

Grazing behaviour of domestic ruminants according to flock type and subsequent vegetation changes on partially improved heathlands

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Abstract

The management of different livestock species may promote different vegetation dynamics that will affect subsequent animal performance and the sustainability of extensive grazing systems. The grazing behaviour of two livestock species (domestic cattle and sheep) under two different managements (monospecific or mixed with goats), and the subsequent vegetation changes were studied on mechanically cleared heathlands (*Ulex gallii* Planchon-*Erica* spp.), with one third of the total area improved with perennial ryegrass-white clover pasture (*Lolium perenne* L.-*Trifolium repens* L.). Results showed that animals in mixed herds spent more time grazing than in monospecific groups. Goats spent more proportional time grazing on shrubland (68%) compared to sheep (35%) and cattle (19%), which spent most of the time on the improved pasture. The diet composition estimates also confirmed that these two animal species basically selected herbaceous species (89-95%) whilst gorse was an important element of goats' diets (28%). Throughout the experiment, an increment of gorse cover, height and phytomass was observed, especially under single grazing; whereas dead matter and herbaceous covers decreased more under single than under mixed grazing. Besides, heather percentage and gorse height underwent a higher increase under cattle than under sheep grazing. On the improved areas the sward height was significantly higher with cattle, and the gorse sprouting was more controlled under sheep grazing treatments. It is concluded that the complementary grazing of goats can enhance the utilization of these heterogeneous plant resources, providing a more efficient way for both productive and environmental goals than single cattle or sheep grazing.

Additional key words: cattle, diet selection, goat, sheep, shrublands

Resumen

Conducta de pastoreo de rumiantes domésticos según el tipo de rebaño y sus efectos sobre la vegetación en brezales parcialmente mejorados

El manejo de distintas especies ganaderas puede generar cambios en la vegetación, afectando al rendimiento animal y a la sostenibilidad de los sistemas extensivos de producción animal en pastoreo. En este trabajo se estudia la conducta de pastoreo de dos especies (vacuno y ovino domésticos) manejadas bajo dos tratamientos (rebaños monoespecíficos o mixtos con caprino) y la dinámica vegetal resultante en brezales-tojales (*Ulex gallii* Planchon-*Erica* spp.) desbrozados, con un tercio de su superficie con raigrás y trébol (*Lolium perenne* L.-*Trifolium repens* L.). Los resultados mostraron que los animales en rebaños mixtos pastaron durante más tiempo, y que las cabras pastaron durante más tiempo en la zona de matorral (68%) que las ovejas (35%) y las vacas (19%). Estas últimas dedicaron más tiempo en la zona mejorada, seleccionando básicamente herbáceas (89-95%). Se observó un mayor incremento generalizado del tojo, y una mayor reducción en la cobertura de materia muerta y de herbáceas con rebaños monoespecíficos que con mixtos. Además se detectó un incremento mayor en el porcentaje de brezo y en la altura del tojo en las parcelas pastadas por vacuno que por ovino. En las zonas de pradera, la altura de la hierba fue significativamente mayor en los tratamientos de vacuno, y los rebrotes de tojo fueron mejor controlados en las parcelas con ovino. Se concluye que el pastoreo mixto con caprino puede ayudar a alcanzar sistemas sostenibles en estas comunidades vegetales heterogéneas al incrementar su utilización, obteniéndose una gestión más efectiva desde un punto de vista productivo y ambiental.

Palabras clave adicionales: caprino, matorral, ovino, selección de dieta, vacuno

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Introduction

Heathlands are shrubby vegetation communities covering large areas of the Atlantic regions of Western Europe with acidic and poor soils (Webb, 1998). With some exceptions, these communities are serial stages that evolve through succession into forest climax communities (Díaz González and Fernández Prieto, 1994). In most of its natural distribution area, *i.e.* from Brittany (France) to Scandinavia and eastwards, heathland areas have decreased drastically during the last century, mainly due to the replacement of traditional livestock farming by intensive systems (overgrazing, agricultural transformation) and eutrophication (Diemont *et al.*, 1996; Webb, 1998), being actually reduced to small and fragmented areas whose conservation is seriously endangered (Habitats Directive 92/43/EEC, OJ, 1992). In contrast, heathlands are actually widespread in the northern Spain and Portugal as consequence of the abandonment of agricultural and livestock managements since 1950s, particularly in the most infertile and erodible lands where the succession to forests is restricted by soil thickness and fertility, and by frequent fires.

In Asturias, heathlands cover 21% of the total area (Álvarez *et al.*, 2004) and are usually extensively managed with domestic livestock, mainly feral cattle and horses, at very low stocking rates. In the last decades, the increasing frequency of wildfires associated to these shrublands (Marquínez *et al.*, 2003), characterised by its high combustibility and flammability (Núñez-Regueira *et al.*, 1996), is becoming a problem as recurrent fires are causing a great soil erosion in many areas, with high environmental and economical losses (MMA, 2007). Hence, it means a high risk for the conservation of the natural resources and the rural development of these marginal and less-favoured areas (Hadjigeorgiou *et al.*, 2005).

The productivity of heathlands is quite low, mainly due to the low nutritive value of the dominant woody species for grazing livestock (Hodgson and Eadie, 1986; Osoro *et al.*, 2007). Currently, partial transformation of heathlands is being studied, establishing adjacent areas of improved pasture, usually of perennial ryegrass (*Lolium perenne* L.) and white clover (*Trifolium repens*

L.), to meet the nutritional requirements of livestock (Osoro *et al.*, 1999). Also some heathland areas are mechanically cleared to reduce the encroachment of woody plants such as heather species (*Erica* spp., *Calluna vulgaris* (L.) Hull) and gorse (*Ulex* spp.), increasing consequently the presence of herbaceous species, and preventing fires. However, the benefit of such investment procedures will depend on the following grazing management (livestock species and breed, single or mixed grazing, stocking rate, etc.).

Animal species display different foraging behaviour due to their different eco-physiological adaptations (mouth and dental anatomy, digestive capacity, etc.), and therefore they have different ability to exploit the available plant resources (Hofmann, 1989; Illius and Gordon, 1993). Cattle are primary grazers that hardly consume woody plants like heather and gorse (Aldeza-bal, 2001; Celaya *et al.*, 2007b). In contrast, small ruminants like sheep or goats are able to select more efficiently the green shoots of these shrubs, complementing their diet when the availability of green herbaceous pasture is reduced (Grant *et al.*, 1984, 1987). Nevertheless, sheep are able to graze on very short swards without reducing the level of intake below their maintenance needs (Osoro *et al.*, 2000a). On the other hand, goat is a more browser species that uses woody species at a higher degree than the former (Lu, 1988; Narjisse, 1991). Therefore, the utilization of different animal species may promote different vegetation dynamics that will affect subsequent animal performance and the sustainability of extensive grazing systems for meat production. The complementary use of goats in partially improved heathlands grazed by cattle or sheep may increase the effective utilization of these heterogeneous resources (Allan and Holst, 1996), *i.e.* reducing the encroachment of shrubs and controlling the re-growth of invasive plants like gorse (Radcliffe, 1985; Celaya *et al.*, 2007a), as well as diversifying the production.

The objective of this work was to study different grazing managements (type of flock) on mechanically cleared heathland areas with one third of improved perennial ryegrass-white clover pasture, regarding aspects on grazing behaviour and subsequent vegetation changes in the heathland areas. For this purpose, single

Abbreviations used: A (animal species), ADF (acid-detergent fibre), ADL (acid-detergent lignin), ANOVA (analysis of variance), AOAC (Association of Official Analytical Chemists), CA (cattle alone), C+G (cattle with goats), CP (crude protein), DM (dry matter), GLM (general linear model), HFRO (Hill Farming Research Organisation), ILS (iterative least-squares procedure), L (livestock), M (management), masl (meters above sea level), MMA (Ministerio de Medio Ambiente - Ministry of Environment), N (nitrogen), NDF (neutral-detergent fibre), Ss (season), SA (sheep alone), SEM (standard error of mean), S+G (sheep with goats), Y (year).

grazing of cattle and sheep and mixed grazing of the former species with goats were assessed.

