C. R. Biologies 333 (2010) 226–234

Contents lists available at ScienceDirect

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Ecology / Écologie

Arthropod fauna on grassland–heathland associations under different grazing managements with domestic ruminants

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ARTICLE INFO

Article history:
Received 17 July 2009
Accepted after revision 6 December 2009
Available online 27 January 2010

Keywords:
Arthropods
Cattle
Flock
Goat
Grassland
Heathland
Sheep

ABSTRACT

The effects of two grazer species (cattle or sheep) and two flock types (single or mixed with goats) on vegetation and arthropod fauna were studied in a factorial design on eight plots which comprised two thirds of mechanically cleared heathland and one third of improved ryegrass-clover grassland. After six grazing seasons, the shrubland areas were dominated by gorse (*Ulex gallii*) in all treatments. Herbaceous cover was higher under mixed than under single grazing, and under sheep than under cattle grazing. Higher captures of Opiliones, Julida, Lithobiomorpha, Microcoryphia and Carabidae were recorded in shrublands than in grasslands, while the reverse was observed for Linyphiidae, Lycosidae and Hemiptera. Within shrublands, fauna responded to the flock type but not to the grazer species. More arthropod groups favoured the patchier areas with higher herbaceous biomass generated by mixed herds with goats. Within grasslands, species-specific responses to the grazer species were observed. Mixed grazing schemes which include goats within partially improved heathlands could contribute to maintain higher biodiversity levels in these marginal areas.

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1. Introduction

Heathlands are shrubby vegetation communities typical from the Atlantic regions of Western Europe with acidic and poor soils [1]. In the humid regions of the northern Iberian Peninsula, heathlands are widespread as consequence of the abandonment of agricultural and livestock managements, particularly in the poorest land where the succession to forests is restricted by soil depth and fertility and frequent fires. In fact, the increasing frequency of wildfires associated to these shrublands [2] causes great environmental and economical losses, endangering the conservation of natural resources and hindering the rural development on these marginal areas. Extensive grazing by livestock is regarded as the most efficient use of heathlands to achieve both agricultural and biodiversity conservation goals [3], although their productivity is quite low because of the low nutritive value of the dominant woody plants [4,5].

Currently, partial transformation of these heathlands is carried out, establishing adjacent areas of improved grassland to meet the nutritional requirements of livestock [6]. Also, some heathland areas are mechanically cleared to reduce shrub encroachment and prevent fires. As different grazer species have distinct foraging behaviour, mixed grazing may increase the effective utilization of heterogeneous resources [6,7]. Although the partial transformation of heathlands to grasslands may promote sustainable livestock production systems, its effects on local biodiversity should not be ignored as heathlands are communities whose conservation is required at European level (Habitats Directive 92/43/EEC 1992).

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doi:10.1016/j.crvi.2009.12.008

As arthropods account for the greatest part of the global biodiversity [8], the interest on the consequences of different management practices on this highly diverse group seems reasonable. In addition, the availability of arthropods is also a key factor for other groups which rely on them as a food resource [9]. Grazing management (e.g. animal species, flock type, stocking rate, etc.) is known to affect sward structure and composition in both grasslands and heathlands [10,11], and consequently might have knock-on effects on the associated arthropod fauna [12–15]. Spiders and ground beetles are known to react strongly to changes in microhabitat conditions and are subsequently often used as indicators of the effects of management practices [16,17]. Harvestmen, a common group in humid and shady places [18], are rarely used as bioindicators, although they have also proved their suitability [19].

The research described here was carried out in previously mechanically cleared heathland areas with one third converted to perennial ryegrass-white clover grasslands. Although the primary objective was to study livestock grazing behaviour in relation to flock type and subsequent changes on vegetation components and biomass [11], it offered the opportunity to test the effects of (a) vegetation type (shrubland or improved grassland), (b) grazer species (cattle or sheep) and (c) type of flock (monospecific or mixed with goats) on the abundance and diversity of ground-dwelling arthropod fauna.

