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Neutral Impact of Cattle Grazing in Pyrenean Oak Forests Integrity

Jordi Bartolomé [1], Antonio Carrasco Amat [2], Jonathan Rubines [3], Javier Sesma [3], Omar López-Garrido [2], Miguel Ibáñez [2], Carlos Hernández-Castellano [2,4], Santiago Lavín [2], Araceli Gort-Esteve [1,5,*], Anahí Hernández-Rodríguez [1], Karen González [1], Mariana Rossa [6], João Carvalho [6] and Emmanuel Serrano [2]

1 Grup de Recerca en Remugants, Departament de Ciencia Animal i dels Aliments, Facultat de Veterinària, Universitat Autònoma de Barcelona, 08193 Cerdanyola del Vallès, Spain; jordi.bartolome@uab.cat (J.B.); anahihr8907@gmail.com (A.H.-R.); gonzalezp6020@gmail.com (K.G.)
2 Wildlife Ecology & Health Group (WE&H), Servei d'Ecopatologia de Fauna Salvatge (SEFaS), Departament de Medicina I Cirurgia Animals, Facultat de Veterinària, Universitat Autònoma de Barcelona, 08193 Cerdanyola del Vallès, Spain; tonicarrascotc@gmail.com (A.C.A.); legolas9099@gmail.com (O.L.-G.); mgl.ibanez@gmail.com (M.I.); carlos.hernandezcastellano@gmail.com (C.H.-C.); santiago.lavin@uab.cat (S.L.); emmanuel.serrano@uab.cat (E.S.)
3 Natura Ondarearen Zerbitzua, Arabako Foru Aldunia, 01001 Vitoria-Gasteiz, Spain; jrubines@externos.araba.eus (J.R.); jsesma@araba.eus (J.S.)
4 Departamento de Sistemas y Recursos Naturales, Universidad Politécnica de Madrid, 28040 Madrid, Spain
5 Institute for Game and Wildlife Research, IREC (CSIC-UCLM-JCCM), 13005 Ciudad Real, Spain
6 Department of Biology & Centre for Environmental and Marine Studies (CESAM), University of Aveiro, 3810-168 Aveiro, Portugal; m.rossa@ua.pt (M.R.); jlcarvalho@ua.pt (J.C.)
* Correspondence: araceli.gort@uclm.es

Abstract: The combination of logging, burning, and livestock farming has been the main driver of European landscape sustainability for thousands of years. Whether or not livestock could keep these habitats on their own is under debate when extensive livestock grazing is kept understory in forests of high environmental value that, in turn, are affected by global warming. In this work, the impact of beef cattle on the diversity, shrub cover, and primary production of the Atlantic Pyrenean oak (*Quercus pyrenaica* Willd.) in northern Spain has been evaluated. The research studied their feeding habits using the faecal cuticle micro histological analysis in dung samples. Then, the effects of cattle grazing on the cover and alpha diversity of woody plants were evaluated. Finally, oaks' primary production and phenology in grazed and control areas were compared. The results show that cattle feed on woody (an average of 30% of non-leguminous woody) and annual plant species (more than 20% of forbs) but do not affect plant cover or alpha diversity of vegetation. However, oak phenology differed between grazed and ungrazed treatments, probably due to the spatial variability of grazed forests. It can be concluded that understory grazing in Pyrenean oak forests could be considered a sustainable silvopastoral activity with a neutral impact on forest integrity.

Keywords: sylvopastoralism; diet composition; phenology; understory diversity; *Quercus pyrenaica*

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1. Introduction

Oak forests are one of the most widespread vegetation types in the Northern Hemisphere and offer many ecological, social, and economic benefits, including extensive livestock grazing. Pyrenean oak (*Quercus pyrenaica* Willd.), a deciduous species, thrives in the western Mediterranean region, covering an expansive 1.19 million hectares. This species spans from southwest France to northern Morocco but predominantly occupies the transitional areas between the Mediterranean and Euro-Siberian regions of the Iberian Peninsula [1,2]. Pyrenean oak forests have been included in the Habitats Directive as a habitat of Community interest in the "Mediterranean deciduous forests" group (code

9230) because of their importance for the conservation of biodiversity within the European Union [3]. However, scientific work on *Quercus pyrenaica* is scarce compared to the numerous studies on other Quercus species of the genus *Quercus* (see [4]). Historically, the woodlands of Pyrenean oak have been exploited mainly for firewood, charcoal and tannins [5]. Despite the expansion of these oak groves, the cessation of traditional practices involving root and stump sprouts poses a significant threat to the sustainability of Pyrenean oak stands. This shift has been associated with indicators such as shrub encroachment, overstocking, top-drying, and growth stagnation [4], particularly evident in the Mediterranean basin [6]. However, some authors [7] point out that the relationship of the Pyrenean oak with extensive livestock farming is widely documented, allowing us to glimpse a management model much closer to silvopastoral systems than typical forest management models. According to this author, insufficient or absent livestock management could be the main cause of forest degradation.

The potential effects of extensive livestock farming for encroachment reduction and plant heterogeneity creation are driven by the interaction between habitat productivity and herbivore size [8], grazing intensity [9], and the extent and length of grazing [10]. Thus, the long-term exclusion of large herbivores has negative effects on plant diversity in high-productivity areas but positive effects in low-productivity sceneries [8]. Along the same lines, the effects of large herbivores differ between vegetation communities with grasslands being more resilient to overgrazing than shrublands due to the compensatory growth of grasses after grazing [11]. This fact justifies keeping livestock at high densities in forests to reduce shrub biomass and, thus, the risk of wildfires [12].

However, there is evidence that extensive livestock has a null contribution to slowing down the shrubification process at a large scale [13]. The small contribution of cattle to deal with the increase in shrubification is supported by the fact that the diet of cattle is mainly based on graminoids and forbs [14], and, thus, cattle have little potential to feed on woody vegetation. Other studies, however, have shown that cattle could consume wood vegetation when kept at high densities (e.g., [15,16]) and that some breeds of cattle, such as the Alberes cattle [17], can actively feed on woody plants.

