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Cattle Grazing Fails to Control Shrub Encroachment in Mediterranean Landscapes

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Abstract

The Common Agricultural Policy supports the use of free-ranging cattle herds to control woody encroachment and fire hazards in Europe. There is, however, little empirical evidence about the effectiveness of extensive grazing to preserve open landscapes in the Mediterranean Basin. In this work, we evaluated the effects of extensive beef cattle grazing on the vegetation structure in a Mediterranean ecosystem using a twofold framework: 1) analyzing temporal changes in the forest, shrub, and grassland cover in areas under different grazing pressures for 16 yr (1993–2009) and 2) studying diet selection to assess the impact of cattle on the local Mediterranean vegetation. Our landscape structure analyses revealed a remarkable change in land cover over the study period. However, woody community dynamics seemed to be more related to natural vegetation succession than to cattle effects. Extensive grazing seemed to preserve grasslands but only at high stocking rates. On the other hand, the diet analyses supported the lack of a role for cattle in encroachment control. Beef cattle diets were based on herbaceous plants (59%) with lower contribution of woody ones (41%). Cattle only showed a significant preference ($P < 0.05$) for few woody species (*Erica multiflora*, *Olea europaea*, *Quercus ilex*, and *Rosmarinus officinalis*), mostly at high-density stocking rates. Hence, our results support the idea that extensive cattle grazing alone exerts a negligible effect on shrub encroachment and thus on the risk of fire in the studied Mediterranean area. We urge a redesign of current research to truly integrate extensive cattle grazing as High Nature Value farming in European policies to successfully meet its putative goals, such as shrub encroachment control and wildfire risk prevention.

Introduction

Land abandonment and the decline of extensive farming landscapes are promoting homogenous landscapes dominated by woody plants in Mediterranean areas (Perevolotsky and Seligman, 1998; Hadjigeorgiou et al., 2005; Keenleyside and Tucker, 2010). The consequences of woody encroachment are context dependent (Skarpe and Hester, 2008; Anadón et al., 2014) but generally entail changes in soil chemistry and structure (Rivest et al., 2011), species composition shifts (Slancarova et al., 2016), changes in productivity and functionality (Quero et al., 2013; Anadón et al., 2014), a greater risk of wildfires (Moreira et al., 2009), and a loss of quality or cover of habitats, especially open habitats (Bartolomé et al., 2005; Gibon, 2005; Bullock et al., 2011).

Since the early 1990s, the Common Agricultural Policy (CAP) has supported extensive livestock production systems and “greening payment” to endorse profitable farmland practices and promote the conservation of biodiversity (Henle et al., 2008; Bullock et al., 2011; Kerven and Behnke, 2011; Nori and Gemini, 2011; Price, 2013). Extensive live-stock grazing has been included as High Nature Value (HNV) farming (McCracken and Huband, 2005; Kerven and Behnke, 2011; Nori and Gemini, 2011; Oppermann et al., 2012) and is currently subsidized to control shrub encroachment of grasslands and prevent landscape homogenization and fire hazards (Gutman et al., 2000; Casasús et al., 2007; Evlagon et al., 2012; Lopez-i-Gelats et al., 2015).

Extensive grazing by domestic herbivores seems to be a cheap and efficient management approach to reduce flammable (woody and herbaceous) biomass and limit population recruitment of woody plants in Mediterranean environments (Bernués et al., 2005; Launchbaugh, 2006; Casasús et al., 2007; da Silveira Pontes et al., 2012). In contrast, burning or mechanical clearing is constrained by rough topography and may trigger unintended consequences like rapid germination and sprouting of Mediterranean woody taxa (Dell et al., 1986; Bashan and Bar-Massada, 2017), in addition to soil deterioration and erosion (Launchbaugh, 2006).

Beef cattle have been preferably selected by farmers, as they render a higher productivity thanks to the CAP subsidy and are easier to manage compared with smaller ruminants or mixed herds (Gutman et al., 2000; de Rancourt et al., 2006; Bernués et al., 2011; Nori and Gemini, 2011). Conversely, beef cattle may perform worse than other ruminants as shrub encroachment drivers in dry Mediterranean areas, due to the poor quality of the edible browse phytomass (Perevolotsky, 1994; Brosh et al., 2006; Bashan and Bar-Massada, 2017). In fact, the low productivity of Mediterranean grasslands and shrublands may demand moderate or even high incomes (e.g., feed supplementation) for a successful beef cattle management (Gutman et al., 2000).

To date, we lack robust empirical evidence to evaluate whether HNV farming, including extensive grazing, achieves its putative environmental goals (Henle et al., 2008). Long-term (e.g., ≥ 10 yr) studies analyzing the effectiveness of extensive grazing by beef cattle to control scrub encroachment in the Mediterranean region are scarce (Gutman et al., 2000; Seifan and Kadmon, 2006; DeMalach et al., 2014). Likewise, research has neglected to address whether the intake of woody species by beef cattle is common in the Mediterranean area, and to what extent the proportion of woody taxa in the diet depends on cattle density.

We evaluate the effectiveness of extensive beef cattle grazing and discuss its prospects as a management tool to influence vegetation dynamics related to shrub encroachment. We specifically studied the effects of beef cattle in the evolution of landscape structure in a Mediterranean ecosystem in northeastern Spain. This protected area encompasses forests, shrublands, and open seminatural grasslands related to priority European Union Habitat, apparently driven by land abandonment and the subsequent woody plant colonization (Fig. 1). We analyze the impact of the extensive grazing implemented since the 1990s by using two methodological approaches in five farmlands grazed under three different stocking rates: We evaluate temporal changes in forest, shrubland, and grassland covers in plots grazed and ungrazed by cattle for 16 yr, and we analyze cattle feeding preferences during summer synthesizing diet habits of domestic and wild herbivores in Mediterranean environments.