2. Material and methods

2.1. Study site and experimental design

The experiment was conducted at the Carbayal Research Station, Sierra de San Isidro, Illano, western Asturias, NW Spain (43° 21' N, 6° 53' W). It is located at an altitude of 950–1000 m a.s.l. and the climate is oceanic. Annual rainfalls average 1536 mm and mean temperature is 10.0 °C. Soils are acid and nutrient poor. Natural dominant vegetation in the area is composed of heather species such as *Erica umbellata*, *Erica cinerea* and *Calluna vulgaris*, gorse (*Ulex gallii*), and grasses such as *Pseudarrhenatherum longifolium* and *Agrostis curtisii*.

A factorial design of two grazer species (Asturiana de los Valles beef cattle or Gallega sheep) and two flock types (monospecific or mixed with Cashmere goats) with two replicates was established on eight plots (0.9–2.7 ha). Before the experiment started, in 2001, a surface of heather–gorse shrublands was mechanically cleared and partially improved by ploughing, dressing and sowing perennial ryegrass (*Lolium perenne*) and white clover (*Trifolium repens*). Each plot comprised one third of the area converted to grassland, while the remaining area was a cleared shrubland, where the dominance of gorse increased across the experimental years [11]. After fencing the plots, grazing treatments began in 2002 and lasted until 2008. Grazing season extended from April–May to October–November each year.

Cattle were represented by cows with their winter-born calves or yearly bulls, and were stocked approximately at 1.1 cows/ha or 1.5–1.7 bulls/ha. Mixed flocks of cattle and goats were stocked at a ratio of one cow to seven goats. Sheep and goats grazed with their lambs and kids; monospecific flocks contained 10 adult ewes per hectare and mixed flocks of sheep and goats were stocked at a ratio of 1:1. Every year animals were balanced for body weight and randomly allocated in each plot attending to the treatment.

2.2. Vegetation sampling

At the beginning of the grazing season in 2008, sward height was assessed in each plot at 100 randomly selected points in both grassland and shrubland areas. Plant cover in the cleared heathland areas was assessed with the point-quadrat technique [20] along five transects in each plot and recording 100 vertical hits per transect.

The amount of phytomass in the shrubland areas was estimated by harvesting the vegetation contained in 0.2×1 m quadrats at ten random sites on each plot at the beginning of the grazing season. The samples were fresh weighed, and four of those with middle weights were subsequently sorted 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 then weighed for dry matter (DM) determination. The composition from the sorted samples was converted to the total phytomass from each plot.

2.3. Arthropod sampling

For assessment of arthropod activity densities, twelve pitfall traps were arranged linearly with a specific distance (4 m) to the neighbouring trap in each plot, six within the grassland and six within the shrubland. The pitfall traps consisted of plastic cups of 660 cc with an upper diameter of 10 cm which were 1/3 filled with water and 50% ethylene glycol solution as a preservative. The cups were buried in the ground, made flush with the soil surface, and covered with a tile to protect them against flooding and treading. Arthropod population levels were monitored throughout mid-July until mid-September in 2008, i.e. six years after the establishment of grazing treatments. Traps operated continuously and were emptied every second week. This method samples mostly surface-active arthropods and is a measure of their activity-density (referred as abundance in this study), rather than of the total density [21,22].

Fauna identification was performed using standard keys. The catches of the main orders and relevant families as well as species richness and abundance of wolf spiders (Araneae, Lycosidae), harvestmen (Opiliones) and ground beetles (Coleoptera, Carabidae) were recorded and pooled for each vegetation type within each plot.

2.4. Statistical analysis

All univariate analyses were performed using SAS System software [23]. A factorial analysis of variance (ANOVA) was used to test the effects of the grazing treatments (grazer species and flock type) on vegetation (cover and phytomass recorded within the shrubland areas and sward height in both grasslands and shrublands). Grazer species (Sp: cattle or sheep) and flock type (F: single or mixed with goats) were considered fixed effects and the eight plots corresponded to the experimental units. Percentage data (cover and phytomass) were previously angular transformed (arc sin $\sqrt{[x/100]}$).

