used forest less and grassland more than Alpine Grey multiparous and Brown Swiss multiparous cows (probability of forest use, Alpine Grey primiparous: 0.207, SE = 0.004; Alpine Grey multiparous: 0.235, SE = 0.004; Brown Swiss multiparous: 0.254, SE = 0.003; probability of grassland use, Alpine Grey primiparous: 0.443, SE = 0.006; Alpine Grey multiparous: 0.434, SE = 0.007; Brown Swiss multiparous: 0.407, SE = 0.005), while cows of all breed parities used sparse shrub similarly (probability of use: 0.332–0.351, SE = 0.005–0.006).

Fine scale intensity of spatial use

The intensity of use of the pasture area was highly uneven (Figure 4A), with an evident dilution in the peripheral areas and increasing distance from the barn. This pattern was much more intense during the 'night' (Figure 4C) than during the 'day' (Figure 4B). When grazing, the cows used less heterogeneously a wider area of pasture (Figure 4D) than when resting (Figure 4E). When walking, they mostly used narrow paths (Figure 4F).

The posterior estimates of the INLA models analysing the fine-scale spatial use of the pasture by the cows are shown in Table S.2.5. During the day (Figure 5A), the intensity of use of grassland was higher than expected (positive effect) and that of sparse shrub did not differ from expected (no effect) for all bred-parity categories. The intensity of use of forest was lower than expected for Alpine Grey primiparous, did not differ from expected for Alpine Grey multiparous, and was higher than expected for Brown Swiss multiparous cows. Distance from barn and slope significantly negatively affected the intensity of use for all breed-parity categories, less markedly for Alpine Grey primiparous than for the other categories. During the 'night' (Figure 4C), the intensity of use was higher than expected in grassland and did not differ from expected in sparse shrub and forest for all breed-parity categories. Distance from the barn and slope confirmed the negative effect on the intensity of use observed during the day.

Total areas and core areas used

The size of both the total areas and core areas decreased with increasing Julian date ($p < 0.001$; Table S.2.6 and Figure S.2.2) and was strongly influenced by the 2-way interaction between day-period and breed-parity (Table S.2.6). The total areas (Figure 6A) did not differ between breed-parity categories and were much wider during the 'day' (12.45–12.92 ha, SE = 0.03–0.04) than during the 'night' when they were smaller for Brown Swiss multiparous (4.32 ha, SE = 0.02) than for