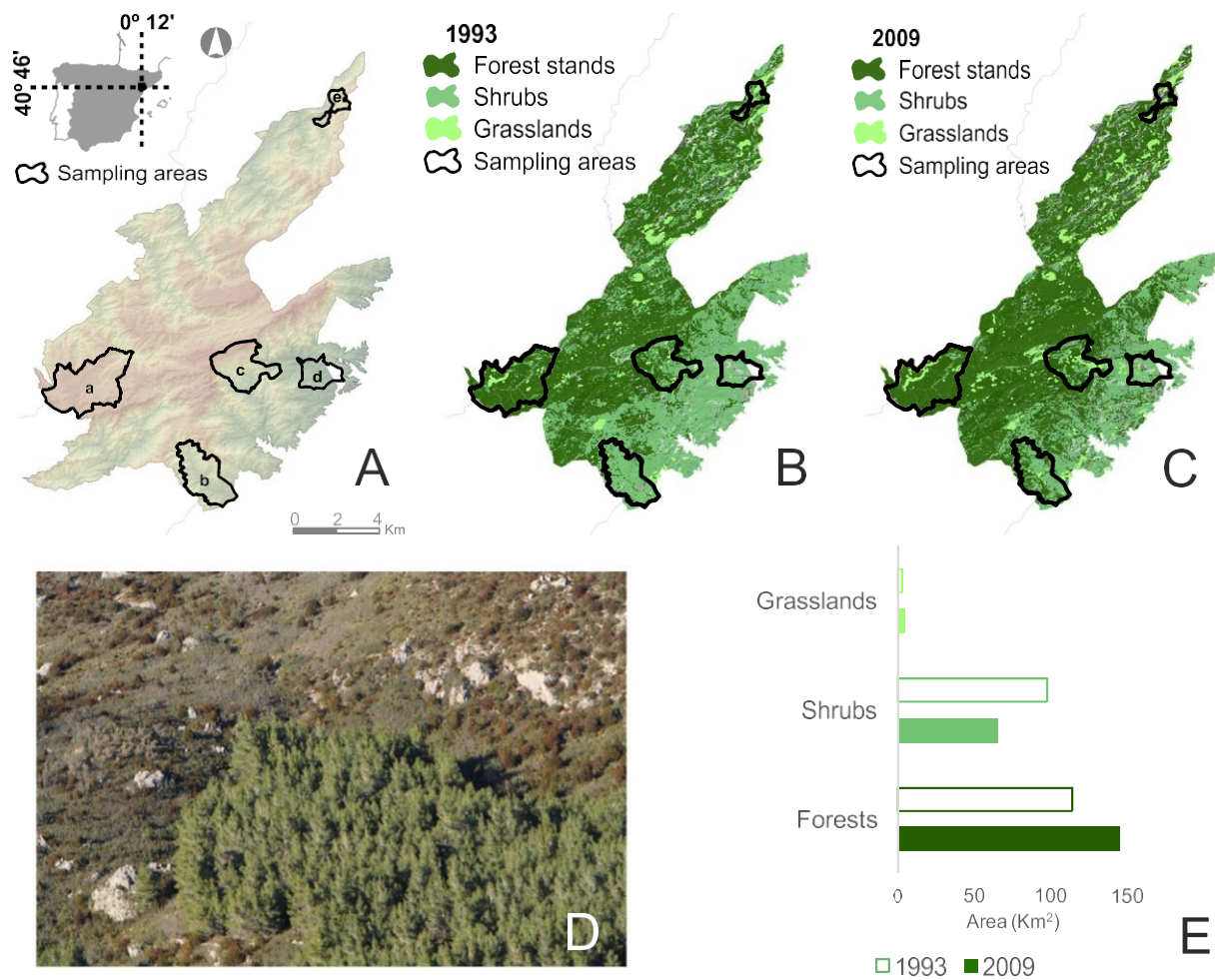


Figure 1. Studied area (A) and land cover temporal changes (B, 1993 and C, 2009) within Els Ports de Tortosa-Beseit Natural Park, Spain, a study evaluating extensive grazing effects on plant community succession specifically focused on retarding shrub encroachment. Five studied farms: *a*—Refalgari, *b*—Valdebous, *c*—La Vall, *d*—Lloret, and *e*—Els Reguers. The bottom left picture (D) illustrates the dominant physiognomy of the vegetation in the study area: forested areas immersed in dense shrublands with scattered grasslands patches. The bottom right figure (E) shows coverage changes in three vegetation types (grasslands, shrubs, and forest) between 1993 and 2009.

Material and Methods

Study Area

The study area was located in northeastern Spain within Els Ports de Tortosa-Beseit Natural Park (PTBNP, see Fig. 1). This protected area is close to the Mediterranean Sea and encompasses a wide and rugged mountainous range (N 35,000 ha) with an altitudinal gradient that varies from 12 to 1441 meters above sea level. The lithology is characterized by limestone and dolomites, and soils are poorly developed. The climate is Mediterranean with a prolonged summer drought (2–4 mo) partially buffered by the sea's influence and summer storms. Annual average rainfall and temperatures differ according to altitude and slope (516.9–900 mm and 10°C–16.65°C, respectively; <http://opengis.uab.es/wms/iberia>). Vegetation in the PTBNP comprises a mosaic of shrublands, oak and pine forests, as well as scattered grassland patches.

Grasslands are seminatural habitats that currently represent only 7% of the total area of the PTBNP (http://parcsnaturals.gencat.cat/es/ports/coneixenos/dades_generals/) and are recognized as a priority European Union Habitat (Álvarez de la Campa Fayos 2009, 2010; European Commission DG Environment, 2013). They are dominated by *Brachypodium retusum* (Pers.) Beauv and, to a lesser extent, by other *Brachypodium* species (*B. distachyon* L., *B. phoenicoides* L., and *B. sylvaticum* [Huds.] Beauv), as well as a large number of other annual and perennial herb taxa.

Shrublands comprise a large number of Mediterranean perennial and sclerophyllous species like *Erica multiflora* L., *Pistacia lentiscus* L., *Quercus coccifera* L., *Rosmarinus officinalis* L., *Cistus albidus* L., *C. salvifolius* L., *Olea europaea* L., *Buxus sempervirens* L., *Juniperus* spp., and several Leguminosae (*Argyrolobium zanonii* [Turra] P.W. Ball, *Astragalus* spp., *Dorycnium* spp., *Genista scorpius* [L.] DC. in Lam. et DC., *Ononis* spp., *Ulex parviflorus* Pourr.), and Rosaceae taxa (*Crataegus monogyna* Jacq., *Rubus ulmifolius* Schott, *Prunus* spp., *Rosa* spp.). These Mediterranean shrubby communities represent 21.5% of the total area of the PTBNP and play a secondary role in the vegetation dynamics (Álvarez de la Campa Fayos 2009, 2010).

The forest layer consists of dense oak (*Quercus ilex* L.) and pine forests (*Pinus* spp.) that represent 47% of the total area of the PTBNP. Conifer stands are dominated by *Pinus halepensis* Mill. in the lower and warmer sites, whereas in higher or colder areas *Pinus nigra* subsp. *salzmannii* Dunal and *Pinus sylvestris* L. (sometimes extensively planted) gain relevance along with some sub-Mediterranean woody species, such as *Ilex aquifolium* L., *Juniperus communis* L., *Lonicera xylosteum* L., and *Prunus mahaleb* L. (Álvarez de la Campa Fayos 2009, 2010; European Commission DG Environment, 2013). In the past few decades, the vegetation in the PTBNP shows a trend toward afforestation (see Fig. 1) in parallel with a decrease in the relevance of shrub communities and an apparently steady phase of grasslands.

Cattle Management in PTBNP

Cattle (*Bos taurus* L.) in the study area belong to the beef cattle breeds of Avileña Negra-Ibérica and Limousine (Ministerio de Medio Ambiente y Medio Rural y Marino, 2010). Livestock were introduced at the end of 1993. Herd sizes (30–150) and grazing length periods (permanent or from late spring to winter) varied across the five studied farms (Table 1, PTBNP unpublished data). To synthesize the analyses of the potential impact of cattle on landscape structure, cattle density or stocking rates (LU) were grouped into three categories (see Table 1): low: LU/ha ≤ 0.2 , moderate: LU/ha N 0.2–1, and high: LU/ha ≥ 1 (Bianchetto et al., 2015). LU was calculated as follows: herd size \times number of grazing months per year/number of grazed and browsed hectares.

Table 1

Farm and cattle data in Els Ports de Tortosa-Beseit Natural Park (PTBNP), Spain, describing stocking rates and areas of five farms from 1993 to 2009 for a study evaluating extensive grazing effects on plant community succession specifically focused on retarding shrub encroachment. According to livestock units (LU), cattle density is grouped into three categories (LU cat.): L = Low density (LU/ha ≤ 0.2), M = Moderate density (LU/ha N 0.2–1), and H = High density (LU/ha ≥ 1). Control pixels are randomly selected outside of the five farms. Pixels are 6.25 ha each.

Control and farm	Area (ha)	Altitudinal range (m)	Herd size	Grazing time (no. mo)	LU/ha	LU cat	No. pixels/yr			No. pixels/LU cat.
							1993	2005	2009	
Control areas	281.3	275–1198	—	—	—	—	15	15	15	45
Refalgari	1 350.2	850–1180	30	6	0.13	L	15	15	15	45
Valldebus	809	430–900	30	12	0.44	M	10	9	5	45
La Vall	764.3	525–1170	70	7	0.64	M	5	6	10	
Els Reguers	228.8	330–780	99	12	5.19	H	5	5	6	45
Lloret	377	240–620	150	12	4.77	H	10	10	9	
Total	3 810.6	240–1198	379	—	—	—	60	60	60	180

Landscape Structure Analyses

The changes in landscape structure over time were assessed through the description of land use in three distinct time periods: preceding (1993) and following (2005 and 2009) the introduction of cattle. Spatial information on the main landscape vegetation types was gathered from the Centre for Ecological Research and Forestry (CREAF, <http://www.creaf.uab.es/mcsc/>) and comprised three classes: forests (oak and pine forests), shrublands (scrub vegetation), and grasslands (natural grasslands and meadows). The pixel size was 6.25 ha, and a percentage of the three vegetation types for the 3 yr (1993, 2005, and 2009) was assigned to each pixel. All the information was stored and managed using the software ArcGIS 10.0 (ESRI, 2011).