ANOVA analyses were conducted for testing the effects of grazer species, flock type and vegetation type on arthropod fauna in a split-plot randomized design. Fauna catches were pooled for each vegetation type within each plot and over the whole sampling period. A mixed model procedure was used on log-transformed (Log_{10} $[x+1]$) fauna data. Grazer species and flock type, considered as whole plot factors, and vegetation type (grassland or shrubland) as the split-plot factor, were treated as fixed effects. The plot was included as a random variable. Treatment means were compared using Bonferroni multiple-comparison test.

For those taxa whose presence was linked to one vegetation type so ANOVA requirements for homogeneity of variance were not fulfilled, non-parametric Wilcoxon rank sum test was applied to search for differences between vegetation types. Two-way ANOVA was subsequently used within each vegetation type to study the effects of grazer species and management type once the ANOVA requirements were fulfilled.

Multivariate redundancy analysis (RDA) was used to analyse the relationship between arthropod species composition and the vegetation variables (considered as explanatory variables) recorded within shrublands, using Canoco 4.0 software [24]. The decision about which type of ordination to run was based on the results of a detrended correspondence analysis (DCA) that showed a small length of the main gradient (1.497), indicating that the linear method was the appropriate one. A forward stepwise procedure was carried out to select only significant explanatory variables and the improvement of the reduced model with each new selected variable was determined by a Monte Carlo permutation test with 4999 randomizations. The statistical significance of the model was evaluated building the F-ratio [25] based on the trace and 4999 unrestricted permutations.

3. Results

On the cleared heathland areas, the mean percentage of shrub cover was higher under single than under mixed grazing (ANOVA, $F_{1,4} = 10.50$, $P = 0.032$), while the reverse was true for herbaceous cover ($F_{1,4} = 18.75$, $P = 0.012$), which was lower under cattle than under sheep grazing ($F_{1,4} = 13.69$, $P = 0.021$). The total amount of aerial phytomass was not significantly different between the treatments (Table 1), although the percentages of herbaceous biomass tended to be higher under mixed than under single grazing ($F_{1,4} = 6.52$, $P = 0.063$). Mean sward height was higher under single than under mixed grazing with goats ($F_{1,4} = 11.21$, $P = 0.029$), whereas no differences between grazer species were observed.

Sward height within grasslands was broadly similar across plots and no effects of either grazer species or flock type were observed (Table 1).

Among the total of 10,377 arthropods recorded, the most abundant ones were ants (Hymenoptera, Formicidae), beetles (Coleoptera), spiders (Araneae) and harvestmen (Opiliones), as they accounted for 35.0%, 30.9%, 19.6% and 6.8% of the total catch, respectively. A total of 375 wolf spiders (Araneae, Lycosidae) from 6 species, 702 opilionids (Opiliones) from 10 species and 459 carabids (Coleoptera, Carabidae) from 22 species were captured (for more details see the Appendix).

ANOVA showed that total arthropod abundance was not significantly affected by the grazer species, type of flock or vegetation type (Table 2).

The total abundance of spiders (Araneae), and particularly of Linyphiidae, were higher in grasslands than in shrublands as indicated by the Wilcoxon test ($Z = -2.521$, $P = 0.012$), although they did not differ according to grazer species or flock type. Higher catches of Lycosidae were also recorded in grasslands than in shrublands ($F_{1,8} = 13.70$, $P = 0.006$) and in sheep than in cattle grazed sites ($F_{1,8} = 6.93$, $P = 0.030$). A nearly significant interaction between grazer species and vegetation type ($F_{1,8} = 3.74$, $P = 0.089$) also occurred and revealed that those differences between vegetation types occurred under sheep grazing ($P = 0.024$, Bonferroni test), but not under cattle grazing.