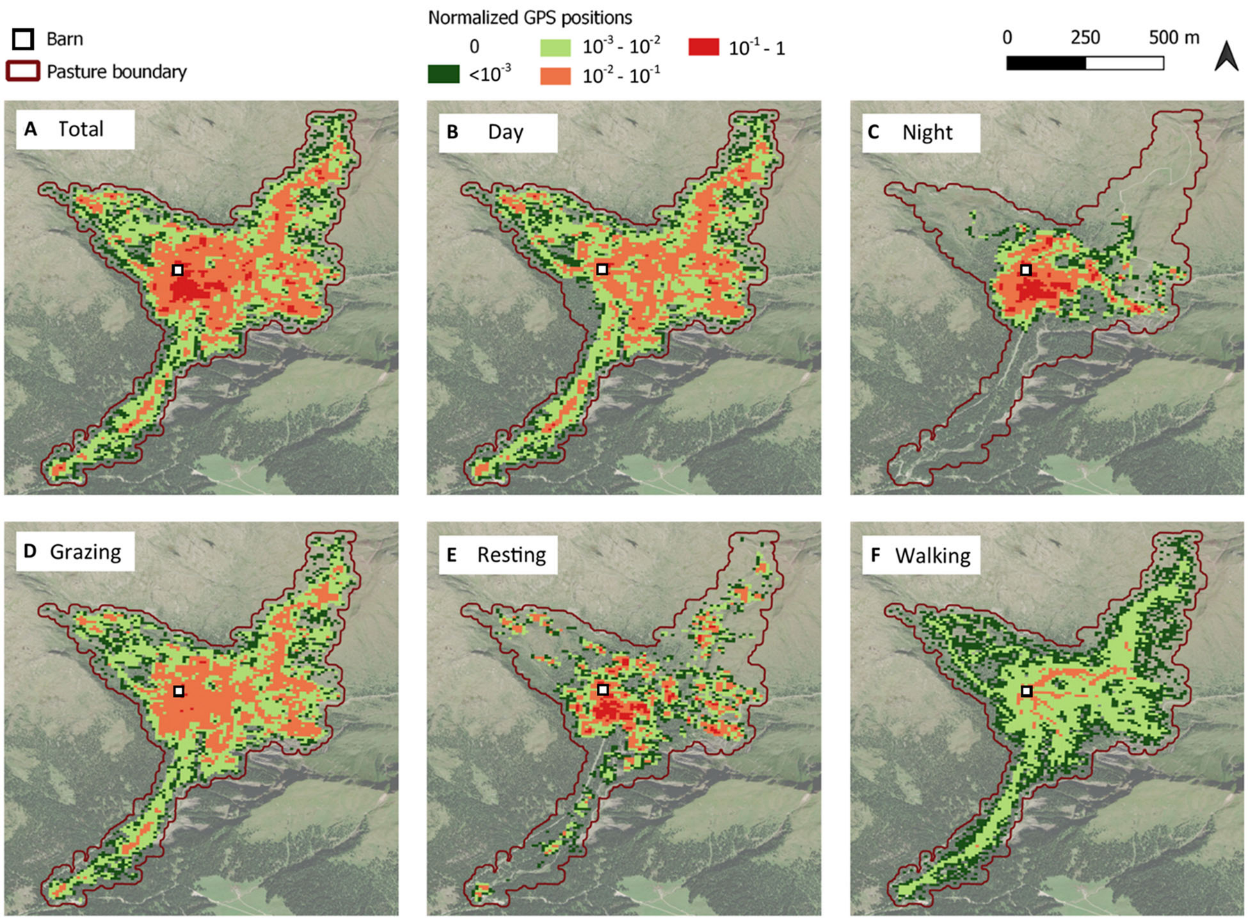

Figure 4. Maps of the intensity of fine-scale spatial use of the pasture area by all the cows, normalised as proportion of the maximum number of locations per pixels, during the whole day (panel A) and during the day-periods 'day' (panel B) and 'night' (panel C), and when grazing (panel D), resting (panel E) and walking (panel F).