An extensive body of the literature provides support for the use of moderate grazing to preserve the production [18] and diversity of open landscapes [19], but little attention has been paid to the impact of extensive livestock farming on understorey shrubs that are fast increasing in Europe [20]. While some studies propose that controlling shrub encroachment can be achieved through adequate fire measures and artificial removal [21], others indicate that livestock grazing can be an effective tool against it [22–24]. Even though beef cattle may be less efficient in controlling shrubs than other ruminants like goats or sheep [13,25,26], beef cattle are also chosen by farmers as they generate higher productivity thanks to the Common Agricultural Policy payment and their work as shrub controllers [17], although sometimes with the handicap of needing supplementary feeding [27].

Another concern arising from grazing in the understory is its potential medium- or long-term impact on the primary production of the forest canopy tree species. In this sense, for some decades, the evolution of the primary production and phenology of forests is being increasingly analysed through remotely sensed vegetation indices, such as the Normalized Difference Vegetation Index and the Leaf Area Index (LAI) [28,29]. However, they have rarely been used to determine the effect of understory grazing on primary production and phenology over time [30].

To contribute relevant information to this discussion, the primary objective of this study was to describe the effects of cattle browsing within a Pyrenean oak forest. To do so, three goals were defined: (1) to determine the proportion of woody plants present in the diet of cattle herds; (2) to investigate the effect of cattle exclusion on the diversity of the shrub layer; and (3) to evaluate the evolution during the last decades in the forest canopy phenology and primary production using satellite data. This information is necessary to better understand how livestock grazing in the forest can affect its environment and to develop management guidelines for forest management.

2. Material and Methods

2.1. Study Area

The study area is in the southern part of the Basque country, in northern Spain, within the Izki Natural Park (INP) (42.70423168, −2.49158539; see Figure 1A). This area is 9.044 ha and has 3 municipalities sharing the space with an altitudinal gradient that ranges from 700 to 1177 m a.s.l. (average 800 m a.s.l.). The climate of INP could be considered as a transition between the Mediterranean and the Atlantic climates, making it evident with moderate summer droughts and an ombrotype between subhumid and humid [31]. These characteristics are marked by a mean annual temperature of 11 °C and an annual average rainfall of 600–800 mm.

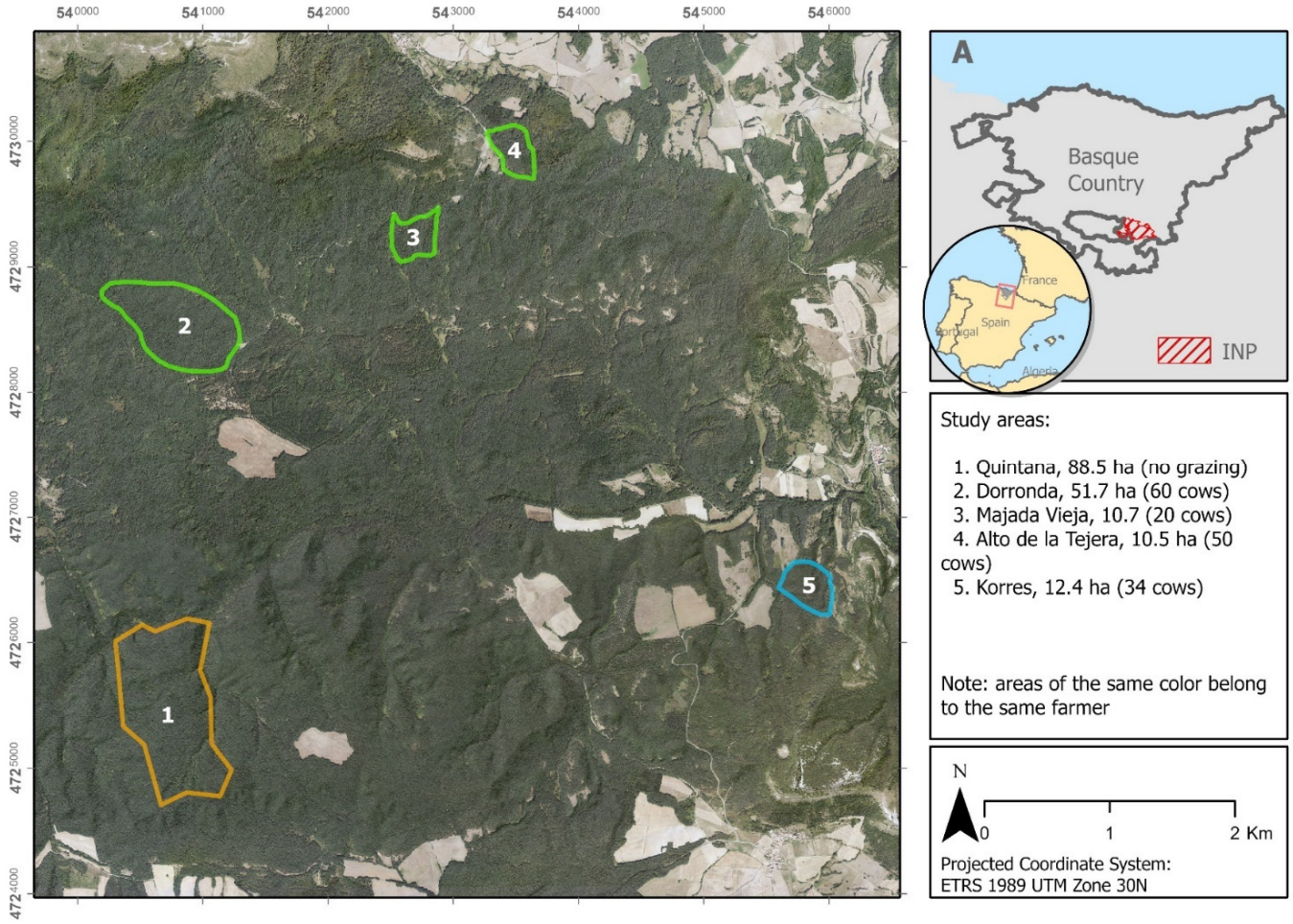


Figure 1. Study areas in the Izki Natural Park, Basque Country, northern Spain (A). The Quintana area has been fenced without grazing for the last 20 years. The other areas are not fenced and represent the forested areas where the herds graze all year round.