Material and methods

Study site

The experimental site was located in the north-west of Spain, San Isidro mountain range, Illano, Asturias (43° 21' N, 6° 53' W), at an altitude of 950-1000 m.a.s.l. The climate is oceanic, humid temperate of medium mountain, with annual mean temperatures of 10.2°C (averaged 4.7°C in January and 16.1°C in August) and annual rainfalls of 1550 mm occurring mainly from October to January (data recorded in the experimental site from 2002 to 2007). The soils are shallow acidic (pH around 4) and deficient in most nutrients, particularly phosphorus, calcium and magnesium (2, 6 and 25 mg kg⁻¹, respectively).

The natural vegetation is composed of shrublands dominated by heather species such as *Erica umbellata* L., *E. cinerea* L. and *Calluna vulgaris* (L.) Hull., together with gorse (*Ulex gallii* Planchon), a thorny and woody legume. Herbaceous species, mainly tough grasses such as *Pseudarrhenatherum longifolium* (Thore) Rouy and *Agrostis curtisii* Kerguelen, cover the gaps remaining among the shrubs. This community is classified as *Halimio alyssoidis-Ulicetum gallii* association (Díaz González and Fernández Prieto, 1994).

Experimental design and animals

The trial was conducted in eight plots (0.9-2.7 ha), grouped in two blocks (Table 1). The plots were estab-

lished in a west-facing slope, originally covered with heather-gorse shrublands. In 2001 all surface was mechanically cleared using a brush cutter, and one third of the area was improved by ploughing, dressing and sowing perennial ryegrass and white clover. Heathland area was in the upper part of the plots and the improved pasture area was in the lower one. Although each plot had an outer fence, no fences were used between the different vegetation areas, so animals had access to every type of vegetation within the plot.

Each block comprised two plots with cattle and two plots with sheep, both under two management options (monospecific or mixed herds with goats). Therefore, four treatments replicated twice were studied: cattle alone (CA), cattle with goats (C+G), sheep alone (SA) and sheep with goats (S+G). Asturiana de los Valles beef cows with their winter-born calves or yearly bulls grazed at a stocking rate of approximately 1.1 lactating cows per hectare or 1.5-1.7 yearly bulls per hectare, and in mixed herds (C+G) a ratio of 1 cow to 7 goats was established (Table 1). Sheep of Gallega breed and Cashmere goats, with their lambs and kids, grazed at a stocking rate of 10 adult breeding females per hectare, and in mixed flocks (S+G) they grazed at a ratio of 1:1. These treatments were maintained during four grazing seasons (from April-May to October-November), from 2002 to 2005.

In the following growing seasons (2006 and 2007), the plot with sheep grazing alone of one block was replaced by goats to compare their grazing behaviour at single grazing.

In addition to the grazing treatment plots, at the beginning of the experiment (2002) small enclosures of approximately 20 x 4 m in the heathland areas were fenced and excluded from grazing as control treatment

Table 1. Total surface area of the experimental plots and number of animals managed in each year and treatment

	Block 1				Block 2			
	CA ¹	C+G ²	SA ³	S+G ⁴	CA ¹	C+G ²	SA ³	S+G ⁴
Plot area (ha)	1.8	2.7	0.9	1.8	2.7	2.7	0.9	1.8
No. of animals ⁵								
-2002	4 b	4 b + 12 g	12 s	12 s + 12 g	7 b	4 b + 12 g	12 s	12 s + 12 g
-2003	2 c	3 c + 20 g	10 s	10 s + 10 g	3 c	3 c + 20 g	10 s	10 s + 10 g
-2004	2 c	4 b + 12 g	9 s	9 s + 9 g	3 c	4 b + 12 g	9 s	9 s + 9 g
-2005	2 c	4 b + 16 g	10 s	10 s + 10 g	3 c	4 b + 16 g	10 s	10 s + 10 g
-2006	2 c	3 c + 18 g	10 g	12 s + 12 g	3 c	3 c + 18 g	10 s	12 s + 12 g
-2007	2 c	3 c + 22 g	12 g	18 s + 18 g	3 c	3 c + 22 g	12 s	18 s + 18 g

¹ CA: cattle alone. ² C+G: cattle with goats. ³ SA: sheep alone. ⁴ S+G: sheep with goats. ⁵ b: yearling bulls; c: cows with calves; s: ewes with lambs; g: goats with kids.

(no grazing). There were six ungrazed enclosures (three per block) allocated in between the large grazed plots.

Every year animals were balanced for body weight and randomly assigned to each plot according to the treatment. Lambs and kids were born in March-April and weaned in July. Calves were born in February-March and weaned in September. Ewes were sheared in June. All animals were drenched with ivermectin (Oramec®, Merial Lyon, France) against gastrointestinal nematodes two weeks before turning them out.

Grazing behaviour and diet selection

The time spent grazing by each animal species on each vegetation type (improved ryegrass-clover pasture or cleared heathland) was determined by recording the grazing activity of adult animals every 15 min from dawn to dusk during two consecutive days in 2003 (14-15 May), 2005 (17-18 July), 2006 (18-19 July) and 2007 (30-31 July).

The composition of the diet selected by grazing animals was estimated in May of 2003 and 2004 using *n*-alkane markers (Dove and Mayes, 1991). Faecal grab samples were collected from individual animals in each plot. Samples of the main plant components, gorse, heather, natural grasses (*P. longifolium* and *A. capillaris* L.), perennial ryegrass and white clover, were also collected. All samples were stored at -20°C and then freeze-dried and milled prior to analytical procedures. The alkanes (from C₂₁ to C₃₆) were extracted using the method of Mayes *et al.* (1986) modified by Oliván and Osoro (1999), and quantified by gas chromatography. The percentages of the plant components in the diet were estimated using an iterative least-squares procedure (ILS; Dove and Moore 1995) which minimises the discrepancies between the observed concentrations of each *n*-alkane in the faeces and the estimated proportions of plant components in the diet. Alkanes from C₂₅ to C₃₃ were used in the ILS due to the very low concentrations of shorter- and longer-chain alkanes in both faeces and herbage. Faecal alkane concentrations were previously adjusted for incomplete faecal recovery using recovery data obtained in validation studies carried out with cattle (Ferreira *et al.*, 2007a), sheep (Ferreira *et al.*, 2007b) and goats (Ferreira *et al.*, 2005). The inclusion of clover in the ILS gave non-sensical results, probably because of its much lower alkane concentrations than the other plant components, so it was removed from such procedure. Even more, the grass species had simi-

lar alkane profiles and thus could not be discriminated from each other, so their averaged alkane concentrations were used in the ILS, coming to three final diet components: gorse, heather and herbaceous plants.

Vegetation measurements

Chemical composition of plant samples harvested in May of 2003, including gorse, heather, natural grasses (*P. longifolium* and *A. capillaris*), perennial ryegrass and white clover, was analysed following the procedures of the Association of Official Analytical Chemists (AOAC, 2006) for ash and nitrogen (N). Crude protein (CP) was calculated as N x 6.25. Neutral-detergent fibre (NDF), acid-detergent fibre (ADF) and acid-detergent lignin (ADL) were analysed by the methods of Van Soest *et al.* (1991).

In order to evaluate the herbage availability in the improved pasture and assess the grazing pressure over it, the sward surface height was measured several times throughout the grazing seasons since 2002 to 2005, recording randomly 100 measurements per plot using the HFRO swardstick (Barthram, 1986).