Species-specific responses to the grazing treatments and vegetation type were observed within the family Lycosidae. The abundance of *Pardosa nigriceps* (Thorell, 1856) was higher in shrublands than in grasslands ($Z = -2.524$, $P = 0.012$). Within shrublands, more individuals were collected under single than under mixed grazing ($F_{1,4} = 10.16$, $P = 0.033$). By contrast, higher catches of *Pardosa pullata* (Clerck, 1757) were recorded in grasslands than in shrublands ($F_{1,8} = 50.55$, $P < 0.001$), under mixed than under single grazing schemes ($F_{1,8} = 6.54$, $P = 0.034$), and in sheep than in cattle grazed sites ($F_{1,8} = 9.45$, $P = 0.015$). A nearly significant interaction between grazer species and flock type was observed ($F_{1,8} = 4.20$, $P = 0.074$), and higher abundances of *P. pullata* were found in sheep than in cattle-grazed sites when managed monospecifically ($P = 0.040$, Bonferroni test), while no differences between grazer species were detected for mixed grazing schemes. A significant interaction between flock type and vegetation type also occurred ($F_{1,8} = 22.47$, $P = 0.001$); catches of *P. pullata* tended to be higher under mixed than under single grazing in shrublands ($P = 0.052$, Bonferroni test), while no differences were observed within grasslands.

The abundance of harvestmen (Opiliones) was higher in shrublands than in grasslands ($Z = -2.524$, $P = 0.012$), as well as its species richness ($Z = -2.536$, $P = 0.011$), but no significant differences between grazer species or flock types were observed. The most common species in the area, *Nemastoma hankiewiczii* Kulczynski 1909, was also consistently more abundant in shrublands than in grasslands ($Z = -2.521$, $P = 0.012$).

Higher abundances of Julida ($Z = -2.357$, $P = 0.018$), Lithobiomorpha ($Z = -2.316$, $P = 0.021$) and Microcoryphia ($Z = -2.524$, $P = 0.012$) were also collected in shrublands

Table 1
Vegetation cover, biomass and height in shrubland areas and sward height in grassland areas according to the grazer species (cattle or sheep) and flock type (single or mixed with goats) in partially improved heathlands (least square means of two plots per treatment).

Grazer species	Cattle		Sheep		
Flock type	Single	Mixed	Single	Mixed	SEM
Cover (%)					
Shrubs	79.6	64.3	69.1	56.4	4.20
Gorse	66.0	61.4	68.3	52.9	6.18
Heather	13.6	2.9	0.8	3.5	3.03
Herbaceous	8.7	25.3	23.4	34.0	3.40
Dead matter	11.4	10.1	7.2	8.6	2.14
Bare ground	0.3	0.3	0.3	1.0	0.38
Phytomass (kg DM/ha)	27,744	18,578	20,550	16,527	3,052
Gorse (%)	82.1	72.9	76.3	73.1	8.41
Heather (%)	13.4	1.5	1.1	3.5	5.99
Herbaceous (%)	4.5	25.6	22.7	23.4	5.19
Sward height (cm)					
Shrubland	37.5	23.0	28.2	22.9	2.95
Grassland	7.1	6.0	5.8	6.2	0.36

SEM: standard error of the mean.

Table 2
Abundance of ground-dwelling arthropods and species richness of Lycosidae, Opiliones and Carabidae in partially improved heathlands according to vegetation type (grassland or shrubland), grazer species (cattle or sheep) and flock type (single or mixed with goats). Least square means of two plots per treatment (six pitfall traps per plot within each vegetation type) are included.