The INP is home to one of the biggest Pyrenean oak (*Quercus pyrenaica*) forests in Europe. This forest is settled over the sandy soils of the Izki river's basin. The INP has been traditionally used for forestry and farming purposes [32]. The forest clearings contain pastures and some cereal crops (Figure 1). Currently, about 750 heads of cattle are in the park, distributed among about 10 farms.

2.2. Animal Management

Four Asturiana and Terreña herds grazing freely throughout the year in open pastures and surrounding undergrowth have been considered in our study (Figure 2). The herds have never been stabled and give birth throughout the year. During the late autumn and

winter (November to February), they are supplied with ryegrass and fescue hay, cereal grain (corn, barley, and oats) and silages made with mixtures of vetch, pea, ryegrass, and fescue. This food is distributed in the field, either in feeders or directly on the ground.

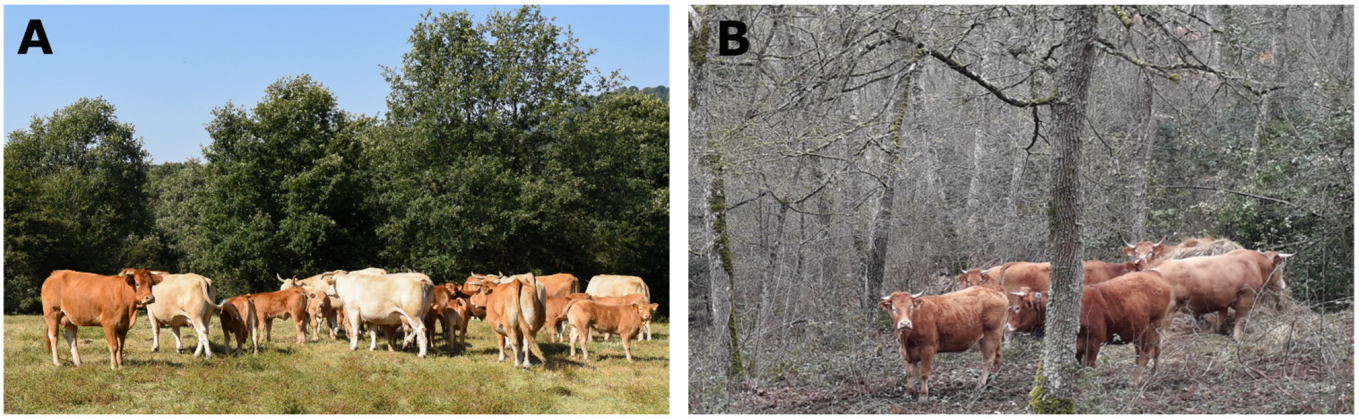


Figure 2. Herds in the study area are Asturiana or Terreña cattle breeds. They are kept unfenced all year round grazing freely in open pastures (**A**) and the surrounding red oak forests (**B**). From November to February, they are supplied with ryegrass and fescue hay, cereal grain (corn, barley, and oats) and silages made with mixtures of vetch, pea, ryegrass, and fescue.

2.3. Diet Composition

As to the diet composition analysis, each month (from January to October) fresh faecal samples from five individuals of the four stocks of cows were collected. The samples were frozen at −20 °C until they were processed. To process the samples, first the portion of the sample used was oven-dried at 60 °C for 72 h, after dehydration, all samples were ground in a cyclone-type mill (FOSS Tecator, FOSS Group, Barcelona, Spain, 1093) [33] to pass a 1 mm screen and stored in zip-lock bags in a cool, dry place before analysis.

Once ready, samples were used to make a faecal cuticle microhistological analysis to determine dietary composition. This protocol is an adaptation from the ones described by Stewrad [34] and Bartolomé [35]. This method has the advantage of providing good diet representation without interfering with animal behaviour [17] and, compared with molecular analysis, it enables quantitative data to be obtained for plant diet composition [36]. The samples from the same stock and month were mixed, then placed in a test tube containing enough concentrated nitric acid (65%) to cover them, boiled in a water bath for 2 min and diluted with 200 mL of water. This suspension was passed through 1.00- and 0.25-mm filters. The 0.25–1.00 mm fraction was again placed in a test tube to bleach it with sodic hypochlorite (10%) for 15 min, and after that, the samples were diluted with 200 mL of water and passed through the 0.25 mm filter. This fraction was spread on glass microscope slides in 50% glycerol, and coverslips were fixed with a DPX microhistological varnish. Three slides were prepared from each mix of samples. The slides were microscopically examined by the same operator at magnifications of 100× and 400×, and 200 fragments of plant epidermis were identified per sample. An epidermis collection atlas was used to help with the identification of the fragments [37].

The fragments inferred from the samples were later used to test the monthly variation in diet composition using the generalised additive mixed models (GAMM, Zuur et al. [38]) approach, including the proportion of fragments found in our faecal samples as a response variable and the interaction between the month of sampling (smoothed term) and the functional group of plants (see Table 1) as a fixed explanatory term (see also Table S1). The replica was included as a random term.

Table 1. Average number of individuals (considering each patch of a species as a single individual) and relative cover per transect below two meters in height between the grazed (n = 20) and, shaded, the control areas (n = 10). Minimum and maximum values are indicated in parentheses.