To analyze the potential effects of different cattle densities on landscape structure over time and avoid statistical artifacts, we selected a smaller number of pixels from each year to minimize the large number of zero values for the three vegetation types, particularly for grasslands. The pixel selection was random but constrained to areas potentially accessible to cattle. Our selection resulted in a total of 180 samples from the five farms and surrounding nongrazed areas: 15 per yr (1993, 2005, and 2009) and per cattle density (control, i.e., without cattle, light, moderate, and high density) (see Table 1). Next, we extracted the coverage percentage values of the three vegetation types: forests, shrublands, and grasslands.

The statistical analyses process was the following. Firstly, we discarded potential biases in the main vegetation coverage types (forests, shrublands, and grasslands) on the studied farms before cattle introduction (yr 1993) using a Mann-Whitney U test (forest: $P = 0.3839$, $U = 286.5$, $Z = -0.8706$; shrubland: $P = 0.9387$, $U = 333.0$, $Z = 0.0768$; grassland: $P = 0.4322$, $U = 291.5$, $Z = -0.7852$). In that Mann-Whitney test, vegetation coverage types in 1993 were the response variables, whereas the presence/absence of cattle was the explanatory variable. We then performed a model selection based on the Akaike Information Criterion corrected for small sample sizes (AICc, Burnham and Anderson, 2013) including the pixel (6.25 ha) as the random intercept and the vegetation types “shrubland” and “grassland,” as well as their interaction, as fixed response factors. The explanatory variables were considered as fixed explanatory factors: forest cover in %: yr (1993, 2005, 2009); and cattle density (low, moderate, and high). The contribution of the

random terms from the best model was subsequently analyzed by checking their marginal and conditional contributions (according to Nakagawa and Schielzeth, 2013). All analyses were implemented using the plotrix (plot results), car (regressions analyses), moments (kurtosis and skewness), gvlma (validation of linear model assumptions), and MuMin (model selection based on AIC) libraries in R Statistical Software (R Core Team, <https://www.R-project.org/>).

Fecal Sampling, Diet Estimation, and Diet Selection Index Analyses

From late spring to summer (2010), 53 fresh fecal samples (mean weight 79.6 g) were collected from cattle grazing on the five farms: 15 in Els Reguers, 10 in La Vall and Valdebous, and 9 in the Lloret and Refalgari (see Fig. 1). It was assumed that each sample belonged to different cows by simultaneously collecting them from separated sites with different individuals and waiting for their defecation. All samples were stored separately in the laboratory at −20°C. Diet composition was inferred by microhistological analysis of fecal samples. This is a robust and noninvasive methodology to study vegetal diet composition of wild and domestic animals (Croker, 1959; Alipayo et al., 1992; Bartolomé et al., 2011). The protocol employed in this work was adapted from Stewart (1967). All samples were thawed and moistened with water and lightly ground in a mortar to separate epidermal fragments. Ten grams (wet weight) of each sample were placed in test tubes with 5 mL of 65% concentrated HNO₃ and boiled in a water bath for 2 min. The samples were then diluted with 200 mL of water and filtered through 1.00- and 0.25-mm filters. The 0.25- to 1.00-mm fraction was spread on glass microscope slides in a 50% aqueous glycerine solution. Three slides were prepared from each sample and examined under a microscope at × 100 and × 400 magnifications. Two hundred plant fragments per sample were counted and identified. An epidermis collection of plant taxa of the area was used to identify epidermal fragments. Diet estimation was addressed for each farm. The proportion of the plant taxa “i” consumed within the farm “j” was obtained by adding all “i” fragments identified in all fecal samples from farm “j” divided by the total identified plant taxa fragments in all fecal samples from farm “j” and multiplied by 100.

To obtain data on plant availability and assess the foraging preferences of beef cattle, the mean basal coverage of the main plant taxa was recorded in late spring (June 2010) within 18 transects of 50 × 0.5 m in each farm (Els Reguers, La Vall, Lloret, Refalgari, and Valdebous). All transects were set randomly but always within the three main vegetation types (forest, shrublands, and grasslands) and avoiding unsuitable areas for grazing (cliffs and steep, N 60-degree, rocky slopes). The mean basal coverage was obtained by measuring the major and minor diameters of each plant. The percentage of each plant taxa was calculated for each transect, and the arithmetic mean was obtained for each farm. The latter value represents the availability of each plant taxa in each farm. Then, the Savage index (Manly et al., 2002) was used to calculate the diet selection for each plant taxa in each farm. This index (W) determines the food resource selectivity taking into account both its use (e.g., the proportion of plant taxa identified in our fecal samples) and its availability in our vegetation transects: $W = O_i / \pi_i$, where “O_i” is the proportion of microhistological fragments of the plant taxa “i” consumed, and “ π_i ” refers to the proportional availability of plant taxa “i” according to belt transects of each farm. This index varies from zero (maximum rejection) to infinite, and a value of one indicates a random selection (Manly et al., 2002). The significance of this index was statistically tested by comparing the *Savage statistic* with that corresponding to the critical value (Manly et al., 2002): *Savage statistic* = (Wi-1)²/se (Wi)². The standard error “se” is calculated by the formula: $se(W_i) = \sqrt{(1 - \pi) / (u_i + \pi)}$, where “u_i” is the total number of microhistological fragments of all plant taxa within the same farm. To control the error produced by multiple comparisons in the Savage index, the Bonferroni correction was used to adjust the significance of the statistical test (Manly et al., 2002).

Results

Landscape Structure

According to our model selection (Fig. 2, Table 2), the decline of shrub communities in our study area was best correlated with an increase in forested types (Wi Forest = 1, $\beta_{Forest} = -0.93$, $R^2m = 85.3\%$) and slightly with cattle density (models including cattle had $\Delta i \geq 10$). In other words, independent of cattle density, shrubland abundance was inversely related to the natural photodynamic afforestation in the study area (see Fig. 2). The spatial factor (plot included as a random term) had little influence (1.9%) on the observed relationship between forest and shrub cover.

Table 2
Summary of the most parsimonious generalized linear mixed models aimed at exploring the effects of time (yr: 1993, 2005, and 2009), cattle grazing, and forest cover on shrubland and grassland cover in Els Ports de Tortosa-Beceit Natural Park, Spain for a study focused on evaluating the extensive grazing effects on retarding shrub encroachment. K, Number of parameters; AICc, second-order corrected Akaike Information Criterion for small sample sizes; Δi , difference of AICc with respect to the best model; Wi, Akaike weight. The proportion (%) of variability explained by fixed (R^2m) and both fixed and random factors (R^2c) is also shown. The best models ($\Delta i < 2$ units) are shown in bold, and only models Δi lower than 12 units are presented. Mo, Null model.

Biological models	K	AICc	Δi	Wi	R^2m	R^2c
Shrub cover						
Forest	4	1 413.60	0	1.0	85.3	87.2
Forest + Cattle density + Yr	9	1 425.19	12	< 0.01		
Grassland cover						
Yr	5	146.66	0	1.0	6.91	7.01
Forest + Cattle density + Yr	9	149.13	2.5	0.3		
Forest + Cattle density	7	150.62	3.9	0.1		
Mo	3	154.90	8.2	< 0.01		
Forest	4	156.70	10.1	< 0.01	0.06	4.24
Cattle density	6	158.70	12.0	< 0.01	2.07	4.13

encroachment under four livestock density levels (LU): Absent = Control; L = Low (< 0.2), M = Moderate (0.2–1), and H = High (> 1).