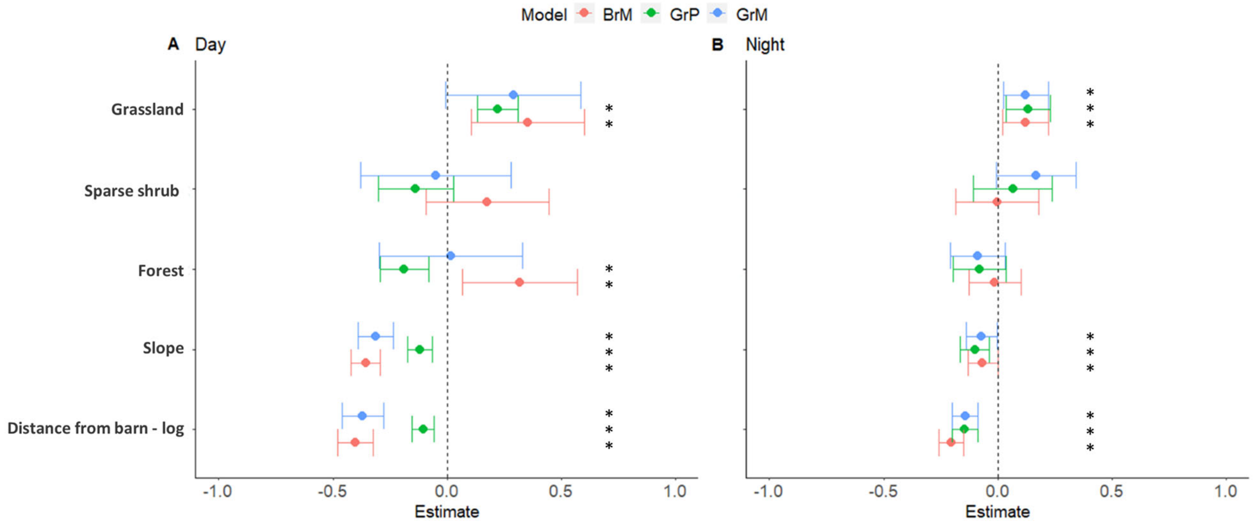

Figure 5. Estimated effects of prevalent habitat type (grassland, sparse shrub and forest), distance from barn, slope, and breed-parity (BrM: Brown Swiss multiparous; GrM: Alpine Grey multiparous; GrP: Alpine Grey primiparous) on intensity of pasture use during 'day' (panel A) and 'night' (panel B). horizontal whiskers indicate 95% credibility intervals of posterior estimates, which differ significantly when whiskers do not overlap with the dotted line at estimate = 0. The asterisks (*) indicate statistical relevance. The INLA (Integrated Nested Laplace Approximation) structured spatial effect was based on a Gamma prior to τ_s with shape 1 and rate 0.00025. For details of the parametric coefficients of the statistical models see Supplementary Table S.2.3.

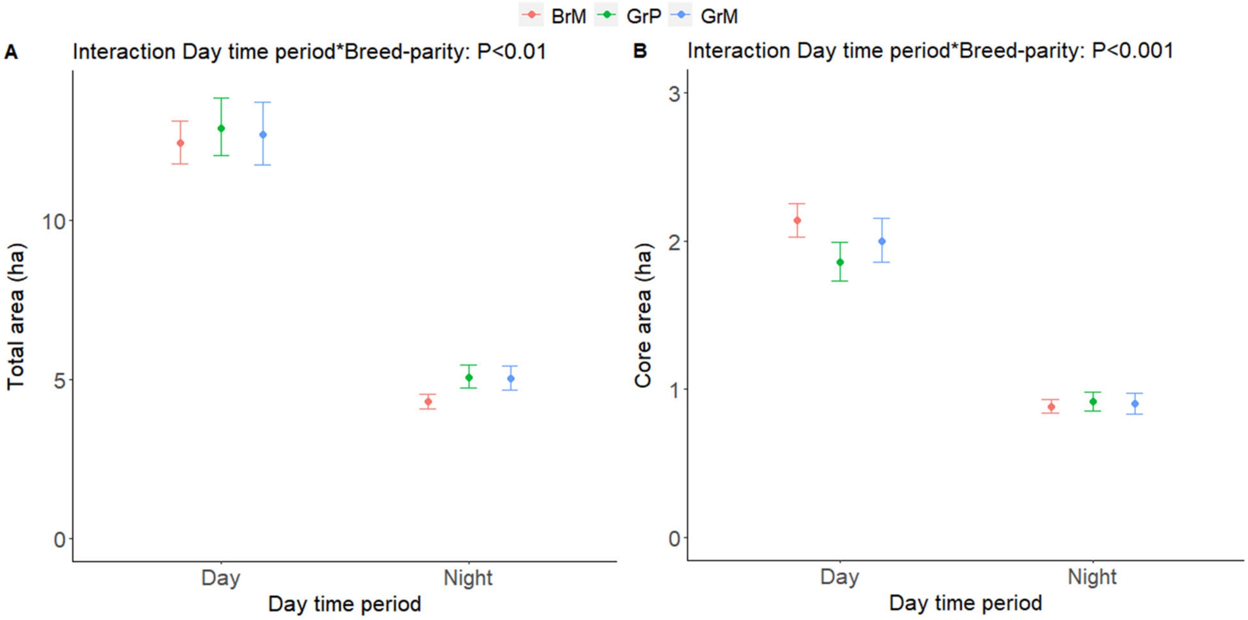

Figure 6. Effects of the 2-way interaction between breed-parity and day-period on the surface (ha) of total areas (90% of locations, panel A) and core areas (50% of locations, panel B; note that the scale of the y axis differs from that of panel a). Whiskers indicate 95% confidence intervals. BrM: Brown Swiss multiparous; GrM: Alpine Grey multiparous; GrP: Alpine Grey primiparous. For details of the parametric coefficients of the statistical models see Supplementary Table S.2.4.