At the beginning of each grazing season, plant cover and height in the cleared heathland areas were assessed using the point-quadrat technique (Grant, 1981) along five 13 m-long permanent transects in each plot. Transects were randomly allocated the first time and marked. In every transect, 100 vertical hits at 4 cm intervals were recorded, grouped in 5 segments separated 2.2 m each other (500 hits per plot). In May 2006 the ungrazed enclosures were also controlled using the same technique and recording 100 hits per enclosure (300 per block).

Phytomass samples were collected in the shrubland areas every year, harvesting the vegetation contained in 0.2 x 1 m quadrats at 10 random sites on each plot at the beginning of every grazing season. The samples were fresh weighed, and four of those with middle weights were selected for subsequent separation into three main components: gorse, heather and herbaceous plants. These botanical components together with the non-sorted samples were dried in a forced-air oven at 80°C for 24 h and weighed for dry matter (DM) determination. The composition from the sorted samples was applied to the total phytomass accounted for the 10 samples from each plot. In 2006, phytomass from ungrazed enclosures was also sampled taking off six quadrats per block (two per enclosure) and sorting all of them.

The control of gorse sprouting in the improved areas by the different types of flock was estimated in May 2006. A quadrat of 1 x 1 m was randomly thrown 100 times per plot and the presence or absence of gorse sprouts was recorded, and when present they were clipped and pooled per plot. Then the samples were dried in a forced-air oven at 80°C for 24 h and weighed for DM determination.

Statistical analyses

All analyses were performed using SAS System software (SAS Institute, 2001). Plant chemical composition (CP, NDF, ADF, ADL) was analysed by one-way analysis of variance (ANOVA) to examine the differences between the main plant components.

Sward height in the improved pasture areas was analysed using a mixed model procedure (Proc Mixed) for repeated measures (Littell *et al.*, 1998), including in the model the fixed effects of livestock (L: cattle *vs.* sheep), management (M: single *vs.* mixed grazing), year (Y: 2002-2005), and season (Ss: sampling date nested to year as the repeated measure), and the interactions L x M, L x Y, M x Y, L x M x Y, L x Ss(Y), M x Ss(Y) and L x M x Ss(Y), considering plots as the experimental units.

Grazing behaviour data were subjected to a General Linear Model procedure (Proc GLM), examining the fixed effects of animal species (A: cattle, sheep, goat), management (M: single *vs.* mixed) and year (Y: 2003, 2005, 2006, 2007), and the interactions A x M, A x Y, M x Y and A x M x Y. In the case of goats, mixed grazing was either with cattle or sheep, so it was previously checked and verified that no significant differences in the goats' behaviour occurred according to the companion species. Diet composition data were analysed using Proc Mixed for the effects of animal species, management, year (2003, 2004) and their interactions, with plots as a random source of variation and individual animals as replicates.

Botanical data (cover, height and phytomass in the shrubland areas) from 2002 to 2006 were analysed using the Proc Mixed for repeated measures, examining the fixed effects of livestock (L), management (M) and year (Y: 2002-2006) as the repeated measure factor (with plots as the experimental units), and the interactions L x M, L x Y, M x Y and L x M x Y. Final botanical data at the end of the experimental treatments (May 2006) were subjected to 1-way ANOVA to check the differences

between the four grazing treatments and the ungrazed control treatment, using Tukey's test to examine the pairwise differences. Data from the three ungrazed enclosures in each block were pooled, coming to two replicates, to equalize the sampling effort and accuracy between the ungrazed and grazed treatments. All percentage data were angular transformed prior to analyses.

Data on gorse sprouting in the improved pasture areas (% presence and plant weight) did not meet the homogeneity of variances assumption because of zero values. Thus, the non-parametric Mann-Whitney *U* test was employed to examine the effects of livestock species (cattle *vs.* sheep) and management (single *vs.* mixed) independently.

Results

Nutritive quality of vegetation

Nutritive quality of the vegetation showed significant differences between the main plant components ($P < 0.001$). Clover presented the highest mean CP concentration, 359 g kg⁻¹ DM, and heather (108 g kg⁻¹ DM) and *P. longifolium* (148 g kg⁻¹ DM) the lowest one, even lower than that obtained with gorse (204 g kg⁻¹ DM). Cell wall components (NDF) were particularly high in *P. longifolium* (731 g kg⁻¹ DM), followed by *A. capillaris* and woody species, gorse and heather (568-576 g kg⁻¹ DM). Large differences in the lignin content (ADL) were found. The woody species registered ADL contents around 330 and 132 g kg⁻¹ DM in heather and gorse, respectively, being significantly higher than those observed in ryegrass and clover (11 and 17 g kg⁻¹ DM, respectively).

Sward height in the improved pasture area

Sward height in the improved pasture area decreased significantly as the season advanced ($P < 0.001$; Fig. 1). It also varied significantly between years ($P < 0.001$). The type of livestock (cattle *vs.* sheep) significantly affected the sward height ($P < 0.01$), with higher mean values in cattle grazed plots than in sheep ones (8.0 *vs.* 6.8 cm; SEM 0.33). The interactions between livestock species and year ($P < 0.01$) and between livestock and season ($P < 0.001$) were also significant, with higher differences found during the first half of the grazing season (Fig. 1). On the other hand, no significant diffe-

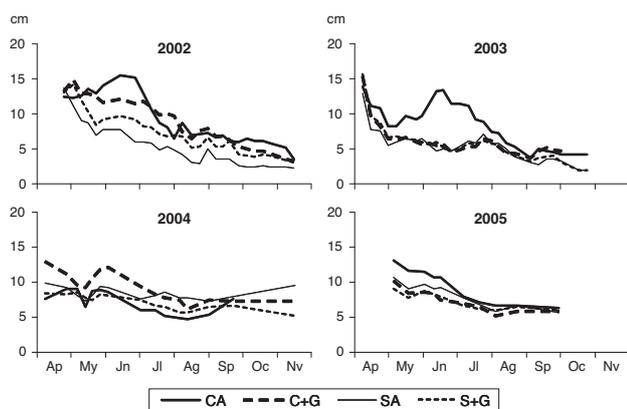


Figure 1. Mean sward height in the improved pasture area of partially improved heathlands grazed by cattle alone (CA), cattle with goats (C+G), sheep alone (SA) or sheep with goats (S+G) across four grazing seasons.

rences were found between both managements (7.44 cm under single grazing vs. 7.38 cm under mixed grazing with goats; SEM 0.34), though the interaction with year was significant ($P < 0.001$).

Foraging behaviour

Grazing time

In general, goats spent more time grazing than cattle and sheep (595, 550 and 512 min d⁻¹, respectively; $P < 0.05$), though there was a strong interaction with year ($P < 0.001$). In 2003, sheep grazed more time than cattle, while in 2007 the grazing times of both sheep and goats were much lower than those observed in cattle (Fig. 2). The grazing management (type of flock) also affected significantly the grazing time ($P < 0.001$); all three species grazed for longer when they were managed in mixed herds compared to single grazing (576 vs. 524 min day⁻¹ in cattle; 534 vs. 491 in sheep; 605 vs. 505 in goats in 2006-2007).