Regarding grassland cover, the model including the time factor (year) was the best to explain the observed variability in the proportion of grasslands in the study area ($W_i \text{ Year} = 1$, $\beta \text{ Year} = 0.23$, $R^2_m = 6.91\%$, Fig. 3). Along the same lines, the role of the spatial factor was practically negligible (0.1%). The second competing model ($\Delta i = 2.5$, see Table 2) suggests that cattle density (2%) and forest cover (0.6%) have some influence on the proportion of grasses in the PTBNB (see Table 2, Fig. 4). In fact, grassland coverage increased slightly but only under moderate or high cattle density conditions, whereas the opposite trend is observed under low-density livestock (see Fig. 4).

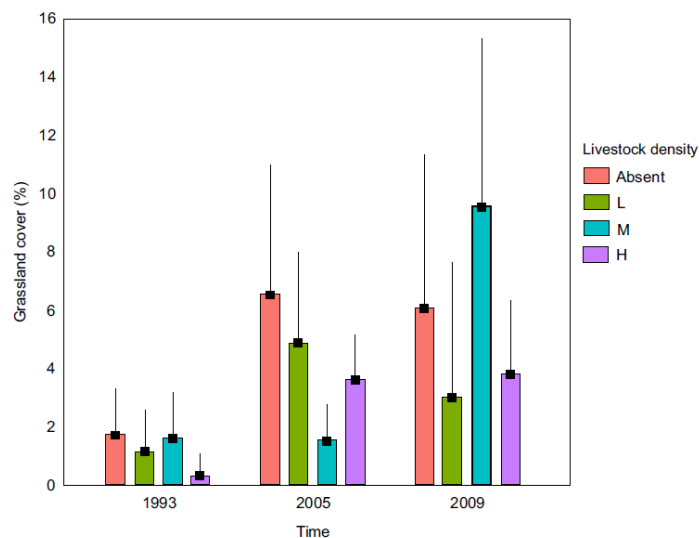


Figure 3. Relationship between grassland cover and livestock density throughout time (1993, 2005, and 2009) in Els Ports de Tortosa-Becit Natural Park, Spain, analyzed to evaluate the extensive grazing effects on retarding shrub encroachment under four livestock density levels (LU): Absent = Control; L = Low (< 0.2), M = Moderate (0.2–1), and H = High (> 1). Black quadrats and vertical lines refer to the mean and the mean \pm standard deviation respectively.

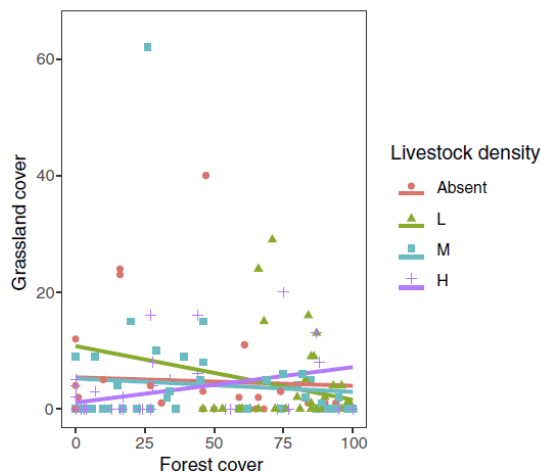


Figure 4. Relationship between grassland and forest cover in Els Ports de Tortosa-Becit Natural Park, Spain, analyzed to evaluate the extensive grazing effects on retarding shrub encroachment under four livestock density levels (LU): Absent = Control; L = Low (< 0.2), M = Moderate (0.2–1), and H = High (> 1).

Table 3

Percentage of woody and herbaceous fragments detected in cattle feces in Els Ports de Tortosa-Becit Natural Park, Spain, analyzed to evaluate the extensive grazing effects on retarding shrub encroachment under four livestock density levels (LU): Low (< 0.2), Moderate (0.2–1), and High (> 1).

Farmstead	LU density	Woody taxa	Herbaceous taxa
Refalgari	Low	38.4	61.6
La Vall	Moderate	23.7	76.3
Valldebus	Moderate	53.9	46.1
Lloret	High	75.4	24.6
Reguers	High	12.5	87.5
Total		40.8	59.2

Cattle Diet

The number of woody and herbaceous plant fragments in cattle feces in the studied area (PTBNP) varies markedly on our sampled farms, 12.5–74.5% and 24.6–87.5%, respectively (see Table 3). Paradoxically, the highest (75%) and lowest (12.5%) woody consumption is observed on the two farms with the highest density of livestock (see Table 3). Diet preferences of cattle were also highly variable. Herbaceous plants, mainly the genus *Brachypodium*, were preferably consumed by cattle regardless of its density on the farms within PTBNP (see Table 4). Cattle also consumed numerous woody plants, and their spectra increased on farms with medium and high livestock densities. However, only *Erica multiflora*, *Quercus ilex*, *Olea europaea*, and *Rosmarinus officinalis* are positively selected (see Table 4). In parallel, many typical Mediterranean sclerophyllous woody taxa rich in tannins (and other toxic compounds) remained untouched by cattle despite being fairly abundant in the plant communities (N 1% coverage): *Bupleurum frutescens* Loeff. ex L., *Buxus sempervirens*, *Cistus albidus*, *Clematis flammula*, *Daphne gnidium* L., *Juniperus communis*, *Lavandula latifolia* Medic, *Pistacia lentiscus*, *Pteridium aquilinum* (L.) Khun, *Quercus coccifera*, *Rhamnus lycioides* L., *Smilax aspera* L., and *Thymelaea tinctoria* (Pourr.) Endl.

Discussion

This research attempted to assess the ability of free-ranging herds of cattle to control bush encroachment in a Mediterranean ecosystem in northeastern Spain. We used a twofold approach to analyze not only changes in landscape structure in areas with contrasting grazing scenarios but also the use of woody plants by cattle after a diet selection analysis.

Landscape Structure

The forest cover in PTBNP has increased while scrub cover has decreased in the past 16 yr in line with the patterns observed in the Iberian Peninsula and other Mediterranean regions (Asner et al., 2004; Martinez del Castillo et al., 2015; Otero et al., 2015). This result suggests little or no effect of extensive beef cattle on natural vegetation dynamics (i.e., afforestation of the landscape) in the PTBNP. Similar results have been reported in other Mediterranean areas but have been based on short-term surveys (Bernués et al., 2005; Seifan and Kadmon, 2006). Longer studies based on aerial images and field sampling analyses (Henkin et al., 2005; Casasús et al., 2007), however, suggest that shrub encroachment trends may be reduced but not stopped with moderate or heavy grazing densities (LU = 0.4 and 1.6, respectively). On the other hand, climate, grassland productivity, other herbivores, vegetation patchiness, plant species composition, their palatability, the use of supplementary food, and other planned grazing practices all drive the feeding behavior of cattle (Gutman and Seligman, 1979; Asner et al., 2004; Mosquera-Losada, 2005; Caballero et al., 2011; Huntsinger et al., 2015), making it difficult to generalize the role of cattle in Mediterranean vegetation dynamics.

In parallel to the afforestation trend, moderate and high grazing intensities are related to a steady increase in the scarce seminatural grasslands in PTBNP. Although we lack robust statistical support or information on livestock movements, this effect may be the consequence of the observed cattle preference per herbaceous species (e.g., *Brachypodium* sp.pl.) linked to open habitats of PTBNP and its deleterious effects on woody plant recruitment (Skarpe and Hester, 2008). This result may meet the objectives of CAP policies to promote conservation of open habitats, but there is little information from long-term studies on the positive or detrimental impacts of high livestock densities (e.g., cover changes, soil nitrification and compaction, species composition shifts) on Mediterranean seminatural grasslands considered priority habitats within Europe (Noy-Meir et al., 1989; Dahlgren et al., 1997; Mosquera-Losada, 2005; Drewry et al., 2008; Skarpe and Hester, 2008). Moreover, the livestock density classification (“moderate,” “high”) seems to be context dependent (Henkin et al., 2005; Evlagon et al., 2012; Bianchetto et al., 2015; Schoenbaum et al., 2017), and hence detailed comparisons are precluded.