Alpine Grey multiparous and Alpine Grey primiparous cows (5.04 ha, SE = 0.03; 5.09 ha, SE = 0.03, respectively). The core areas (Figure 6B) were wider for Brown Swiss multiparous than for Alpine Grey multiparous and Alpine Grey primiparous cows during the 'day' (2.14 ha, SE = 0.03; 2.00 ha, SE = 0.04; 1.85 ha, SE = 0.04, respectively), and were much smaller without differences between breed-parity categories during the 'night' (0.88–0.92 ha, SE = 0.03–0.04).

The models' conditional R^2 were good (0.68–0.71) and the random effect of the individual was almost negligible (Table S.2.6).

Discussion

Activity budget during day and night

During the 24 h, the cows generally spent approximately 8 h grazing, 10–11 h resting, and 1.5 h walking. Of the total daily grazing time, approximately 30% occurred in the 'night' period between the evening and the morning milking. Therefore, grazing during the 'night' period is important for the daily forage intake of the cows, and this might conflict with specific management practices. In the past, cows were kept inside the barn after the evening milking and released only after the next morning's milking. This practice is now rare but still practised (Raniolo et al. 2022), and likely reduces the time cows have available for grazing. Maintaining high forage intakes might also be problematic if 'night' fencing or keeping in the barn were adopted to protect livestock from the rapidly expanding alpine wolf population (Marucco et al. 2022). However, this practice should be relevant for more vulnerable cattle categories than adult cows, such as young heifers (Faccioni et al. 2015), which we did not consider in this study.

When free to roam, cattle show two major daily bouts of grazing associated with sunrise and sunset (Kilgour 2012). This daily grazing rhythm might be influenced by climate, especially temperature, since cattle respond to heat stress by reducing activity and feed intake (Silanikove 2000). Heat stress is not uncommon for cattle in temperate climates during summer (Veissier et al. 2018) and will become more frequent because of global warming. Under heat stress, cattle might show behavioural plasticity by anticipating the morning grazing bout and delaying and prolonging the evening bout, as observed in other heat-sensitive herbivores (Semenzato et al. 2021) and as claimed by shepherds (Ramanzin M. personal communication). Management practices might conflict with this adaptative response. For example, the hourly activity budget of the cows (Figure S.2.3) shows how grazing did not start in the morning after the milking and was interrupted in the afternoon when they walked back to the barn for the evening milking, to resume only afterwards. A reduced grazing time during the day should be compensated by increased grazing time into the deep hours of the 'night', which are now dedicated almost exclusively to resting.

Habitat use in relation with activity budget and day-period

Grassland was the most used habitat, but sparse shrub and forest were also remarkably used. The fine-scale analysis of the spatial use of pasture indicated that the cows preferred grassland patches but did not show any clear or consistent preference or avoidance for sparse shrub and forest patches. While we expected the positive selection for grassland patches, given that these are typically forage-rich habitats (Kaufmann et al. 2013; Homburger et al. 2015), the lack of a consistent adverse selection for sparse shrub and forest was unexpected (Raniolo et al. 2022). When conducted by the shepherd to most grassland areas, the cows had to pass through forest and sparse shrub (see Figure 1), which might partially explain this result. In fact, the cows used sparse shrub more when walking than when grazing and resting, and at 'day' than at 'night'. However, we found no such indication for forest. While cattle avoid thick stands of high shrubs, such as *Alnus* spp. (Pauler et al. 2022), in sparse shrub, composed of grassland interspersed with patches of dwarf shrub (*Rhododendron* and *Vaccinium* spp.) that did not impede movement, the cows could move easily and find forage. Additionally, cattle might use forest for various reasons, including finding shade and forage on sunny and warm days (de Weerd et al. 2015; Larson-Praplan et al. 2015). Overall, the results of this study indicate that forest and shrub, if sparse as those examined by this study, are actively used even by heavy, adult lactating cows. Different environmental factors may respond to/impact different needs of the animals, which will consequently make different habitat choices according to the activity in which they are involved (Kohler et al. 2006; Homburger et al. 2015). Future studies should address these factors and the animals' responses.