Taxa	Number of Individuals/Patches		Relative Cover (%)		T-Test Comparison *
	Control	Grazing	Control	Grazing	
Acer campestre	0.0 (0–0)	0.35 (0–4)	0.0 (0–0)	0.72 (0–9.12)	-
***Asphodelus* sp.**	1.4 (0–5)	2.8 (0–20)	2.09 (0–7.38)	5.05 (0–43.8)	t = −1.1, df = 23.054, *p*-value = 0.264
Crataegus monogyna	0.3 (0–1)	2.95 (0–15)	1.12 (0–6.33)	7.11 (0–25.8)	t = −2.8, df = 23.47, *p*-value = 0.009 **
***Erica* sp.**	6.7 (1–20)	2.5 (0–16)	7.56 (0.43–19.74)	4.5 (0–39.57)	t = 0.9, df = 24.18, *p*-value = 0.331
Fagus sylvatica	0.4 (0–2)	0.25 (0–2)	0.69 (0–4.98)	0.3 (0–1.98)	-
Poaceae	10.3 (0–21)	16.5 (3–34)	29.41 (0–89.32)	41.42 (9.59–106.59)	t = −1.2, df = 16.37, *p*-value = 0.242
Hedera helix	1.5 (0–5)	2.8 (0–9)	0.81 (0–3.09)	2.84 (0–10.6)	-
Forbs	12.6 (0–20)	13.15 (3–33)	16.33 (0–26.93)	21.69 (3.76–44.16)	t = −1.48, df = 27.73, *p*-value = 0.149
Ilex aquifolium	5.9 (0–15)	1.45 (0–6)	15.85 (0–63.25)	4.38 (0–19.08)	t = 1.6, df = 9.7, *p*-value = 0.1285
Woody legumes	2.3 (0–6)	1.65 (0–10)	1.58 (0–4.92)	2.32 (0–9.21)	-
Lonicera sp.	2.4 (0–13)	1.1 (0–10)	4.47 (0–25.16)	1.54 (0–14.97)	-
Malus sylvestris	0.5 (0–3)	0.1 (0–1)	0.51 (0–4.27)	0.98 (0–19.18)	-
Prunus spinosa	0.0 (0–0)	0.3 (0–4)	0.0 (0–0)	0.61 (0–7.19)	-
Pteridium aquilinum	14.6 (5–33)	7.5 (0–30)	32.38 (12.36–67.62)	22.82 (0–93.37)	t = 1.0685, df = 23.34, *p*-value = 0.296
Quercus pyrenaica	10.6 (0–28)	7.2 (0–19)	9.14 (0–23.99)	7.03 (0–24.06)	t = 0.702, df = 13.32, *p*-value = 0.493
Quercus robur	0.5 (0–4)	0.05 (0–1)	3.14 (0–30.47)	0.02 (0–0.45)	-
Rosa sp.	0.0 (0–0)	0.65 (0–5)	0.0 (0–0)	1.62 (0–10.71)	-
***Rubus* sp.**	8.9 (0–20)	6.1 (0–21)	11.75 (0–37.55)	12.02 (0–44.49)	t = −0.06, df = 20.34, *p*-value = 0.953
Ulex europaeus	2.2 (0–6)	0.35 (0–5)	3.56 (0–8.44)	1.41 (0–24.77)	-
Vaccinium myrtillus	0.8 (0–5)	0.0 (0–0)	2.87 (0–26.61)	0.0 (0–0)	-

* *T*-test comparisons of relative plant cover of plants with at least 5% of representation in one of the two treatments), taxa were marked in bold. ** indicates statistically significant differences.

2.4. Biodiversity Analysis

To examine the undergrowth diversity differences in vegetal communities between the Quintana area (control area without grazing) and the areas with livestock presence, a Line-Intercept Method has been used adapted from Cummings and Smith [39]. The transects were carried out in late spring when most species are present and easy to identify. Transects of 25 m were randomly placed in each study area into 30 transects (10 in the

Quintana area and five in each grazed area). In each transect, the segments of each plant intercepted by a tape measure, within reach of livestock (below two meters in height), were recorded. Each data entry should account for a different plant individual (but graminoids and herbaceous plants were accounted for in patches). Bare ground and leaf litter were also identified to calculate relative cover.

The data were processed to obtain the coverage of each taxon in each transect, the number of individuals/patches per transect, and the absolute and relative cover of each taxon (the relative cover does not include the proportion of bare ground and leaf litter). This information calculates each treatment's alpha diversity (grazed and not grazed). Shannon's index [40], richness, and Pielou's Evenness [41] were inferred, and a linear model (LM) was used with the treatment as an explanatory variable and the Shannon index as a response variable (see also Table S1). All statistical analyses have been performed using the Vegan package for R [42]. In addition, the taxa with the most relative cover in all transects (more than 5% in at least one of the treatment zones) were individually compared using a *t*-test to check for statistical differences.

2.5. Phenology Analysis

Various sampling points within the INP have been designated to examine canopy phenology, comparing regions with continuous grazing to those where grazing has been absent since 2001. The methodology was the same as that used by Jarque-Bascuñana et al. [18]. The Application for Extracting and Exploring Analysis Ready Samples (AppEEARS, V 4.216.0) to obtain values from January 2003 to December 2021 was used to detect changes in vegetation. The variables considered were the Leaf Area Index (LAI), in m^2/m^2 and the Normalized Difference Vegetation Index (NDVI). Values were extracted from nine different sampling points, five in the Quintana area and four in the different zones where cattle livestock is known to roam (see Figure 1). To acquire the data records, we created a shapefile containing the nine sampling points with QGIS [43]. Then, we requested the LAI and NDVI values from the United States Geological Survey (USGS, see [44]) through the AppEEARS platform (https://lpdaacsvc.cr.usgs.gov/appeears/ accessed on 12 July 2023). We obtained the data using the MOD15A2H geospatial product from the Moderate Resolution Imaging Spectroradiometer set in Terra Spacecraft [45]. This approach has already been used to estimate biomass production in different studies [18,46,47].

In this case, the data will be used to analyse the phenology of the canopy following the methodology of Forkel and Wutzler [48] and using the Greenbrown package for R [48]. Using the function "Phenology ()" in each of the time series created, we obtained yearly values from different variables such as SOS (start of season), EOS (end of season), and POP (peak of production).