Table 4. Summary of diet preferences of beef cattle in Els Ports de Tortosa-Becit Natural Park, Spain, analyzed to evaluate the extensive grazing effects on retarding shrub encroachment. W-index values for woody (W) and herbaceous (H) plant taxa are grouped according to three livestock density levels (LU): Low (b 0.2), Moderate (0.2–1), and High (N 1). Significant values ($P < 0.05$) are highlighted in bold.

Taxa	Biotype	Low density	Moderate density	High density
<i>Asparagus acutifolius</i>	H			0.24
<i>Brachypodium</i> spp.	H	12.06	0.81-1.50	0.37-0.43
Other herbaceous taxa	H	1.25	1.16-1.46	1.87-6.49
<i>Cistus salviifolius</i>	W		0.49	1.96
<i>Genista scorpius</i>	W	0.46	0.58	0.16-1.22
Other woody	W	0.13	0.01-0.58	0.05
Leguminosae				
<i>Erica multiflora</i>	W	0.79	1.02-2.86	1.07-4.10
<i>Juniperus oxycedrus</i>	W		0.10-13.60	0.19
<i>Olea europaea</i>	W			9.05-13.73
<i>Pinus</i> spp.	W	1.55	0.11-0.44	0.04-1.30
<i>Quercus coccifera</i>	W		0.15	
<i>Quercus ilex</i>	W	0.86	2.76-11.15	1.11-1.40
<i>Rosmarinus officinalis</i>	W	1.60	0.15-0.21	0.24
<i>Rubus ulmifolius</i>	W		0.04	0.02
Other woody Rosaceae	W	0.07	7.45	
<i>Thymus vulgaris</i>	W	0.29	0.08-0.18	

Cattle Diet

Beef cattle involved in the extensive pastoralism implemented in PTBNP show a clear preference for herbaceous plants (e.g., *Brachypodium* spp.), which agrees with previous studies (e.g. Provenza et al., 2003). In addition, grazing reduces dead herbaceous biomass, which in turn lessens fire risk (Bernués et al., 2005; Casasús et al., 2007; Archer and Predick, 2014; but see Blackhall et al., 2015). Cattle also browse on a variable amount of woody plants (12.5.4%–75.5%), as has been shown across studies performed in Mediterranean areas where woody taxa represent between 10% and 88.7% of the diet (Kie and Boroski, 1996; Papachristou, 1997; Brosh et al., 2006; Casasús et al., 2007; Bartolomé et al., 2011). The lack of sufficient replicates inhibits the study of the relationship between cattle density and the percentage of woody taxa consumed. Moreover, meta-analysis may also be limited because the published works (Kie and Boroski, 1996; Papachristou, 1997; Brosh et al., 2006; Casasús et al., 2007; Bartolomé et al., 2011; Schoenbaum et al., 2017) omit or show heterogeneous management conditions like livestock density (LU: 0.4–3) and the amount and time applied (none, weeks, seasons) of supplementary feeding.

Most of the fairly abundant woody taxa recorded on the studied farms in PTBNP remain unbrowsed except under moderate or high cattle density. These results reinforce those from the landscape analysis over 16 yr and stress that scrub control by beef cattle is limited (Gutman et al., 2000). It is observed that only high livestock density forces animals to eat a broader array of plant species including woody and poorly palatable species (Provenza et al., 2003; Estell et al., 2012; Schoenbaum et al., 2017). Conversely, overgrazing exerts several detrimental impacts on community structure and ecosystem functioning, such as plant richness and plant animal interactions decline, soil erosion, and contamination (Butzer, 2005; Skarpe and Hester, 2008; Kairis et al., 2015). Therefore, herd mobility has been historically used and claimed to minimize environmental impacts (Butzer, 2005; Caballero et al., 2011). Paradoxically, this type of management may have biased cattle feeding behavior toward avoiding the less palatable species such as many Mediterranean woody plants (Provenza et al., 2003). Hence, Provenza et al. (2003) suggest the use of high stock densities for short periods (boom-bust grazing) to force animals to feed and forage on a broader array of plant species and habitats.

The current empirical evidence shows that the thickness of Mediterranean shrublands plus their low palatability and the poor quality of their

phytomass (rich in tannins and other toxic compounds) drive cattle behaviors and preferences (Perevolotsky, 1994; Provenza et al., 2003; Brosh et al., 2006; Bartolomé et al., 2011; Bashan and Bar-Massada, 2017). The deterrent traits of the woody plants along with the low productivity of grasslands make the Mediterranean vegetation unsuitable to satisfy cattle nutritional requirements, and thus moderate or even high incomes (e.g., feed supplementation) are usually implemented (Gutman et al., 2000; Casasús et al., 2005), which in turn reduce cattle browsing on woody plants (Mosquera-Losada et al., 2005). Preliminary work revealed that fecal nitrogen and energy status of cattle indicate the detrimental impact of exclusively browsing and grazing in a Mediterranean woody landscape (Teruel-Coll et al., 2019). Nonetheless, to date, no long-term study has evaluated whether beef cattle under high density is able to adapt its grazing preferences to the Mediterranean woody plants and control shrub encroachment without supplementary feeding.

Alternatives to Control Woody Encroachment and Fire Hazards

The limited impacts of beef cattle grazing on woody vegetation calls into question the CAP policies that have promoted the replacement of sheep and goat herds by cattle for extensive pastoralism in Mediterranean areas (Plaza Gutiérrez and Llorente Pinto, 2000; Mosquera-Losada et al., 2005; de Rancourt et al., 2006; Bernués et al., 2011; Nori and Gemini, 2011).

Some authors have suggested the use of more adapted cattle breeds (Gutman et al., 2000; Mosquera-Losada et al., 2005; Bartolomé et al., 2011; Shabtay, 2015) and focus on recovering native breeds or developing animals able to use shrubs more efficiently (Rogosic et al., 2008; Braghieri et al., 2011; Estell et al., 2012; Shabtay, 2015). Some Mediterranean native cows (e.g., the Albera breed) mainly feed on woody plants (Bartolomé et al., 2011), but they render a lower production of meat or milk than commercial breeds (Verrier et al., 2005) and supplementary feeding has to be implemented (Gutman et al., 2000; Casasús et al., 2005; Henkin et al., 2005; Brosh et al., 2006; Bartolomé et al., 2011). Other authors, instead of free-ranging grazing, have proposed planned grazing practices since they modify cattle movements and feeding behavior, exerting significant changes in vegetation including woody encroachment decline (Probo et al., 2014; Pittarello et al., 2016). However, there are controversial results in semiarid habitats (Bailey and Brown, 2011), and empirical evidence is scarce in Mediterranean environments (Huntsinger et al., 2015).

In contrast, short-term studies reveal that the use of other domestic animals like goats (Mancilla-Leytón et al., 2013), some wild ungulates (Verheyden-Tixier et al., 1998; Minder, 2012; Bashan and Bar-Massada, 2017), or mixed flocks (Benavides et al., 2009; Papachristou and Platis, 2011; Huntsinger et al., 2015) would be more effective to reduce woody encroachment and wildfire risk in Mediterranean environments. Goats and deer, roe deer, or Iberian ibis browse a wider spectrum and greater amount of woody phytomass than cattle (e.g., Papachristou and Platis, 2011) and are well adapted to the deterrent chemical compounds of the Mediterranean woody plants (Baraza et al., 2009; Minder, 2012; Ferraz de Oliveira et al., 2013). However, disease transmission is one of the major potential handicaps of the coexistence of wild and domestic livestock (San Miguel-Ayán et al., 2010; Martin et al., 2011), and, once more, we lack long-term studies of the effect of mixed herds of domestic and wild herbivores on vegetation dynamics in Mediterranean areas (Sá-Sousa, 2014).