Significant differences in the proportional grazing time spent on improved pasture and on shrubland were also registered between animal species (Fig. 2). Goats spent more grazing time on shrubland (68%) than sheep (35%) and cattle (19%; $P < 0.001$). Furthermore, these values varied according to the type of flock ($P < 0.05$). The time spent by cattle and sheep on improved pasture was slightly higher in monospecific groups compared to mixed herds (84 vs. 78% in cattle, 67 vs. 64% in sheep), while the difference was especially noted in goats (50 vs. 30% in 2006-2007), although no significant interaction was found between animal species and manage-

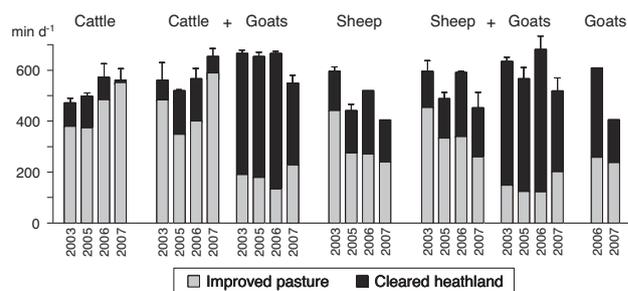


Figure 2. Distribution of the daily grazing time of cattle, sheep and goats on improved pasture areas and mechanically cleared heathland areas according to the type of flock (single or mixed grazing). Vertical bars show standard deviations of total grazing time.

ment. Year had a significant effect on the proportional times grazing on improved pasture or shrubland ($P < 0.01$), but no significant interaction of year with animal species or management was observed.

Diet selection

The percentages of the main vegetation components selected by each animal species in different types of flock are shown in Table 2. Significant differences between animal species were observed in the selection of gorse and herbaceous species ($P < 0.001$). The mean percentage of gorse accounted for 28% in the diet of goats while it accounted for 7% in sheep and 2% in cattle diets. Herbaceous species represented higher percentages in cattle and sheep diets (95 and 89% respectively) than in goat diets (68%). Heather was consumed at similar low percentages by goats (4%), sheep (4%) and cattle (3%). For cattle and sheep, a significant management effect ($P < 0.05$) was observed in the selection of gorse, with higher percentages found in the diets of animals grazing in single flocks (5%) compared to those grazing with goats (3%). In general, gorse percentage increased from 2003 to 2004 whilst that of herbaceous plants decreased ($P < 0.05$).

Vegetation dynamics in mechanically cleared heathlands

Cover

In April 2002, data taken at the beginning of the trial reported an initial mean cover of $33.7\% \pm 7.12$ of live

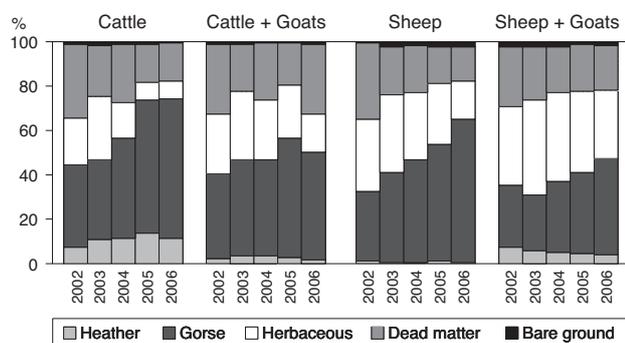
Table 2. Diet composition of cattle, sheep and goats on partially improved gorse-heather shrublands, according to the flock type (single or mixed grazing)

	CA ¹	C+G ²		SA ³	S+G ⁴		SEM ⁵	Significances			
		C	G		S	G		A ⁶	M ⁷	Y ⁸	A x M ⁹
May 2003											
-Gorse (%)	1.3	1.0	29.6	7.2	1.7	23.3	4.35				
-Heather (%)	3.8	3.0	4.3	2.5	5.3	4.1	0.93				
-Herbaceous (%)	94.9	96.0	66.1	90.3	93.0	72.6	4.26				
May 2004											
-Gorse (%)	3.3	1.6	17.2	10.1	7.7	34.3	7.87				
-Heather (%)	3.0	2.8	3.4	3.1	4.5	3.7	1.62				
-Herbaceous (%)	93.7	95.6	79.4	86.8	87.8	62.0	7.75				
Average											
-Gorse (%)	2.3	1.3	23.4	8.7	4.7	28.8	4.01	***	*	*	NS
-Heather (%)	3.4	2.9	3.8	2.8	4.9	3.9	0.85	NS	NS	NS	***
-Herbaceous (%)	94.3	95.8	72.8	88.5	90.4	67.3	3.98	***	NS	*	NS

¹ CA: cattle alone. ² C+G: cattle with goats. ³ SA: sheep alone. ⁴ S+G: sheep with goats. ⁵ SEM: standard error of means. ⁶ A: animal species effect (cattle vs. sheep vs. goats). ⁷ M: management effect (single vs. mixed). ⁸ Y: year effect (2003 vs. 2004). ⁹ A x M are only for cattle and sheep. Y x A, Y x M, and Y x A x M interaction effects were non-significant for all variables. * $P < 0.05$; *** $P < 0.001$; NS not significant ($P > 0.05$).

gorse, $4.6\% \pm 3.81$ of live heather, $29.0\% \pm 8.93$ of live herbaceous plants and $1.3\% \pm 0.94$ of bare ground. There was a high cover of dead matter, $31.3\% \pm 7.23$, mostly due to the debris coming from the mechanical clearing performed the year before.

The cover changes during the trial (2002-2006) are shown in Figure 3 for each treatment. From 2002 to 2006 the mean cover percentage of gorse increased significantly ($P < 0.001$), while that of herbaceous plants and dead matter decreased ($P < 0.001$). The mean percentages of heather and bare ground showed no significant changes throughout the years (Table 3).

**Figure 3.** Mean cover percentages in mechanically cleared heathlands grazed during four grazing seasons by cattle or sheep at single or mixed grazing with goats.

There was a significant interaction between type of management and year for all the examined components, due to the different trends found between monospecific and mixed groups. From 2002 to 2006, gorse cover increased more ($P < 0.01$) under single grazing (from 36.6 to 63.1% in CA; from 31.7 to 64.3% in SA) than under mixed grazing (from 38.3 to 48.5% in C+G; from 28.3 to 43.3% in S+G). Heather cover increased under single grazing from 4.4 to 6.0%, whereas it decreased under mixed grazing from 4.9 to 2.9% ($P < 0.05$). The cover of herbaceous plants increased the first year, and then decreased in both managements until the end of the trial, with a higher reduction rate ($P < 0.05$) under single grazing (from 21.5% in 2002 to 7.8% in 2006 in CA; from 32.4 to 17.4% in SA) than under mixed grazing (from 27.0 to 17.4% in C+G; from 35.1 to 31.0% in S+G).

The percentage of dead matter decreased more ($P < 0.05$) under single (from 33.7 to 16.3%) than under mixed grazing (from 29.0 to 25.7%) through the years. The percentage of bare ground increased from 0.9 to 1.5% under single grazing, whereas it decreased from 1.8 to 1.3% under mixed grazing ($P < 0.05$). Nevertheless, it never exceeded maximum values of 2.3% in any treatment and year.