Vegetation type	Grassland				Shrubland				
Grazer species	Cattle		Sheep		Cattle		Sheep		
Flock type	Single	Mixed	Single	Mixed	Single	Mixed	Single	Mixed	SEM
Abundance									
Arthropoda	529.0	512.0	610.0	656.5	831.0	466.0	918.5	665.0	157.09
O. Araneae	163.0	215.0	178.0	190.5	72.5	63.5	67.0	66.0	22.71
F. Linyphiidae	128.5	176.0	121.5	128.0	23.5	22.5	20.5	14.0	16.11
F. Lycosidae	21.5	21.0	34.5	40.0	14.5	19.0	19.5	17.5	4.17
Pardosa nigriceps	0.0	0.0	0.0	0.5	9.0	3.0	9.5	2.5	1.40
Pardosa pullata	19.0	12.5	28.5	22.5	2.0	14.0	7.0	10.5	2.96
O. Opiliones	3.0	3.0	3.0	1.5	104.5	64.0	93.0	79.0	18.14
Nemastoma hankiewiczii	1.5	0.5	0.5	1.0	32.0	28.5	47.5	40.5	8.41
O. Isopoda	0.5	0.0	1.0	0.0	28.5	18.0	1.0	22.0	13.68
O. Julida	0.5	0.0	0.5	0.0	11.5	2.0	7.5	3.5	1.70
O. Lithobiomorpha	4.0	1.5	3.5	1.5	4.5	7.0	8.0	14.0	2.15
O. Microcoryphia	0.0	0.0	1.0	1.0	18.0	26.5	33.5	33.0	9.65
O. Hemiptera	34.5	26.5	14.0	16.0	5.0	9.0	16.0	8.5	4.09
O. Coleoptera	207.0	174.0	218.0	214.5	285.5	158.5	153.5	194.5	50.76
F. Carabidae	8.0	16.5	12.5	10.0	54.5	51.5	32.5	44.0	13.17
Carabus macrocephalus	4.5	10.5	5.5	3.5	50.5	30.0	22.0	25.0	9.35
F. Formicidae	114.5	91.0	189.0	228.5	298.5	116.5	538.0	242.5	142.76
Species richness									
F. Lycosidae	2.5	4.0	3.0	3.0	2.5	3.5	4.0	4.0	0.68
O. Opiliones	2.0	2.5	1.5	1.5	6.0	5.5	6.0	7.5	0.73
F. Carabidae	4.5	6.0	3.5	5.5	4.0	7.0	6.5	5.5	1.32

SEM: standard error of the mean.

than in grasslands. On the contrary, abundances of Hemiptera tended to be higher in grasslands ($Z = -1.863$, $P = 0.063$), where their abundance was higher under cattle than under sheep grazing ($F_{1,4} = 17.84$, $P = 0.013$).

The catches of beetles (Coleoptera) and ants (Hymenoptera, Formicidae) were not significantly different between vegetation types, grazer species or flock types.

Within the order Coleoptera, there were higher catches of the family Carabidae in shrublands than in grasslands ($F_{1,8} = 30.22$, $P = 0.001$) but no differences between grazer species or flock types. The species richness of this family was unaffected by the vegetation type or the grazing treatments. The most common carabid in the study site, *Carabus macrocephalus* Dejean, 1826, was also more abundant ($F_{1,8} = 19.14$, $P = 0.002$) in shrublands than in grasslands.

The RDA analysis showed that, within shrublands, shrub height as a single explanatory variable explained 39.0% of the variance in arthropod species data ($F = 3.84$, $P = 0.001$). On the contrary, within grasslands, vegetation height did not explain a significant amount of the variance in species data. The subsequent forward stepwise procedure conducted for all the explanatory variables within shrublands, revealed that herbaceous biomass ($P < 0.05$)

Table 3
Eigenvalues, cumulative explained variance (%) of ground-dwelling arthropod species data and species correlation coefficients for the first four axes obtained by RDA analysis using a reduced set of environmental variables selected by stepwise procedure. Intra-set correlations of selected environmental variables with the axes are also included. The *F*-test and significance after 4999 Monte-Carlo permutations of the first canonical axis for the model and of the *F*-test of each environmental variable are indicated.