Prospects of Extensive Grazing for Environmental and Socioeconomical Purposes

Open habitats within the majority of the Mediterranean Basin have been historically generated and managed by multiple human interventions like grazing but also fires, shrub, and forestry practices (Blondel et al., 2010; Henkin, 2013; Plieninger et al., 2015). The current woody encroachment and subsequent landscape homogenization and fire hazard risk can be almost impossible to reduce by using only one measurement, such as extensive grazing (Lasanta et al., 2018). Therefore, current CAP policies promoting extensive livestock grazing as HNV farming may be based on weak and even contradictory evidence (McCracken and Huband, 2005; Plieninger and Bieling, 2013; Beaufoy and Poux, 2014). The current and future CAP policies (https://ec.europa.eu/info/food-farming-fisheries/key-policies/common-agricultural-policy/future-cap_en) seem to ignore the urgent necessity of a research framework to successfully meet biodiversity conservation and economic sustainability of rural areas (Lemaire, 2007; Sanderson et al., 2016). Long-term monitoring projects focused on ungrazed, intensively grazed, and extensively grazed environments in Mediterranean areas dominated by woody plants should consider crucial management factors (supplementary food and livestock density, flock species composition, rotational or planned grazing), livestock health, economic profits, and relevant environmental impacts (Bernués et al., 2011; Huntsinger et al., 2015; Sanderson et al., 2016; Nadal-Romero et al., 2018). After all, long-term basic research and applied projects will provide useful guidelines to revise and improve the current common agricultural policies of Europe and thus reconcile profitable farmland business and extensive grazing devoted to biodiversity conservation and fire prevention in Mediterranean areas.

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References

- Alipayo, D., Valdez, R., Holecchek, J.L., Cardenas, M., 1992. Evaluation of microhistological analysis for determining ruminant diet botanical composition. *Journal of Range Management* 45, 148–152.
- Álvarez de la Campa Fayos, J.M., 2009. Digital cartography of the CORINE habitats and Habitats of Community Interest of the Partial Natural Reserve of the Beech Forest of the Ports and adjacent areas, scale 1: 10,000. University of Barcelona (UB), Barcelona, Spain, pp. 1–71.
- Álvarez de la Campa Fayos, J.M., 2010. Digital cartography of the CORINE habitats and Habitats of Community Interest of the Ports Natural Park: II. South-west zone, at scale 1: 10,000. University of Barcelona (UB), Barcelona, Spain, pp. 1–58.
- Anadón, J.D., Sala, O.E., Turner, B.L., Bennett, E.M., 2014. Effect of woody-plant encroachment on livestock production in North and South America. *Proceedings of the National Academy of Sciences of the United States of America* 111, 12948–12953.

- Archer, S.R., Predick, K.I., 2014. An ecosystem services perspective on brush management: research priorities for competing land-use objectives. *Journal of Ecology* 102, 1394–1407.
- Asner, G.P., Elmore, A.J., Olander, L.P., Martin, R.E., Harris, A.T., 2004. Grazing systems, ecosystem responses, and global change. *Annual Review of Environment and Resources* 29, 261–299.
- Bailey, D.W., Brown, J.R., 2011. Rotational grazing systems and livestock grazing behavior in shrub-dominated semi-arid and arid rangelands. *Rangeland Ecology & Management* 64, 1–9.
- Baraza, E., Hódar, J.A., Zamora, R., 2009. Consequences of plant–chemical diversity for domestic goat food preference in Mediterranean forests. *Acta Oecologica* 35, 117–127.
- Bartolomé, J., López, Z.G., José Broncano, M., Plaixats, J., 2005. Grassland colonization by *Erica scoparia* (L.) in the Montseny Biosphere Reserve (Spain) after land-use changes. *Agriculture, Ecosystems and Environment* 111, 253–260.
- Bartolomé, J., Plaixats, J., Piedrafitá, J., Fina, M., Adroba, E., Aixàs, A., Bonet, M., Grau, J., Polo, L., 2011. Foraging behavior of Albar cattle in a Mediterranean forest ecosystem. *Rangeland Ecology & Management* 64, 319–324.
- Bashan, D., Bar-Massada, A., 2017. Regeneration dynamics of woody vegetation in a Mediterranean landscape under different disturbance-based management treatments. *Applied Vegetation Science* 20, 106–114.
- Beaufou, G., Poux, X., 2014. Supporting HNV extensive livestock systems in Mountain and Mediterranean areas—the need for an adapted European Policy. *Options Méditerranéennes* 109, 19–30.
- Benavides, R., Celaya, R., Ferreira, L., Jáuregui, B., García, U., Osoro, K., 2009. Grazing behaviour of domestic ruminants according to flock type and subsequent vegetation changes on partially improved heathlands. *Spanish Journal of Agricultural Research* 7 (2), 17–30.
- Bernués, A., Riedel, J.L., Asensio, M.A., Blanco, M., Sanz, A., Revilla, R., Casasús, I., 2005. An integrated approach to studying the role of grazing livestock systems in the conservation of rangelands in a protected natural park (Sierra de Guara, Spain). *Livestock Production Science* 96, 75–85.
- Bernués, A., Ruiz, R., Olaizola, A., Villalba, D., Casasús, I., 2011. Sustainability of pasture-based livestock farming systems in the European Mediterranean context: synergies and trade-offs. *Livestock Science* 139, 44–57.
- Bianchetto, E., Buscemi, I., Corona, P., Giardina, G., La Mantia, T., Pasta, S., 2015. Fitting the stocking rate with pastoral resources to manage and preserve Mediterranean forest lands: a case study. *Sustainability* 7, 7232.
- Blackhall, M., Veblen, T., Raffaele, E., 2015. Recent fire and cattle herbivory enhance plant-level fuel flammability in shrublands. *Journal of Vegetation Science* 26, 123–133.
- Blondel, J., Aronson, J., Boeuf, G., 2010. *The Mediterranean Region*. Oxford University Press, Oxford, England, p. 376.
- Braghieri, A., Pacelli, C., Girolami, A., Napolitano, F., 2011. Time budget, social and ingestive behaviours expressed by native beef cows in Mediterranean conditions. *Livestock Science* 141, 47–52.
- Brosh, A., Henkin, Z., Orlov, A., Aharoni, Y., 2006. Diet composition and energy balance of cows grazing on Mediterranean woodland. *Livestock Science* 102, 11–22.
- Bullock, J.M., Jefferson, R.G., Blackstock, T.H., Pakeman, R.J., Emmett, B.A., Pywell, R.J., Grime, J.P., Silvertown, J., 2011. Semi-natural grasslands. Technical report: the UK National Ecosystem Assessment. UNEP-WCMC, Cambridge, UK, pp. 162–195.
- Burnham, K.P., Anderson, D.R., 2013. *Model selection and inference: a practical information-theoretic approach*. Springer, New York, NY, USA.
- Butzer, K.W., 2005. Environmental history in the Mediterranean world: cross-disciplinary investigation of cause-and-effect for degradation and soil erosion. *Journal of Archaeological Science* 32, 1773–1800.
- Caballero, R., Fernandez-Gonzalez, F., Perez Badia, R., Molle, G., Roggero, P.P., Bagella, S., D'Ottavio, P., Papanastasis, V.P., Fotiadis, G., Sidiropoulou, A., Ispikoudis, I., 2011. Grazing systems and biodiversity in Mediterranean areas: Spain, Italy and Greece. *Pastos* 39, 9–154.
- Casasús, I., Bernués, A., Sanz, A., Riedel, J.L., Revilla, R., 2005. Utilization of Mediterranean forest pastures by suckler cows: animal performance and impact on vegetation dynamics. In: Georgoudis, A., Rosati, A., Mosconi, C. (Eds.), *Animal production and natural resources utilisation in the Mediterranean mountain areas*. Wageningen Academic Publishers, Wageningen, The Netherlands, pp. 82–88.
- Casasús, I., Bernués, A., Sanz, A., Villalba, D., Riedel, J.L., Revilla, R., 2007. Vegetation dynamics in Mediterranean forest pastures as affected by beef cattle grazing. *Agriculture, Ecosystems and Environment* 121, 365–370.
- Crocker, B.H., 1959. A method of estimating the botanical composition of the diet of sheep. *New Zealand Journal of Agricultural Research* 2, 72–85.
- Dahlgren, R.A., Singer, M.J., Huang, X., 1997. Oak tree and grazing impacts on soil properties and nutrients in a California oak woodland. *Biogeochemistry* 39, 45–64.
- Dell, B., Hopkins, A.J.M., Lamont, B.B., 1986. *Resilience in Mediterranean-type ecosystems*. Kluwer Academic Publishers.
- DeMalach, N., Kigel, J., Voet, H., Ungar, E.D., 2014. Are semiarid shrubs resilient to drought and grazing? Differences and similarities among species and habitats in a long-term study. *Journal of Arid Environments* 102, 1–8.
- Drewry, J.J., Cameron, K.C., Buchan, G.D., 2008. Pasture yield and soil physical property responses to soil compaction from treading and grazing: a review. *Soil Research* 46, 237–256.
- ESRI [software], 2011. *ArcGIS Desktop: release 10*. Environmental Systems Research Institute, Redlands, CA, USA.
- Estell, R.E., Havstad, K.M., Cibils, A.F., Fredrickson, E.L., Anderson, D.M., Schrader, T.S., James, D.K., 2012. Increasing shrub use by livestock in a World with less grass. *Rangeland Ecology & Management* 65, 553–562.
- European Commission DG Environment, 2013. Interpretation manual of European Union Habitats EUR 28. Nature ENV B.3. Habitats Committee, Croatia, p. 144.
- Evlagon, D., Kommisarchik, S., Gurevich, B., Leinweber, M., Nissan, Y., Seligman, N.G., 2012. Estimating normative grazing capacity of planted Mediterranean forests in a fire-prone environment. *Agriculture, Ecosystems and Environment* 155, 133–141.
- Ferraz de Oliveira, M.I., Lamy, E., Bugalho, M.N., Vaz, M., Pinheiro, C., Cancela d'Abreu, M.,
- Capela e Silva, F., Sales-Baptista, E., 2013. Assessing foraging strategies of herbivores in Mediterranean oak woodlands: a review of key issues and selected methodologies. *Agroforestry Systems* 87, 1421–1437.
- Gibon, A., 2005. Managing grassland for production, the environment and the landscape. Challenges at the farm and the landscape level. *Livestock Production Science* 96, 11–31.
- Gutman, M., Henkin, Z., Holzer, Z., Noy-Meir, I., Seligman, N.G., 2000. A case study of beef cattle grazing in a Mediterranean-type woodland. *Agroforestry Systems* 48, 119–140.
- Gutman, M., Seligman, N.G., 1979. Grazing management of Mediterranean foothill range in the Upper Jordan river valley. *Journal of Range Management* 32 (2), 86–92.
- Hadjigeorgiou, I., Osoro, K., Fragoso de Almeida, J.P., Molle, G., 2005. Southern European grazing lands: production, environmental and landscape management aspects. *Livestock Production Science* 96, 51–59.