The interaction between livestock species (cattle or sheep) and year was not significant for any of the studied components, except for heather ($P < 0.05$). Its cover percentage increased under cattle grazing from 5.0% in

Table 3. Effects of main livestock species (cattle vs. sheep), management (single grazing vs. mixed grazing with goats) and year on plant cover, gorse height, and phytomass of mechanically cleared gorse-heather shrublands (least square means from 2002 to 2006)

	CA ¹	C+G ²	SA ³	S+G ⁴	SEM ⁵	Significances					
						L ⁶	M ⁷	L × M	Y ⁸	Y × L	Y × M
Cover (%)											
-Gorse	48.2	45.6	47.1	33.0	6.79	NS	NS	NS	***	NS	**
-Heather	10.9	2.7	0.8	5.4	2.75	NS	NS	*	NS	*	*
-Herbaceous	16.5	25.2	28.3	37.2	4.65	+	NS	NS	***	NS	*
-Dead matter	23.3	25.6	22.0	22.6	2.70	NS	NS	NS	***	NS	*
-Bare ground	1.1	0.9	1.8	1.9	0.65	NS	NS	NS	NS	NS	*
Gorse height (cm)	14.2	10.6	11.0	8.6	1.14	*	*	NS	***	**	***
Phytomass (kg DM ha ⁻¹)											
-Gorse	11914	8242	12980	7559	2279	NS	+	NS	***	NS	*
-Heather	2045	735	294	891	609	NS	NS	NS	NS	+	+
-Herbaceous	4221	4629	3132	4695	748	NS	NS	NS	NS	NS	NS
-Total	18180	13605	16406	13145	1631	NS	+	NS	***	NS	*
Phytomass (%)											
-Gorse	62.6	59.9	76.2	57.2	6.81	NS	NS	NS	***	NS	NS
-Heather	12.1	5.4	1.8	7.0	3.69	NS	NS	NS	*	**	+
-Herbaceous	25.3	34.7	21.9	35.9	6.48	NS	+	NS	**	NS	NS

¹ CA: cattle alone. ² C+G: cattle with goats. ³ SA: sheep alone. ⁴ S+G: sheep with goats. ⁵ SEM: standard error of means. ⁶ L: livestock species effect (cattle vs. sheep). ⁷ M: management effect (single vs. mixed). ⁸ Y: year effect (2002-2006). + $P < 0.1$; * $P < 0.05$; ** $P < 0.01$; *** $P < 0.001$; NS not significant ($P > 0.1$). Y × L × M interaction was non-significant for all variables.

2002 to 6.5% in 2006, whereas it decreased from 4.3 to 2.3% under sheep grazing (Table 3).

Comparing at the end of the experiment (May 2006) grazed and ungrazed plots, significant differences among them were observed in the cover percentage of every component, except for bare ground (Table 4). Gorse cover was significantly higher in the ungrazed enclosures (94.3%) compared to mixed grazing treatments (45.9%; $P < 0.05$). Heather cover was higher in CA (11.2%) than in SA (0.7%; $P < 0.05$), although no significant differences were found between the ungrazed treatment and any grazed treatment. The percentage of herbaceous plants was lower in the ungrazed treatment (2.7%) compared to C+G and SA (17.4% in both cases; $P < 0.05$), and to S+G treatment (31.0%; $P < 0.01$). The percentage of dead matter was lower ($P < 0.01$) in the ungrazed enclosures (1.4%) than in the grazing treatments (15.5-31.3%).

Height

Mean heights of all examined plant components showed similar trends and similar treatment effects as they were highly correlated among themselves, so only

the results concerning the dominant species, *i.e.* gorse, will be reported (Fig. 4).

Gorse height increased significantly across years ($P < 0.001$). Such increase was significantly ($P < 0.001$) higher under single grazing (from 4.9 cm in 2002 to 18.9 cm in 2006) than under mixed grazing (from 5.2 to 13.3 cm), and it was also higher ($P < 0.01$) under cattle (from 4.9 to 18.4 cm) than under sheep grazing (from 5.2 cm to 13.7 cm). The mean gorse height resulted significantly different between both managements (12.6 cm under single grazing vs. 9.6 cm under mixed grazing; $P < 0.05$), and also between both livestock species (12.4 cm under cattle grazing vs. 9.8 cm under sheep grazing; $P < 0.05$; Table 3), through the experiment.

At the end of the trial, gorse height was significantly higher in the ungrazed enclosures (53.7 cm) compared to the grazed plots (16.1 cm; $P < 0.001$). The difference was also significant ($P < 0.05$) between CA and S+G treatments (21.9 and 11.5 cm, respectively; Table 4).

Phytomass

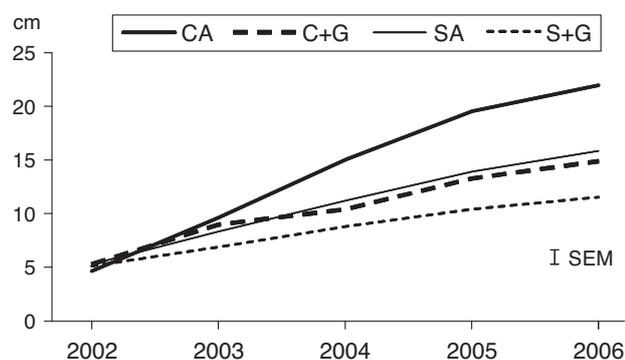
The total amount of aerial phytomass increased significantly ($P < 0.001$) during the experiment from 12.0

Table 4. Treatment effects on the final (2006) cover percentages, gorse height and phytomass of mechanically cleared gorse-heather shrublands grazed since 2002

	CA ¹	C+G ²	SA ³	S+G ⁴	NO ⁵	SEM ⁶	Significance
Cover (%)							
-Gorse	63.1ab	48.5b	64.3ab	43.3b	94.3a	7.14	*
-Heather	11.2a	1.8ab	0.7b	3.9ab	1.6ab	2.20	*
-Herbaceous	7.8bc	17.4ab	17.4ab	31.0a	2.7c	2.89	**
-Dead matter	17.2a	31.3a	15.5a	20.1a	1.4b	3.40	**
-Bare ground	0.7	0.9	2.3	1.7	0.0	0.59	NS
Gorse height (cm)	21.9b	15.0bc	15.9bc	11.5c	53.7a	1.58	***
Phytomass (kg DM ha ⁻¹)							
-Gorse	20272ab	11311b	18969ab	9840b	36403a	3665	*
-Heather	2622	902	417	760	402	870	NS
-Herbaceous	3004	4885	3463	4630	2809	814	NS
-Total	25899ab	17098b	22849ab	15230b	39614a	3384	*
Phytomass (%)							
-Gorse	76.8ab	65.8b	81.8ab	64.7b	91.9a	4.45	*
-Heather	12.3	4.9	1.9	4.8	1.0	4.71	NS
-Herbaceous	10.9ab	29.3a	16.3ab	30.5a	7.1b	4.40	*

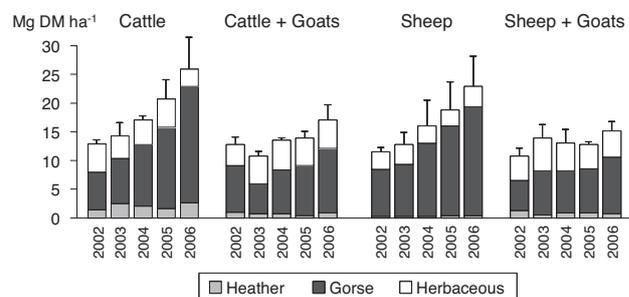
¹ CA: cattle alone. ² C+G: cattle with goats. ³ SA: sheep alone. ⁴ S+G: sheep with goats. ⁵ NO: no grazing. ⁶ SEM: standard error of means. * $P < 0.05$; ** $P < 0.01$; *** $P < 0.001$; NS not significant ($P > 0.05$). Means with different lowercase are significantly different using Tukey's test ($P < 0.05$).

Mg DM ha⁻¹ in 2002 to 20.3 Mg DM ha⁻¹ in 2006 (Table 3), being higher ($P < 0.05$) under single grazing (from 12.2 to 24.4 Mg DM ha⁻¹) than under mixed grazing (from 11.8 to 16.2 Mg DM ha⁻¹; Fig. 5). Gorse was the main component of the phytomass, so its amount was affected by the same year and management effects. Although its percentage was not affected by the grazing treatment, a significant increase across years (from 58.9 to 72.3%; $P < 0.001$) was observed. Heather percentage increased from 6.8% in 2002 to 7.1% in 2006 under sin-

**Figure 4.** Mean height of gorse in mechanically cleared heathlands grazed during four grazing seasons by cattle alone (CA), cattle with goats (C+G), sheep alone (SA) or sheep with goats (S+G). SEM indicates standard error of mean.

gle grazing, whereas it decreased from 9.9 to 4.8% under mixed grazing ($P < 0.01$). The decrease was somewhat greater ($P = 0.052$) under sheep grazing (from 7.2 to 3.3%) compared to cattle grazing (from 9.4 to 8.6%). Herbaceous percentage was reduced across years, from 32.7% in 2002 to 21.8% in 2006 ($P < 0.01$), without significant differences between treatments.