The Spatial use of pasture was highly uneven, as we expected for this grazing system (Probo et al. 2014; Homburger et al. 2015; Raniolo et al. 2022). Such heterogeneity is the result of a complex set of interactions between the cows' habitats preferences (discussed above) and behaviours (see Figure 4, panels D, E, and F), and the grazing management practices (the shepherds' daily decisions of where to drive the cows for the day certainly helped to increase the use of the areas farther from the barn, but not to the same intensity as those closer to the barn). Additionally, slope negatively affected the intensity of use, which was expected and confirmed the findings of other studies (Kaufmann et al. 2013; Pittarello et al. 2021; Rivero et al. 2021; Raniolo et al. 2022). On the individual scale, the heterogeneity of pasture use is indicated by the daily core areas occupying 20% of the surface of the total areas while containing 50% of the locations. In other words, individual cows spent half the outdoor time on one-fifth of the total surface they used. This heterogeneity increased during the 'night' when the cows stayed in total areas and core areas 2–2.5 times smaller than during the 'day' and remained much closer to the barn. Therefore, the animals' load per area unit was higher and spatially concentrated near the barn. These areas of higher use are likely to have intense deposition of excreta and trampling (White et al. 2001), which might impact soil physical properties, nutrient balance, and vegetation (Pietola et al. 2005; Bilotta et al. 2007; Jewell et al. 2007; Taboada et al. 2011). Reducing the heterogeneity of animals' load, balancing the spatial release of excreta, and maintaining good sward conditions are challenging in most alpine grazing systems where cattle are left free at 'night'. It would require a rotational system where cows are also guided at 'night'. However, this might conflict with the need to reduce labour that is typical of extensive grazing systems (Probo et al. 2014; Herzog and Seidl 2018).

Differences between breed-parities

During the 'night', the differences between breed-parity categories were non-significant (activity budget, probably because cows spent most of the 'night' resting) or followed patterns consistent with the 'day' (fine-scale analysis of the spatial intensity of use and analysis of areas used daily), therefore we will concentrate the discussion on the latter day period.

The literature comparing cattle breeds in alpine grazing conditions has so far mainly focused on morphology, behaviour, and performance (Zendri et al. 2016; Toledo-Alvarado et al. 2017) while grazing patterns have been compared between genotypes highly divergent for productivity and body size (Hessle et al. 2008; Pauler et al. 2020). In this study we compared much less divergent cattle breeds. Because of the limitations in groups composition, we may discuss the breed effect by contrasting Alpine Grey multiparous with Brown Swiss multiparous cows and the parity effect by contrasting primiparous with multiparous cows within the Alpine Grey breed. Brown Swiss multiparous did not differ in activity budget from Alpine