- Henkin, Z., 2013. Cattle grazing and vegetation management for multiple use of Mediterranean shrubland in Israel. *Israel Journal of Ecology and Evolution* 57, 43–51.
- Henkin, Z., Gutman, M., Aharon, H., Perevolotsky, A., Ungar, E.D., Seligman, N.G., 2005. Suitability of Mediterranean oak woodland for beef herd husbandry. *Agriculture, Ecosystems & Environment* 109, 255–261.
- Henle, K., Alard, D., Clitherow, J., Cobb, P., Firbank, L., Kull, T., McCracken, D., Moritz, R.F.A., Niemelä, J., Rebane, M., Wascher, D., Watt, A., Young, J., 2008. Identifying and managing the conflicts between agriculture and biodiversity conservation in Europe—a review. *Agriculture Ecosystems & Environment* 124, 60–71.
- Available at: <http://opengis.uab.es/wms/iberia/>. Accessed 05/09/2017 Available at: http://parcsnaturals.gencat.cat/es/ports/coneixe-nos/dades_generals/. Accessed 05/09/2017
- Available at: http://ec.europa.eu/info/food-farming-fisheries/key-policies/common-agricultural-policy/future-cap_en. Accessed 06/09/2017
- Huntsinger, L., Bartolome, J.W., D'Antonio, C.M., 2015. Grazing management on California's Mediterranean grasslands. In: Corbin, J., Stromberg, M., D'Antonio, C.M. (Eds.), *California grasslands: ecology and management*. University of California Press, Oakland, CA, USA, pp. 233–253.
- Kairis, O., Karavitis, C., Salvati, L., Kounalaki, A., Kosmas, K., 2015. Exploring the impact of overgrazing on soil erosion and land degradation in a dry mediterranean agroforest landscape (Crete, Greece). *Arid Land Research and Management* 29 (3), 360–374.
- Keenleyside, C., Tucker, G.M., 2010. Farmland Abandonment in the EU: an assessment of trends and prospects. Institute for European Environmental Policy, London, England, p. 93.
- Kerven, C., Behnke, R., 2011. Policies and practices of pastoralism in Europe. *Pastoralism: Research, Policy and Practice* 1, 28.
- Kie, J.G., Boroski, B.B., 1996. Cattle distribution, habitats, and diets in the Sierra Nevada of California. *Journal of Range Management* 49, 482–488.
- Lasanta, T., Khorchani, M., Pérez-Cabello, F., Errea, P., Sáenz-Blanco, R., Nadal-Romero, E., 2018. Clearing shrubland and extensive livestock farming: active prevention to control wildfires in the Mediterranean mountains. *Journal of Environmental Management* 227, 256–266.
- Launchbaugh, K., 2006. Targeted grazing: a natural approach to vegetation management and landscape enhancement. American Sheep Industry Association (ASD), Denver, USA, p. 199.
- Lemaire, G., 2007. Research priorities for grassland science: the need of long term integrated experiments networks. *Revista Brasileira de Zootecnia* 36, 93–100.
- Lopez-i-Gelats, F., Rivera-Ferre, M.G., Madruga-Andreu, C., Bartolomé-Filella, J., 2015. Is multifunctionality the future of mountain pastoralism? Lessons from the management of semi-natural grasslands in the Pyrenees. *Spanish Journal of Agricultural Research* 13 (4), e0307.
- Mancilla-Leytón, J.M., Pino Mejías, R., Martín Vicente, A., 2013. Do goats preserve the forest? Evaluating the effects of grazing goats on combustible Mediterranean scrub. *Applied Vegetation Science* 16, 63–73.
- Manly, B.F., McDonald, L., Thomas, D., McDonald, T.L., Erickson, W.P., 2002. Resource selection by animals statistical design and analysis for field studies. Springer, The Netherlands.
- Martin, C., Pastoret, P.-P., Brochier, B., Humblet, M.-F., Saegerman, C., 2011. A survey of the transmission of infectious diseases/infections between wild and domestic ungulates. *European Veterinary Research* 42, 70.
- Martinez del Castillo, E., García-Martin, A., Longares Aladrén, L.A., de Luis, M., 2015. Evaluation of forest cover change using remote sensing techniques and landscape metrics in Moncayo Natural Park (Spain). *Applied Geography* 62, 247–255.
- McCracken, D.I., Huband, S., 2005. Nature conservation value of European mountain farming systems. In: Huber, U.M., Bugmann, H.K.M., Reasoner, M.A. (Eds.), *Global change and mountain regions: an overview of current knowledge*. Springer, Dordrecht, The Netherlands, pp. 573–582.
- Minder, I., 2012. Local and seasonal variations of roe deer diet in relation to food resource availability in a Mediterranean environment. *European Journal of Wildlife Research* 58, 215–225.
- Ministerio de Medio Ambiente y Medio Rural y Marino, 2010. Razas de ganado del catálogo oficial de España. Ministerio de Medio Ambiente y Medio Rural y Marino, Madrid, Spain.
- Moreira, F., Vaz, P., Catry, F., Silva, J.S., 2009. Regional variations in wildfire susceptibility of land-cover types in Portugal: implications for landscape management to minimize fire hazard. *International Journal of Wildland Fire* 18, 563–574.
- Mosquera-Losada, M., Rigueiro-Rodríguez, A., McAdam, J., 2005. Silvopastoralism and sustainable land management. CABI Publishing, Wallingford, UK, p. 170.
- Nadal-Romero, E., Lasanta, T., Cerda, A., 2018. Integrating extensive livestock and soil conservation policies in Mediterranean areas for recovery of abandoned lands in the central Spanish Pyrenees. A long-term research assessment. *Land Degradation and Development* 29, 262–273.
- Nakagawa, S., Schielzeth, H., 2013. A general and simple method for obtaining R² from generalized linear mixed-effects models. *Methods in Ecology and Evolution* 4 (2), 133–142.
- Nori, S., Gemini, M., 2011. The Common Agricultural Policy vis-à-vis European pastoralists: principles and practices. *Pastoralism: Research, Policy and Practice* 1, 27.
- Noy-Meir, I., Gutman, M., Kaplan, Y., 1989. Responses of Mediterranean Grassland Plants to Grazing and Protection. *Journal of Ecology* 77, 290–310.
- Oppermann, R., Beaufoy, G., Jones, G., 2012. High Nature Value Farming in Europe: 35 European Countries - Experiences and Perspectives. Verlag Regionalkultur, Ubstadt-Weiher, Germany, p. 544.
- Otero, I., Marull, J., Tello, E., Diana, G.L., Pons, M., Coll, F., Boada, M., 2015. Land abandonment, landscape, and biodiversity: questioning the restorative character of the forest transition in the Mediterranean. *Ecology and Society* 20, 7.
- Papachristou, T.G., 1997. Foraging behaviour of goats and sheep on Mediterranean kermes oak shrublands. *Small Ruminant Research* 24, 85–93.
- Papachristou, T.G., Platis, P.D., 2011. The impact of cattle and goats grazing on vegetation in oak stands of varying coppicing age. *Acta Oecologica* 37, 16–22.
- Perevolotsky, A., 1994. Tannins in Mediterranean woodland species: lack of response to browsing and thinning. *Oikos* 71, 333–340.
- Perevolotsky, A., Seligman, N.G., 1998. Role of grazing in Mediterranean rangeland ecosystems. *BioScience* 48, 1007–1017.
- Pittarello, M., Probo, M., Lonati, M., Lombardi, G., 2016. Restoration of sub-alpine shrub-encroached grasslands through pastoral practices: effects on vegetation structure and botanical composition. *Applied Vegetation Science* 19 (3), 381–390.
- Plaza Gutiérrez, J.I., Llorente Pinto, J.M., 2000. The contrasts in free-range livestock and the repercussions of P.A.C. Second Anglo Spanish Symposium on Rural Geography; July 2000. University of Valladolid, Spain.
- Plieninger, T., Bieling, C., 2013. Resilience-based perspectives to guiding high-nature-value farmland through socioeconomic change. *Ecology and Society* 18.
- Plieninger, T., Hartel, T., Martín-López, B., Beaufoy, G., Bergmeier, E., Kirby, K., Montero, M.J., Moreno, G., Oteros-Rozas, E., Van Uytvanck, J., 2015. Wood-pastures of Europe: geographic coverage, social-ecological values, conservation management, and policy implications. *Biological Conservation* 190, 70–79.
- Probo, M., Lonati, M., Pittarello, M., Bailey, D., Garbarino, M., Gorlier, A., Lombardi, G., 2014. Implementation of a rotational grazing system with large paddocks changes the distribution of grazing cattle in the southwestern Italian Alps. *Rangeland Journal* 36 (5), 445–458.