At the end of the trial (2006), gorse amounts (and so total phytomass) were significantly higher under no grazing (36.4 Mg DM ha⁻¹) than under mixed grazing with goats (10.6 Mg DM ha⁻¹; $P < 0.05$; Table 4). Gorse percentage was also greater in the ungrazed enclosures

**Figure 5.** Phytomass amount and composition in mechanically cleared heathlands grazed during four grazing seasons by cattle or sheep at single or mixed grazing with goats. Vertical bars show standard deviations of total phytomass.

(91.9%) compared to mixed grazing treatments (65.3%; $P < 0.05$). Conversely, herbaceous percentage was lower in the ungrazed treatment (7.1%) than in the mixed grazing treatments (29.9%; $P < 0.05$). CA and SA treatments were not significantly different from the other treatments for any phytomass component.

Gorse sprouting in the improved areas

Gorse sprouts in the improved pasture areas were more efficiently controlled under sheep grazing (0% presence) than under cattle grazing (3.8% presence, 1.0 g DM m⁻²; $P < 0.05$). The management, single or mixed grazing, did not significantly affect the gorse sprouting, although in the case of cattle treatments, both the presence percentage and plant weight were lower in C+G (0.5%, 0.01 g DM m⁻²) than in CA (7.0%, 1.9 g DM m⁻²; $P = 0.121$).

Discussion

Nutritive quality of vegetation

In general, the chemical composition of the main components showed the low nutritive quality of the natural vegetation, particularly of heather. For the sampling date (May), gorse presented high CP concentrations, around 200 g kg⁻¹ DM, which seems reasonable for a leguminous plant. Conversely, *P. longifolium* revealed a low nutritive quality, as it is a tough grass, with lower CP concentrations than gorse, and remarkably high NDF concentrations. Similar values were observed in other studies conducted in the same site (Celaya *et al.*, 2007b; Osoro *et al.*, 2007), even though higher lignin concentrations were found in gorse (200-300 g kg⁻¹ DM) in the aforementioned works than in the present one (120-150 g kg⁻¹ DM). The reason may be related to climatological conditions occurred throughout each trial and to the sampling dates, because in this study the samples were only taken in May (spring) when the ADL content is usually lower, while in the previous studies samples were taken during the whole grazing season (from May-June to November-December).

As expected the improved pasture (ryegrass and clover) showed a higher nutritive quality compared to the natural vegetation, as described previously in other works (Hodgson and Eadie, 1986; Celaya *et al.*, 2007b), pointing out the convenience of establishing improved

pasture areas adjacent to this heathland vegetation, in order to meet the livestock's requirements throughout the grazing season (Maxwell *et al.*, 1986; Osoro *et al.*, 1999).

Pasture availability and grazing pressure

The results showed a general trend for lower sward height in the improved pasture under sheep (SA and S+G) than under cattle grazing (CA and C+G). This is in accordance with other studies where it was observed a higher ability of sheep to graze shorter swards due to their lower intake limitation than cattle (Forbes and Beattie, 1987; Hodgson *et al.*, 1991). In contrast, the effect of grazing management (single or mixed) on sward height was non-significant, indicating that differences in vegetation dynamics in the cleared heathland areas were a consequence of the presence or absence of goats in the flock, and not due to a different grazing pressure exerted by single or mixed flocks.

Foraging behaviour

The results showed a rather distinct foraging behaviour among the different ruminant species. Cattle are widely considered as grazers, as they normally select herbaceous species and reject the woody ones (Aldeza-bal, 2001; Celaya *et al.*, 2007b). This seems to be related to their muzzle anatomy that gives them a lesser ability to feed selectively on the green shoots, despite their higher capacity to digest fibrous components efficiently, *i.e.* maintaining them for longer time in the digestive tract (Illius and Gordon, 1993). Conversely, small ruminants are able to use woody species when the availability of the improved pasture decreases. However, a distinct foraging behaviour of sheep and goats is acknowledged (Lu, 1988; Narjisse, 1991; Allan and Holst, 1996). Sheep are able to maintain their live weight at a lower sward height (Osoro *et al.*, 2000a) and graze more intensively on improved ryegrass-clover pastures than goats (Grant *et al.*, 1984). It has been observed that goats select gorse species more intensively than sheep, both *Ulex europaeus* (Clark *et al.*, 1982; Radcliffe, 1986) and *U. gallii* (Celaya *et al.*, 2007b). Differences in heather selection between both animal species are not so obvious, as it partly depends on the species (Bartolomé *et al.*, 1998) and season (Celaya *et al.*, 2007b) considered. In addition, in the current study

there was a low proportion of heather available in all plots.

Some differences in the grazing behaviour were noticed in cattle and sheep, and more clearly in goats, according to the type of flock (single or mixed). Another trial conducted in the same farm showed also behavioural differences in goats when they were managed together with sheep, grazing more time on shrubland than on improved pasture relative to single flocks of goats (Osoro *et al.*, 2000a). In the same work, sheep behaviour hardly changed when they were stocked alone or with goats. The higher gorse proportions found in the diets of animals under single than under mixed grazing (mainly in the case of sheep, especially in May 2003) may reflect the differences in gorse availability between both managements. Likewise, the increase in dietary gorse from 2003 to 2004 would reflect a parallel increase in gorse cover percentage in shrublands.

Vegetation dynamics

Gorse (*U. gallii*) was the dominant species in the shrubland since the experiment started (one year after the mechanical clearing). It might be due to its ability to sprouting from basal buds, in addition to the seed bank in the soil (Stokes *et al.*, 2003) and its competitive and stress-tolerant strategy (Clément and Touffet, 1990). Likewise to mechanical clearing, a high re-growth ability of gorse has been observed after superficial fire (Jáuregui *et al.*, 2007). Consequently, after disturbances like clearing or burning, gorse can compete more efficiently than heather species, at least during the early successional stages, though in the longer term heather species usually reach dominance in the absence of disturbances (Celaya *et al.*, 2007a).

Generally, no great differences were noticed in the re-growth of the shrubland after clearing between cattle or sheep grazing. Although the shrub encroachment was higher in CA than in SA, limiting the presence of herbaceous plants, the differences found in most of the studied variables were non-significant. A higher increase in the mean height of gorse was found throughout the cattle treatments than in sheep ones, and heather percentage (both in terms of cover and phytomass) also increased significantly more in the former ones. It has been pointed out the lower ability of cattle to consume the green shoots of shrubs, especially noticed with heather species such as *C. vulgaris* (Grant *et al.*, 1987; Oliván and Osoro, 1998). In spite of this

selective inability of cattle, previous studies found a higher reduction in heather cover and phytomass under cattle than under sheep grazing, due to the fact that cattle can pull up more shoots or even the whole plants (although they will not ingest them), in addition to a higher treading damage compared to sheep (Hodgson and Grant, 1981; Osoro *et al.*, 2000b). The higher increase of heather under cattle than under sheep grazing found in the current study could be the consequence of a limited accessibility to the shrubland by a barrier effect caused by the thorny gorse plants, as also observed in the hills of Galicia, Northwest Spain (Sineiro *et al.*, 1984), and so heather plants were able to thrive protected by gorse.