To compare monthly NDVI and LAI values in Pyrenean oak forests with and without grazing, we used the same approach as in the microhistological analysis, generalised additive mixed models (GAMM [49]). This procedure was chosen because it can include all sources affecting the responses in a model with fixed or random effects, and the distribution of responses is not limited to a normal distribution. A *t*-student test, however, was used to compare mean LAI values between grazed and control areas. This additive modelling allows the fit of non-linear response variables using smoothed and non-smoothed predictor variables [50]. NDVI values were used as the response variables, and the interaction between the month (smoothed term) and grazing/treatment (with and without livestock activity) as fixed explanatory variables (see Table S1). Farm identity was used as a random term in the GAMM analysis. We also followed the same GAMM approach for comparing monthly LAI values and accumulated LAI values between grazed and ungrazed areas (see Figure 1 for locations). For the phenological traits (SOS, EOS, and POP), we used linear models (LM) and the year of sampling and farming as explanatory factors. In any case, both GAMM and LM models were fitted using a Gaussian error distribution and the log-link function. Model selection was based on the Akaike Information Criterion and the Second order Akaike Information Criterion, depending on the n/k ratio [51]. The

Akaike weight (ωi) for each competing model was also calculated. For GAMM, we used the library "gamm4" package version 0.2–6 [52]. GAMM and LM model assumptions were checked using the procedure described by Zuur et al. [38]. All statistical analyses have been performed in the R Statistical Software 4.2.1 version [53].

3. Results

3.1. Diet Composition

Faecal plant fragments were grouped into six functional groups: Graminoids (Gr), Non-leguminous forbs (NLF), Non-leguminous woody (NLW), Leguminous forbs (LF), Leguminous woody (LW), and Bryophytes (Br) (Table S2). Figure 3 shows the distribution of these groups throughout the year. NLW was the most important group in the diet from spring to autumn, with values above 30%, while Gr was the most important in winter, although it also maintained high values (>20%) throughout the rest of the year. A relatively high consumption of NLF (>20%) was also observed during winter and spring. The least consumed groups throughout the year were LF, LW, and Br.

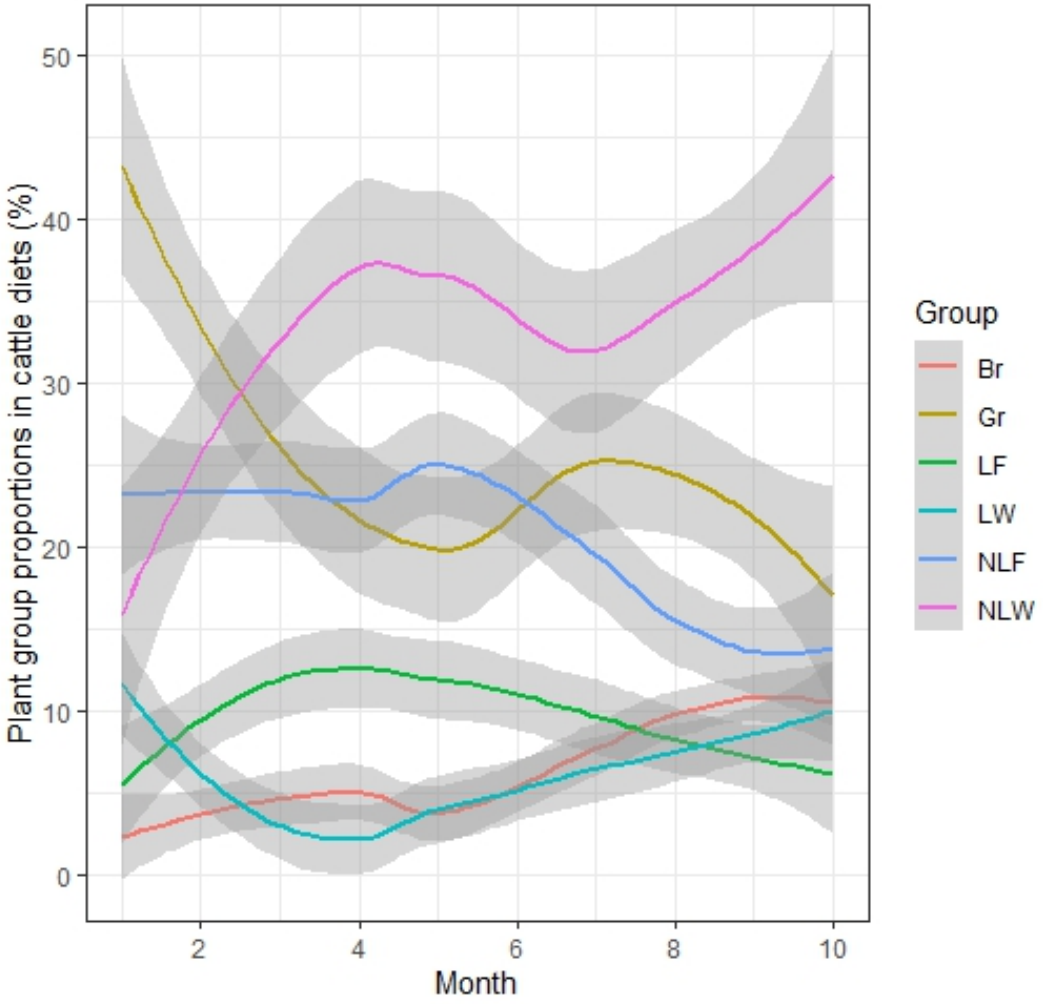


Figure 3. Monthly relative distribution of plant groups found in faeces collected from herds of cattle farmed in oak forests in the Izki Natural Park, Álava, northern Spain. Diet composition (%) was assessed by cuticle microhistological analysis of faecal samples. Plants are grouped into Graminoids (Gr), Non-leguminous forbs (NLF), Non-leguminous woody (NLW), Leguminous forbs (LF), Leguminous woody (LW), and Bryophytes (Br). Confidence intervals are shown in grey.