- Provenza, F.D., Villalba, J.J., Dziba, L.E., Atwood, S.B., Banner, R.E., 2003. Linking herbivore experience, varied diets, and plant biochemical diversity. *Small Ruminant Research* 49, 257–274.
- Quero, J.L., Maestre, F.T., Ochoa, V., García-Gómez, M., Delgado-Baquerizo, M., 2013. On the importance of shrub encroachment by sprouters, climate, species richness and anthropic factors for ecosystem multifunctionality in semi-arid Mediterranean eco-systems. *Ecosystems* 16, 1248–1261.
- R Core Team. Available at: <https://www.R-project.org/>. Accesed date: September 2017. de Rancourt, M., Fois, N., Lavin, M.P., Tchakérian, E., Vallerand, F., 2006. Mediterranean sheep and goats production: an uncertain future. *Small Ruminant Research* 62, 167–179.
- Rivest, D., Rolo, V., López-Díaz, L., Moreno, G., 2011. Shrub encroachment in Mediterranean silvopastoral systems: *Retama sphaerocarpa* and *Cistus ladanifer* induce contrasting effects on pasture and *Quercus ilex* production. *Agriculture Ecosystems & Environment* 141, 447–454.
- Rogosic, J., Estell, R.E., Ivankovic, S., Kezic, J., Razov, J., 2008. Potential mechanisms to increase shrub intake and performance of small ruminants in Mediterranean shrubby ecosystems. *Small Ruminant Research* 74, 1–15.
- San Miguel-Ayanz, A., Perea García-Calvo, R., Fernández-Olalla, M., 2010. Wild ungulates vs. extensive livestock. Looking back to face the future. *Options Méditerranéennes* 92, 27–34.
- Sanderson, M.A., Liebig, M.A., Hendrickson, J.R., Kronberg, S.L., Toledo, D., Derner, J.D., Reeves, J.L., 2016. A century of grazing: the value of long-term research. *Journal of Soil and Water Conservation* 71, 5A–8A.
- Sá-Sousa, P., 2014. The Portuguese montado: conciliating ecological values with human demands within a dynamic agroforestry system. *Annals of Forest Science* 71, 1–3.
- Schoenbaum, I., Kigel, J., Ungar, E.D., Dolev, A., Henkin, Z., 2017. Spatial and temporal activity of cattle grazing in Mediterranean oak woodland. *Applied Animal Behaviour Science* 187, 45–53.
- Seifan, M., Kadmon, R., 2006. Indirect effects of cattle grazing on shrub spatial pattern in a mediterranean scrub community. *Basic and Applied Ecology* 7, 496–506.
- Shabtay, A., 2015. Adaptive traits of indigenous cattle breeds: the Mediterranean Baladi as a case study. *Meat Science* 109, 27–39.
- da Silveira Pontes, L., Magda, D., Jarry, M., Gleizes, B., Agreil, C., 2012. Shrub encroachment control by browsing: targeting the right demographic process. *Acta Oecologica* 45, 25–30.
- Skarpe, C., Hester, A.J., 2008. Plant traits, browsing and grazing herbivores, and vegetation dynamics. In: Gordon, I.J., Prins, H.H.T. (Eds.), *The ecology of browsing and grazing*. Springer, Berlin, Heidelberg, Germany, pp. 217–261.
- Slancarova, J., Bartonova, A., Zapletal, M., Kotilinek, M., Faltynek Fric, Z., Micevski, N., Kati, V., Konvicka, M., 2016. Life history traits reflect changes in mediterranean butterfly communities due to forest encroachment. *PLoS One* 11, e0152026.
- Stewart, D.R.M., 1967. Analysis of plant epidermis in faeces: a technique for studying the food preferences of grazing herbivores. *Journal of Applied Ecology* 4, 83–111.
- Turuel-Coll, M., Pareja, J., Bartolomé, J., Serrano, E., Mentaberre, G., Cuenca, R., Espunyes, J., Pauné, F., Calleja, J.A., 2019. Effects of boom and bust grazing management on vegetation and health of beef cattle used for wildfire prevention in a Mediterranean forest. *Science of the Total Environment* 665, 18–22.
- Verheyden-Tixier, H., Duncan, P., Ballon, P., Guillon, N., 1998. Selection of hardwood saplings by European roe deer: effects of variation in the availability of palatable species and of understory vegetation. *Revue D Ecologie-La Terre Et La Vie* 53, 245–253.
- Verrier, E., Tixier-Boichard, M., Bernigaud, R., Naves, M., 2005. Conservation and value of local livestock breeds: usefulness of niche products and/or adaptation to specific environments. *Animal Genetics* 36, 21–31.