With regard to the grazing management (single vs. mixed), the effects on the temporal trends of the shrubland vegetation were more evident. Mixed grazing treatments slowed down more the shrub encroachment, particularly in the case of gorse, which in turn let a higher growth of herbaceous plants in these treatments compared to single grazing. This was due to the more browser behaviour of goats as stated above. In a previous study carried out in the same experimental farm, on partially improved plots comprising cleared heathland areas as well, it was observed that gorse cover increased greatly after three years under sheep grazing from 21% to 41%, whereas it was maintained around 16-17% under mixed grazing or even decreased from 24% to 19% under goat grazing (Celaya *et al.*, 2007a). A greater control of the re-growth of gorse in previously burnt stands was also noticed under goat grazing compared to sheep grazing (Jáuregui *et al.*, 2007).

In the absence of grazing, the accumulation of phytomass, mostly accounted for gorse, was remarkable, almost reaching 40 Mg DM ha⁻¹ after five years since clearing, with 92% gorse. In the study of Celaya *et al.* (2007a), amounts of 18.5 Mg DM ha⁻¹ with 46% gorse were obtained after five years with no grazing since a mechanical clearing. These differences could be due to different levels of soil fertility between both trials as a consequence of the accumulative nutrient recycling.

A greater control of gorse sprouting in the improved areas was achieved under sheep grazing than under cattle grazing. No gorse was found in the samplings on sheep-grazed plots (neither SA nor S+G), and thus the effect of goats' presence was only noted in the case of cattle grazing, even though previous works had reported a better control of gorse with goats than with sheep (Sineiro, 1982; Celaya *et al.*, 2007a).

Implications

Goats have shown a high level of complementarity with both sheep and cattle when they graze in heath-gorse communities, reducing the accumulation of woody plants such as gorse which is normally rejected by cattle, and in turn contributing to a higher presence of herbaceous plants, more appetizing and nutritive for cattle and sheep. Gorse encroachment in cleared areas becomes a common situation in the absence of goats, whereas its higher control by goats would reduce the risk of fires and their intensity. The fact that height of pasture was higher in plots grazed by cattle would lead to a higher intake and favour goats' performance. On the other hand, it should be borne in mind the higher ability of sheep to utilize the components of these heath-gorse communities, reducing the periods of food shortage, compared to cattle. Goats usually spend more time grazing than sheep and cattle, and they also spend much more time grazing in shrubland areas than the latter. Nevertheless, the presence of goats in mixed herds makes cattle and sheep spend more grazing time in shrublands as well.

In summary, as a result of that complementarity in their foraging behaviour, mixed flocks with goats utilize more efficiently the grazing resources than single flocks of sheep or cattle. Thus, the presence of goats leads to a higher control of woody—highly combustible—phytomass accumulation, and to a higher presence of herbaceous plants.

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References

- ALDEZABAL A., 2001. El sistema de pastoreo del Parque Nacional de Ordesa y Monte Perdido (Pirineo central, Aragón). Interacción entre la vegetación supraforestal y los grandes herbívoros. Consejo de Protección de la Naturaleza de Aragón, Zaragoza, Spain. 317 pp. [In Spanish].
- ALLAN C.J., HOLST P.J., 1996. The ecological role of the goat in maintaining pasture and range. Proc. VI Intl. Conference on Goats. International Academic Publishers, Beijing, China, May 5-11. pp. 427-435.
- ÁLVAREZ M.A., GARCÍA P, VALDERRÁBANO J., 2004. Tipificación, cartografía y evaluación de los pastos españoles: Cartografía de los pastos de Asturias. SEEP-INIA-SERIDA-INDUROT, Oviedo, Spain. [In Spanish].
- AOAC, 2006. Official methods of analysis, 18th edition (1st revision). Association of Official Analytical Chemists, Gaithersburg, MD, USA.
- BARTHURAM G.T., 1986. Experimental techniques: the HFRO swardstick. The Hill Farming Research Organisation Biennial Report, 1984-85. HFRO, Bush Estate, Penicuik, Midlothian, UK. pp. 29-30.
- BARTOLOME J., FRANCH J., PLAIXATS J., SELIGMAN N.G., 1998. Diet selection by sheep and goats on Mediterranean heath-woodland range. *J Range Manage* 51, 383-391. doi: 10.2307/4003322.
- CELAYA R., MARTINEZ A., OSORO K., 2007a. Vegetation dynamics in Cantabrian heathlands associated with improved pasture areas under single or mixed grazing by sheep and goats. *Small Rumin Res* 72, 165-177. doi: 10.1016/j.smallrumres.2006.10.005.
- CELAYA R., OLIVÁN M., FERREIRA L.M.M., MARTÍNEZ A., GARCÍA U., OSORO K., 2007b. Comparison of grazing behaviour, dietary overlap and performance in non-lactating domestic ruminants grazing on marginal heathlands areas. *Livest Sci* 106, 271-281. doi: 10.1016/j.livsci.2006.08.013.
- CLARK D.A., LAMBERT M.G., ROLSTON M.P., DYMOCK N., 1982. Diet selection by goats and sheep on hill country. *Proc N Z Soc Anim Prod* 42, 155-157.
- CLÉMENT B., TOUFFET J., 1990. Plant strategies and secondary succession on Brittany heathlands after severe fire. *J Veg Sci* 1, 195-202. doi: 10.2307/3235658.
- DÍAZ GONZÁLEZ T.E., FERNÁNDEZ PRIETO, J.A., 1994. La vegetación de Asturias. *Itinera Geobotanica* 8, 243-528. [In Spanish].
- DIEMONT W.H., WEBB N., DEGN H.J., 1996. Pan European view on heathland conservation. Proc. National Heathland Conference. English Nature, Peterborough, UK. pp. 21-32.
- DOVE H., MAYES R.W., 1991. The use of plant wax alkanes as markers substances in studies of the nutrition of herbivores: a review. *Aust J Agric Res* 42, 913-957. doi: 10.1071/AR9910913.
- DOVE H., MOORE A.D., 1995. Using a least-squares optimisation procedure to estimate diet composition based on the alkanes of plant cuticular wax. *Aust J Agric Res* 46, 1535-1544.