According to our GAMM modelling, the proportion of Gr ($F_{Month * Gr}$ = 9.2, edf = 2.2, *p*-value = 7.01×10^{-5}), NLW ($F_{Month * NLW}$ = 7.78, edf = 3.4, *p*-value = 1.7×10^{-5}),

NLF ($F_{Month * NLF}$ = 10.06, edf = 1, *p*-value = 0.001), and Br ($F_{Month * NLW}$ = 5.8, edf = 1, *p*-value = 0.01) in cattle diets varied monthly (Figure 3). Even though other plant groups, such as LF and LW, also appear to show a slight monthly variation in cattle diets, we failed to confirm it statistically.

3.2. Plant Cover and Diversity

This study has focused on the woody species of the understory. In the vegetation transects, 18 taxa have been recorded (Table 1), including *Asphodelus* sp. and *Pteridium aquilinum*, due to its size. The herbaceous plants have been grouped into Poaceae and forbs. Three species were found only in the grazed areas, although with little coverage: *Acer campestre*, *Prunus spinosa*, and *Rosa* sp. On the other hand, *Vaccinium myrtillus* was the only species to appear in the control zone, and it had little coverage. In both treatments (control and grazing), Poaceae and Pteridium aquilinum constitute more than 60% of the understory vegetation cover. The only species present in both areas that showed significant differences between treatments was *Crataegus monogyna*, which presented greater coverage in the grazed areas.

The alpha diversity showed no clear differences between treatment areas since all the metrics used to calculate alpha diversity (Shannon's H', species richness, and Pielou's Evenness) had similar values between treatments. Shannon's H' ranges between 2.0 and 2.3 in the ungrazed treatment and 1.9 to 2.3 in the grazed treatment. Species richness varies between 13 and 15 species in the ungrazed treatment and between 11 and 17 in the grazed treatment. Finally, Pielou's Evenness ranged between 0.78 and 0.90 in the ungrazed treatment and between 0.75 and 0.85 in the grazed treatment. The linear model outputs demonstrate no significant relationship between Shannon's H' and treatment ($F_{1,8}$ = 0.5914, *p*-value = 0.464, R^2 = 0.06883, Adj. R^2 = −0.04756).

3.3. Phenology Analysis

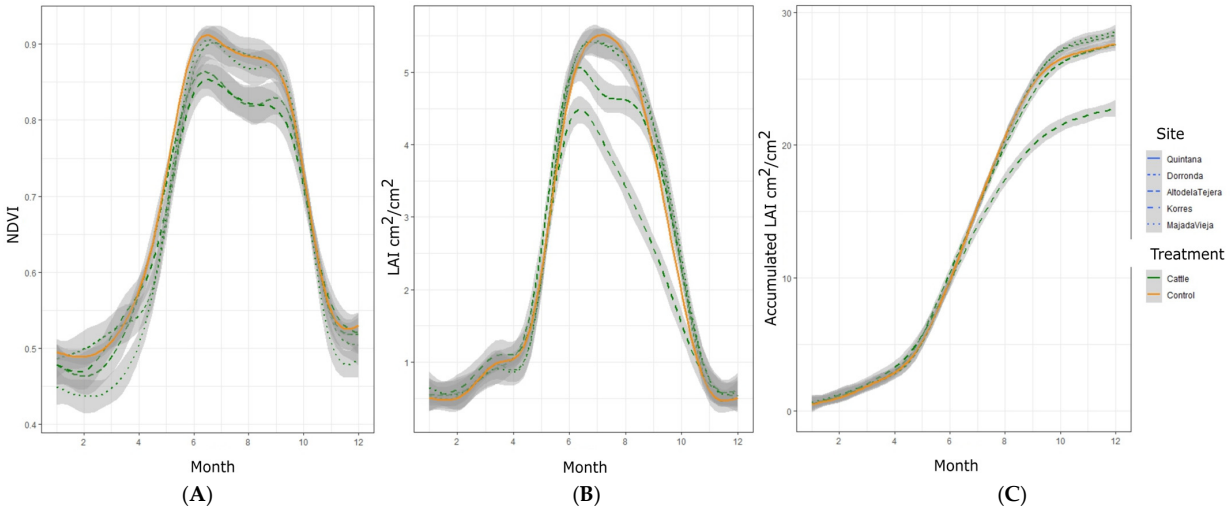
According to our model selection, the most parsimonious GAMM model explaining the effects of grazing undercover on the NDVI only included the effect of the month of sampling (AIC_{Month} = −5886.5, Wi = 0.64, Table 2), explaining 88.8% of the observed NDVI variability. The NDVI followed the typical seasonal pattern of temperate forests with a peak in summer and a minimum in winter (F_{Month} = 1807, edf = 8.9, see Figure 4A). The second competing model included the additive effect of cattle grazing ($AIC_{Month + Grazing}$ = −5885.3, Wi = 0.36, Δi = 1.13, Table 2). Though this model suggests that the average NDVI in grazed areas is statistically lower than in their not-grazed counterparts (t = 3.1754, df = 1958.5, *p*-value = 0.00152), the effect size of grazing is low (2.9% in terms of increment percentage). On the other hand, LAI was better explained by the interaction between month and grazing ($AIC_{Month * Grazing}$ = 3524, Wi = 1, Table 2), explaining 91.2% of the observed LAI variability. This model suggests that oak biomass, assessed through the LAI index, was spatially explicit, meaning that each forest patch has its own LAI dynamic (Figure 4B). Similarly, accumulated LAI was also explained by the interaction between months and grazing ($AIC_{Month * Grazing}$ = 3524.8, Wi = 0.7, Table 2). This model explained 91.2% of the observed variability, suggesting that accumulated biomass also depended on the forest patch (Figure 4C).