Grey multiparous. However, they were less selective in habitat use since, for them, not only grassland but also forest had a positive effect on the intensity of spatial use, and they used less heterogeneously the individual total daily areas, as indicated by larger core areas. We had no indications that, when moving, they should be more limited by slope, which we instead expected. In this study, Brown Swiss multiparous were heavier than Alpine Grey multiparous, which should reduce grazing time (Aharoni et al. 2013) and ability to move on steeper terrain (Rivero et al. 2021), but produced less milk and received more concentrate supplement, which should reduce grazing time and needs of movement (Heublein et al. 2017). It is impossible to disentangle these possibly contrasting effects. Therefore, our results suggest that these breeds may differ in habitat use and movement patterns, but further studies are needed. In general, differences between Alpine Grey primiparous and Alpine Grey multiparous cows were more marked than those between the multiparous cows of the two breeds. Primiparous individuals spent less time grazing and more resting, showed a higher tendency to avoid sparse shrub and especially forest, and were influenced less negatively by slope and distance from the barn in their spatial intensity of use. They had lower feed requirements, being lighter and producing less milk, but received the same amount of concentrate, which could explain the shorter grazing time, since concentrate supplementation has a well-known adverse effect on both grazing time and herbage intake (Krysl and Hess 1993; Gekara et al. 2001; Bovolenta et al. 2002; Soca et al. 2014). Their smaller body size is in accord with their better ability to move on steeper ground (Rivero et al. 2021). While they were more selective in their use of habitats is less clear. It might be related to a lack of knowledge and previous experience, which is important in foraging behaviour (Orr et al. 2014) and pasture use (Bailey et al. 2018). However, we cannot speculate on this because we don't know whether primiparous cows had been grazing on the summer farm when they were heifers.

We found that the individual effect had a higher importance than breed-parity in determining the activity budgets but had a low relevance in the model analysing the areas used daily. However, this model included factors (Julian date and especially day period) that contributed much more than breed-parity to the deviance explained by fixed factors (as suggested by Table S.2.6). Therefore, we may infer that, with respect to breed-parity, individual differences were relevant also for the spatial use of pasture. Wyffels et al. (2020) found high individual variability in cattle grazing patterns in rangelands, which could be related to age, body weight, and supplement intake. We could not verify whether these factors could explain part of the individual variability found in our study because they were nested within breed-parity classes and could not be implemented in the analyses. However, since grazing time and movement of animals are influenced by concentrate supplementation in relation to individual requirements, cows that received a similar amount of supplement (within breed) but had different body weight and milk yields, and hence nutritional requirements, were likely to allocate a different proportion of time to grazing against resting and consequently to movement. We suggest that understanding the relevance of individual variability and of factors determining it should be a future area of research in grazing management.

Conclusion

In this study, we monitored activity budget, habitat use, and spatial use of pasture of lactating cows in a typical alpine extensive grazing system. Grazing was predominant during the day but extended remarkably into the late evening, while resting dominated at night. The use of the pasture area was highly heterogeneous, partly because the cows concentrated their presence close to the barn, especially during the 'night', avoided steeper slopes, and preferred grassland patches. However, they also used habitats with lower forage abundance, such as sparse shrub and forest, mostly when walking but also when grazing and resting. Further research should elucidate the role of concentrate supplementation, climate and environmental covariates, and grazing management on the daily activity budget and movement patterns of grazing livestock at a detailed time scale, especially considering the need to avoid heat stress associated with global warming. The comparisons between breeds and parities yielded no conclusive indications, partly because of the limitation of our sample. However, the local Alpine Grey breed appeared to be more selective in the choice of habitats and the internal use of the total areas explored daily than the specialised Brown Swiss breed. At the same time, primiparous Alpine Grey cows were less limited by slope in their movement while being more selective in habitats' use. These results indicate that grazing patterns and pasture use may differ between breeds, even if not genetically and phenotypically as divergent as those so far studied, and especially parity levels. Understanding the internal and external drivers of activity budgets and pasture use by livestock is crucial to devise grazing management practices combining animals' productivity and welfare with the conservation of grasslands with their associated multiple ecosystem services. In this regard, GPS telemetry should be implemented in further studies with increased sample sizes and environmental variability, possibly complemented with insights into the different sociality and physiological adaptations of cattle breeds and age classes.

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Ethical approval

The study was approved by the ethical committee of the University of Padova with prot. number 49172.

Disclosure statement

No potential conflict of interest was reported by the author(s).

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Data availability statement

The data of this study are freely available from the corresponding author upon request. The data are not publicly available due to the involvement of private partners (farmers).

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