	Axis 1	Axis 2	Axis 3	Axis 4	*F*	*P*
Eigenvalues	0.393	0.094	0.199	0.110	3.23	0.005
Species-environment correlations	0.970	0.884	0	0		
Percentage variance						
Of species data	39.3	48.6	68.5	79.5		
Of species-environment relation	80.7	100	0	0		
Intra-set correlations						
Herbaceous biomass	−0.761	0.548			2.31	0.026
Shrub height	0.966	−0.078			2.03	0.042

and shrub height ($P < 0.05$) together explained 39.3% of the variance of species data (Table 3). The first axis was positively correlated with shrub height and negatively with herbaceous biomass, which was also positively correlated with the second axis (Table 3, Fig. 1). The first axis separated a group of species like *P. nigriceps*, *C. macrocephalus* and *Paroligolophus agrestis* (Meade, 1855), which favoured taller and shrubbier conditions, from another group of taxa like *P. pullata*, *Odiellus spinosus* (Bosc, 1792) or *Pterostichus cantaber* (Chaudoir, 1868), associated to the shrubland areas with shorter vegetation and higher amounts of herbaceous biomass.

4. Discussion

The arthropod fauna was clearly differentiated between grasslands and shrublands. The effects of the different grazer species and flock types were more subtle, species-specific within lycosids, and related to the impact that such grazing treatments had on the vegetation. Although fauna data before the establishment of experimental treatments were lacking, initial vegetation data and the subsequent development recorded in each treatment [11] indicate that the differences found in the fauna may be related to the specific grazing managements applied. Due to the sensitivity of the studied arthropod groups to their environment, the differentiation of their communities between grasslands and shrublands acted on a small spatial scale as the vegetation characteristics (floristic composition, cover, biomass, etc.) were different enough. These findings are consistent with other studies suggesting a small-scale distribution of invertebrates [26,27]. Characteristic carabid assemblages on mature heathlands which differed from other shrub communities of the same area have been

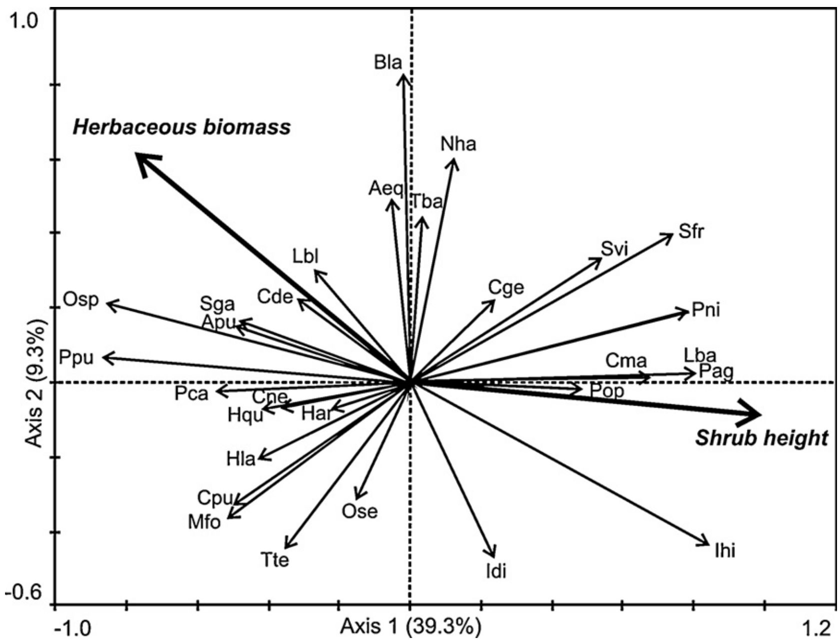

Fig. 1. Biplot of arthropod species vs. significant environmental variables (shrub vegetation height and herbaceous phytomass) chosen by forward selection in RDA as correlated with the axes at $P < 0.05$. Key to species names: Aeq- Amara equestris, Apu- Alopecosa pulverulenta, Bla- Bembidion lampros, Cde- Carabus deyrollei, Cge- Carabus getschmanni, Cma- Carabus macrocephalus, Cne- Carabus nemoralis, Cpu- Carabus purpurascens, Har- Harpalus sp., Hla- Homalenotus laranderas, Hqu- Homalenotus quadridentatus, Idi- Iberodinodes dives, Ihi- Ischyropsalis hispanica, Lba- Leistus barnevillei, Lbl- Leiobunum blackwalli, Mfo- Metabletus foveatus, Nha- Nemastoma hankiewiczii, Ose- Odiellus seoanei, Osp- Odiellus spinosus, Pag- Paroligolophus agrestis, Pca- Pterostichus cantaber, Pni- Pardosa nigriceps, Pop- Phalangium opilio, Ppu- Pardosa pullata, Sfr- Sabacon franzi, Sga- Steropus gallega, Svi- Synuchus vivalis, Tba- Trechus barnevillei, Tte- Trochosa terricola.