Regarding phenological traits, only the SOS and the EOS were related to any of the studied covariables, and the null model was the most parsimonious for POP. In both SOS and EOS, the grazing effect was not detected, and only the effect of the year had a slightly negative effect on the start and end of the growing season ($\beta_{Year} = -0.23 \pm 0.11$, *t*-value = −2.03 for SOS and $\beta_{Year} = -0.22 \pm 0.11$, *t*-value = −1.97 for EOS, Figure 5A,B).

Table 2. Summary of the best Generalized Additive Mixed Models (for NDVI, LAI, and Accumulated LAI) and linear models (for SOS, EOS) analysing the effects of grazing on the primary production (NDVI), monthly (LAI), and accumulated biomass (Accumulated LAI) production of oak (*Quercus pyrenaica*) forests of the Izki Natural park, Álava, northern Spain.

Functional Trait	Biological Models	K	AIC	Δi	ωi
NDVI	**Month**	**5**	**−5886.5**	**0.00**	**0.64**
	Month + Grazing	6	−5885.3	1.13	0.36
	Month * Grazing	7	−5844.8	41.6	0
	Grazing	4	−1364.7	4521.7	0
	Mo	3	−1360.5	4525.9	0
LAI	**Month * Grazing**	**12**	**3524.8**	**0**	**7**
	Month	20	3570.7	45.9	5
	Month + Grazing	10	3572.6	47.7	6
	Mo	3	8495.7	4970.9	3
	Grazing	2	8497.5	4972.7	4
Accumulated LAI	**Month * Grazing**	**7**	**3524.8**	**0**	**0.7**
	Month + grazing	3	3526.7	1.8	0.3
	Month	5	3570.7	45.8	0
	Grazing	3	8495.7	4970.9	0
	Mo	4	8497.5	4972.7	0
SOS	**Year**	**3**	**1215.11**	**0.**	**0.5**
	Year + Grazing	4	1217.10	2.1	0.2
	Mo	2	1217.23	2.1	0.2
	Year * Grazing	5	1219.10	4.2	0.1
	Grazing	3	1354.08	4.1	0
EOS	**Year**	**3**	**1348.5**	**0**	**0.5**
	Year + Grazing	4	1350.2	1.8	0.2
	Grazing	3	1351.9	3.4	0.1
	Mo	5	1352.1	3.8	0.1
	Year * Grazing	2	1352.2	3.6	0.1

Note: K = number of parameters, AIC = Akaike Information Criterion, Δi = difference of AICc for the best model, ωi = Akaike weight, Mo = Null model only including the intercept. The most parsimonious model is shown in bold. Sample size for NDVI, LAI, and Accumulated LAI was 2280, whereas for SOS and EOS, it was 190. * means an interaction.



(**A**) (**B**) (**C**)

Figure 4. Monthly mean NDVI (**A**), LAI (**B**), and accumulated LAI (**C**) values in the four selected farms represented by different broken line types and a control area, without grazing, represented by a solid brown colour line (Quintana), recorded from 2003 to 2021 in the Izki Natural Park, Álava, northern Spain.

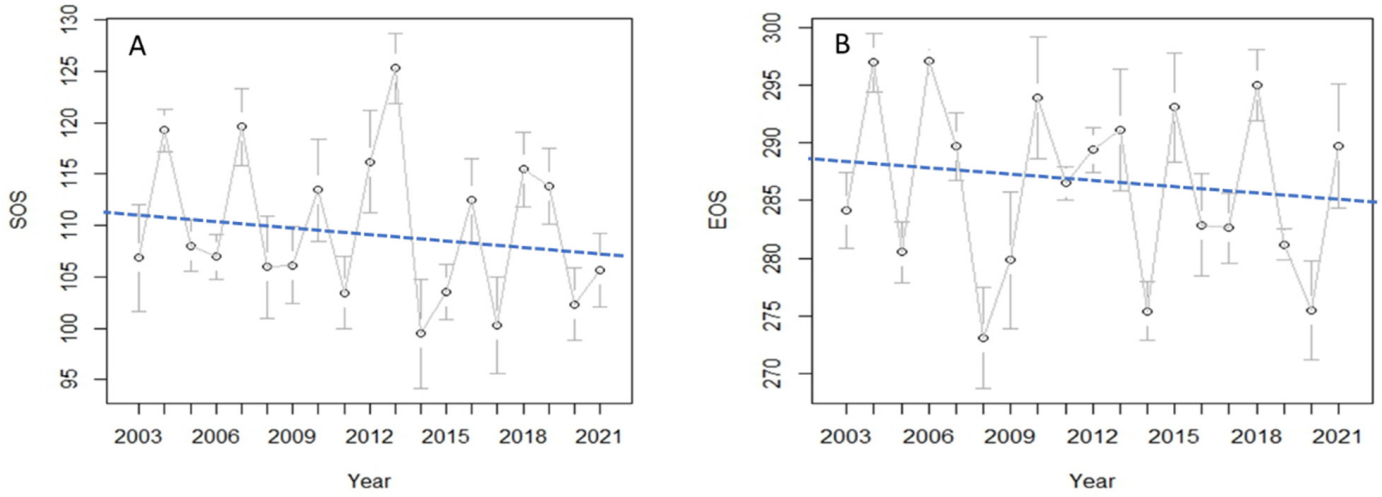


Figure 5. Yearly evolution of the start (SOS) (**A**) and end of the growing season (EOS) (**B**) of Pyrenean oak forests in the Izki Natural Park, Álava, northern Spain.

4. Discussion

4.1. Diet Composition

The results have shown how the livestock diet includes high consumption of woody understory species, a notable fact considering that cattle are usually considered more grazers than browsers [54]. However, these results coincide with other works that show the versatility of cattle in forest environments [12,15,17].