- FERREIRA L.M.M., OLIVÁN M., RODRIGUES M.A.M., GARCIA U., OSORO K., 2005. Validation of the alkane technique to estimate diet selection of goats grazing heather-gorse vegetation communities. *J Sci Food Agric* 85, 1636-1646. doi: 10.1002/jsfa.2162.
- FERREIRA L.M.M., GARCIA U., RODRIGUES M.A.M., CELAYA R., DIAS-DA-SILVA A., OSORO, K., 2007a. The application of the *n*-alkane technique for estimating the composition of diets consumed by equines and cattle feeding on upland vegetation communities. *Anim Feed Sci Technol* 138, 47-60. doi:10.1016/j.anifeedsci.2006.11.007.
- FERREIRA L.M.M., OLIVÁN M., CELAYA R., GARCIA U., RODRIGUES M.A.M., OSORO K., 2007b. The use of the alkane technique to estimate diet selection of sheep grazing grass-clover/heather-gorse vegetation communities. *J Sci Food Agric* 87, 274-285. doi: 10.1002/jsfa.2717.
- FORBES T.D.A., BEATTIE M.M., 1987. Comparative studies of the influence of sward conditions on the ingestive behaviour of cows and sheep. *Grass Forage Sci* 40, 69-77. doi: 10.1111/j.1365-2494.1984.tb.01721.x.
- GRANT S.A., 1981. Sward components. In: *Sward measurement handbook* (Hodgson J., Baker R.D., Davies A., Laidlaw A.S., Leaver J.D., eds). British Grassland Society, Hurlley, Maidenhead, Berkshire, UK. pp. 71-92.
- GRANT S.A., BOLTON G.R., RUSSEL A.J.F., 1984. The utilization of sown and indigenous plant species by sheep and goats grazing hill pastures. *Grass Forage Sci* 39, 361-370. doi: 10.1111/j.1365-2494.1984.tb.01708.x.
- GRANT S.A., TORVELL L., SMITH H.K., SUCKLING D.E., FORBES T.D.A., HODGSON J., 1987. Comparative studies of diet selection by sheep and cattle: blanket bog and heather moor. *J Ecol* 75, 947-960. doi: 10.2307/2260306.
- HADJIGEORGIOU I., OSORO K., FRAGOSO DE ALMEIDA J.P., MOLLE G., 2005. Southern European grazing lands: Production, environmental and landscape management aspects. *Livest Prod Sci* 96, 51-59. doi: 10.1016/j.livprodsci.2005.05.016.
- HODGSON J., GRANT S.A., 1981. Grazing animals and forage resources in the hills and uplands. In: *The effective use of forage and animal resources in the hills and uplands* (Frame J., ed). British Grassland Society, Occasional Symposium No. 12. pp. 41-57.
- HODGSON J., EADIE J., 1986. Vegetation resources and animal nutrition in hill areas: agricultural and environmental implications. In: *Hill Land Symposium* (O'Toole M.A., ed). Galway 1984. An Foras Talúntais, Dublin, Ireland. pp. 118-133.
- HODGSON J., FORBES T.D.A., ARMSTRONG R.M., BEATTIE M.M., HUNTER E.A., 1991. Comparative studies of the ingestive behaviour and herbage intake of sheep and cattle grazing indigenous hill plant communities. *J Appl Ecol* 28, 205-227. doi: 10.2307/2404126.
- HOFMANN R.R., 1989. Evolutionary steps of ecophysiological adaptation and diversification of ruminants: a comparative view of their digestive systems. *Oecologia* 78, 443-457. doi: 10.1007/BF00378733.
- ILLIUS A.W., GORDON I.A., 1993. Diet selection in mammalian herbivores: constraints and tactics. In: *Diet selection. An interdisciplinary approach to foraging behaviour* (Hughes R.N., ed). Blackwell Sci. Publ., Oxford, UK. pp. 157-181.
- JÁUREGUI B.M., CELAYA R., GARCÍA U., OSORO K., 2007. Vegetation dynamics in burnt heather-gorse shrublands under different grazing management with sheep and goats. *Agroforest Syst* 70, 103-111. doi: 10.1007/s10457-007-9045-x.
- LITTELL R.C., HENRY P.R., AMMERMAN C.B., 1998. Statistical analysis of repeated measures data using SAS procedures. *J Anim Sci* 76, 1216-1231.
- LU C.D., 1988. Grazing behaviour and diet selection of goats. *Small Rumin Res* 1, 205-216. doi: 10.1016/0921-4488(88)90049-1.
- MARQUÍNEZ J., MENÉNDEZ R., LASTRA J., FERNÁNDEZ E., JIMÉNEZ-ALFARO B., WOZNIAC E., FERNÁNDEZ S., GARCÍA J., GARCÍA P., ÁLVAREZ M.A., LOBO T., ADRADOS L., 2003. Riesgos naturales en Asturias. Principado de Asturias-INDUROT-KRK ediciones, Oviedo, Spain. 118 pp. [In Spanish].
- MAXWELL T.J., GRANT S.A., MILNE J.A., SIBBALD A.R., 1986. Systems of sheep production on heather moorland. In: *Hill Land Symposium* (O'Toole M.A., ed). Galway 1984. An Foras Talúntais, Dublin, Ireland. pp. 187-211.
- MAYES R.W., LAMB C.S., COLGROVE P.M., 1986. The use of dosed and herbage *n*-alkanes as markers for the determination of herbage intake. *J Agric Sci* 107, 161-170.
- MMA, 2007. Incendios forestales en España. Ministerio de Medio Ambiente, Madrid, Spain. [In Spanish].
- NARJISSE H., 1991. Feeding behaviour of goats on rangelands. In: *Goat nutrition. European Association for Animal Production* (Morand-Fehr P., ed). Pudoc, Wageningen, The Netherlands. pp. 13-24.
- NÚÑEZ-REGUEIRA L., RODRÍGUEZ AÑÓN J.A., PROU-PÍN CASTIÑEIRAS J., 1996. Calorific values and flammability of forest species in Galicia. Coastal and hillside zones. *Bioresour Technol* 57, 283-289.
- OJ, 1992. Directive 92/43/EEC of the Council of May 21, of the conservation of natural habitats and wild fauna and flora. Official Journal of the European Union L 206 22/07/1992. pp. 7-50.

- OLIVÁN M., OSORO K., 1998. Foraging behaviour of grazing ruminants in rangelands. In: Pasture ecology and animal intake (Keane M.G., O'Riordan E.G., eds). Teagasc, Meath, Ireland. pp. 110-126.
- OLIVÁN M., OSORO K., 1999. Effect of temperature on alkane extraction from faeces and herbage. *J Agric Sci* 132, 305-312. doi: 10.1017/S0021859699006358.
- OSORO K., VASSALLO J.M., CELAYA R., MARTÍNEZ A., 1999. Livestock production systems and the vegetation dynamics of less favoured areas (LFAs): developing viable systems to manage semi-natural vegetation in temperate LFAs in Spain. In: Livestock production in the European less favoured areas (Laker J.P., Milne J.A., eds). II Conference of LSIRD. Macaulay Land Use Res. Inst., Aberdeen, UK. pp. 133-143.
- OSORO K., CELAYA R., MARTÍNEZ A., 2000a. The effect of grazing management of sheep and goats on animal performance and vegetation dynamics in partially improved heath-gorse vegetation. In: Grazing management (Rook A.J., Penning P.D., eds). British Grassland Society, Occasional Symposium No. 34, Devon, UK. pp. 135-140.
- OSORO K., CELAYA R., MARTÍNEZ A., ZORITA E., 2000b. Pastoreo de las comunidades vegetales de montaña por rumiantes domésticos: producción animal y dinámica vegetal. *Pastos* 30, 3-50. [In Spanish].
- OSORO K., GARCÍA U., JÁUREGUI B.M., FERREIRA L.M.M., ROOK A.J., CELAYA R., 2007. Diet selection and live-weight changes of two breeds of goats grazing on heathlands. *Animal* 1, 449-467. doi: 10.1017/S1751731107683797.
- RADCLIFFE J.E., 1985. Grazing management of goats and sheep for gorse control. *N Z J Exp Agric* 13, 181-190.
- RADCLIFFE J.E., 1986. Gorse - a resource for goats? *N Z J Exp Agric* 14, 399-410.
- SAS, 2001. SAS/STAT user's guide, Release 8.02. SAS Institute Inc., Cary, NC, USA.
- SINEIRO F., 1982. Aspectos del uso ganadero del monte en Galicia para la producción de carne. *Pastos* 12, 1-39. [In Spanish].
- SINEIRO F., OSORO K., DÍAZ N., 1984. Bases para la producción e intensificación ganadera en el monte gallego: la utilización de la vegetación espontánea y la siembra y mejora del pasto. Proc. XXII Meeting of the Iberian Society of Animal Nutrition. SINA, Santiago de Compostela, Spain. pp. 195-219. [In Spanish].
- STOKES K.E., BULLOCK J.M., WATKINSON A.R., 2003. Biological Flora of the British Isles: *Ulex gallii* Planch. and *Ulex minor* Roth. *J Ecol* 91, 1106-1124.
- VAN SOEST P.J., ROBERTSON J.B., LEWIS B.A., 1991. Methods for dietary fiber, neutral detergent fiber, and non-starch polysaccharides in relation to animal nutrition. *J Dairy Sci* 74, 3583-3597.
- WEBB N.R., 1998. The traditional management of European heathlands. *J Appl Ecol* 35, 987-990.