The diet fluctuates throughout the year depending on the availability of resources. The two main components of the livestock diet, NLW and Gr, follow complementary patterns throughout the year. NLW presents a peak in spring and another in autumn, which is related to tender regrowth in these species. On the other hand, Gr presents a peak in summer and another in winter. This is true since Gr are relatively abundant in the Pyrenean oak understory and remain green in summer, unlike in open pastures, where they dry out in summer. On the other hand, the winter peak of Gr is undoubtedly due to the provision of supplementary food that the animals receive in this season. This supplementary food is necessary for livestock grazing in forests [15,27]. The forbs group has a greater consumption in spring, which can be attributed to the appearance of annual species in the pastures of the open forest glades. Of these, the NLF group stands out, representing a quarter of the identified fragments in spring. For its part, LF remains around 10% all year round. The two minority groups, Br and LW, are consumed mainly in autumn and winter. Their scarcity in the diet is likely because they are not abundant groups in the vegetation; the Br have limited availability due to their size, and the LW are less palatable due to the presence of spines (e.g., *Ulex* sp.).

4.2. Diversity Analysis

Even though some differences between the flora species were found in the grazed and ungrazed areas, the alpha diversity analysis showed no significant differences between treatments. These results contrast with those of other studies that show an increase in diversity due to grazing [55–59]. However, unlike the present work, these studies do not focus on woody understory species only. Instead, Schäfer et al. [60] noted how the diversity of grazed German understory shrubs increased or decreased depending on forest type and management.

The *t*-test comparisons between the relative cover of most extended taxa showed that the understory Pyrenean oak forest composition is the same in both treatments. Only three species appear in a single treatment. These are *Acer campestre* (<1%) and *Rosa* sp. (<2%) in the grazed areas and *Vaccinium myrtillus* (<3%) in the control area. In addition, *Crataegus monogyna* coverage is significantly superior in grazed areas (approximately 6%

more extended). Rosa sp. and Crataegus monogyna's greater presence in grazed areas could be related to their lower palatability due to thorns. On the other hand, *Vaccinium myrtillus* has been considered an indicator of low historic grazing levels [61], and it is known that grazing harms population dynamics [62], which would explain its presence only in the control zone. Another indicator species of the effect of grazing in the understory is *Pteridium aquilinum*, which, according to Perrin et al. [63], is negatively impacted by the large herbivore exclusion. However, although the species is abundant in the study area, our results do not show this effect since its coverage is greater in the control than in the grazed areas. Based on simulations conducted by Birch et al. [64], cattle are ineffective in reducing large patches of this fern species.

These few differences between treatments question the effectiveness of cattle herds as a shrub controller and, thus, their ability to reduce fire risk in the short term in the Pyrenean oak forests. This result was also found in Mediterranean pine forests. In other coniferous forests, Schäfer et al. [60] found that in the medium term, livestock exclusion did not affect the diversity of the herbaceous stratum and suggested longer-term studies to detect effects in the shrubby stratum. See also Newman et al. [61]. The results of several studies show how, in temperate forests, the effects of herbivory on plant composition are detected in the long term, between one and three decades. Taking this into account, the fact that there are no differences between treatments suggests that either the Pyrenean oak groves are very tolerant to herbivory or the changes occur over longer timescales (more than 20 years).

4.3. Phenology Analysis

Considering that NDVI reflects leaf density and increases in proportion to vegetation growth, the results obtained correspond to those expected in a seasonal deciduous forest, with a growth peak in late spring-summer [65]. This pattern is observed in all the farms studied. Although significant differences were detected between treatments, indicating lower growth in grazed areas, they were very small (<3%). For its part, LAI is used to evaluate photosynthesis for gross primary productivity estimation, so it is usually correlated with the NDVI [66]. This explains why it follows the same seasonal pattern, with a peak in late spring-summer. However, in our case, there is an interaction with the grazing treatment, with somewhat lower values of LAI being observed in the grazed farms during peak production but not during the rest of the year. On the other hand, when the accumulated LAI is considered, it is observed that not all grazed farms present lower values than those of the non-grazed area, suggesting that Pyrenean oak forest productivity depends on the forest patch.

The slightly negative trend in SOS and EOS explained by the variable year can be related to climate change, as several studies have described thrifts in vegetal phenology seasonality [67,68]. The null model obtained for POP could indicate that the treatment did not affect this variable. In fact, grazing induces changes in the productive capacity of pasturelands by altering the structure of the plant community [69], a phenomenon that is not observed in the undergrowth of the study area.

Finally, it should be noted that many works show the positive and negative impacts of understory grazing by large herbivores on the ecosystem [70]. In general, they influence the growth and mortality of plant species, which has consequences for the composition and structure of the ecosystem. However, there are few studies, like the one presented here, where the impact can be considered practically neutral. This neutrality could be determined by traditional use based on the multifunctionality of these forests, managed as agro-silvo-pastoral systems and characterised by simultaneously hosting trees and shrubs, an herbaceous stratum and grazing herbivores, mainly domestic [7].

Considering the results obtained, it can be concluded that cattle in the Pyrenean oak forests cannot be considered a threat, a diversifying element, or even a tool for controlling the undergrowth, but are merely one more ecosystem component. When thoughtfully integrated, livestock management can complement conservation initiatives and support sustainable forest management. However, long-term, controlled studies are necessary to

quantify whether grazing represents a disturbance with delayed impacts that may take decades to manifest or if it inherently contributes to ecosystem stability.

Supplementary Materials: The following supporting information can be downloaded at https://www.mdpi.com/article/10.3390/su162410939/s1, Table S1. Mean proportion (min–max) of Non-leguminous woody (NLW), Leguminous woody (LW), Leguminous forbs (LF), Non-leguminous forbs (NLF), Graminoids (Gr), and Bryophytes (Br) plant fragments in faecal samples collected (22 January–23 October 23) from four herds of cattle kept in extensive grazing in the Izki NP, northern Spain. Table S2: Mean proportion (min–max) of Non-leguminous woody (NLW), Leguminous woody (LW), Leguminous forbs (LF), Non-leguminous forbs (NLF), Graminoids (Gr) and Bryophytes (Br) plant fragments in faecal samples collected (22 January–23 October) from four herds of cattle kept in extensive grazing in the Izki NP, North Spain.

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