observed [28], as well as differences in grasshopper [29] and ground-dwelling arthropod assemblages [30] between close heathland sites which held different vegetation cover, height and biomass. Understanding the small-scale distribution of organisms reveals their suitability as bioindicators, which today becomes increasingly important in the context of nature conservation and management [31].

The structure of grasslands and heathlands varies greatly, the composition, height and structure of the vegetation being particularly important for invertebrates [32]. Shrublands hold greater habitat complexity and higher fauna diversity than grasslands [33], in agreement with the higher abundances of most of the groups found in the current study. The habitat preferences of the studied groups are likely related to the physical properties of the environment which provide specific demands (e.g. microclimate, food resources, places for hunting or protection from enemies and desiccation), that vary depending on the organisms and the region [34,35].

In the current study, several groups like lycosids and linyphids showed higher densities in grasslands than in shrublands. Both families are the most abundant spiders on the ground surface [36]. Among lycosids, *P. pullata* clearly dominated in the grasslands. This species is able to endure high temperatures and humidity [37], has a good dispersal capability [38], can sustain populations in new habitats [39] and is found in open grasslands [40] as well as in heathlands with high percentages of herbaceous cover and open ground [30]. In fact, although it is considered an indicator species for heather moorland in Northern Ireland [41], its abundance decreases as vegetation closes in Danish coastal heath habitats [42]. Linyphids might be considered small pioneer agrobiont species [43] that might find their optimal habitat on productive grasslands [44]. Several species of this family are also specialist predators of hemipterans [45], which were also more abundant within the grasslands in the current study. More species of this order have already been recorded in grass-dominated sites than in *Calluna*-dominated ones [46]. The implication of grazing as indirect driver on hemipteran community, owing to its effect on the canopy structure and the competitive balance between *Calluna* and grasses, is already known [47].

Arthropod fauna in the shrubland areas was characterized by taxa which depend on shady and moist microhabitats, like certain Lycosidae, most of Opiliones, Julida, Lithobiomorpha and Carabidae. Shrub cover and soil organic matter content are key environmental variables determining the assemblage structure of many arthropod groups such as carabids [48]. The epiphytic spider *Pardosa nigriceps* (Thorell, 1856) is a typical species of tall and dense scrub vegetation [44,49], and is benefited by lower grazing pressures in Cantabrian heathlands [30]. The harvestmen *Paroligolophus agrestis* (Meade, 1855) is another inhabitant from heather, although it also lives in other plant communities [50]. *Carabus macrocephalus* Dejean, 1826, the most abundant carabid in the area, is widely known in forest and heathland ecosystems [48,51] and it is considered a reliable indicator of the effects of nitrogen deposition in NW Spanish heathlands [52].

Among the few groups that were significantly affected by the grazer species, their responses were heterogeneous and occurred within the grasslands. While lycosids (and *P. pullata* in particular) were enhanced by sheep grazing, more hemipterans were collected in cattle grazed areas. The grazing behaviour of large herbivores might partly explain those effects. Cattle spent longer periods on the grassland [11] and might have promoted a higher trampling effect compared to sheep, and this is known to have mostly negative consequences on spider diversity [15,53,54]. Concerning the Hemiptera, this order is well known to be greatly influenced by the vegetation structure and the botanical composition [55]. Dennis et al. [12] found evidence that cattle might contribute to the maintenance of higher structural diversity and arthropod abundance (considering spiders, true bugs and beetles in their study) in grazed ecosystems due to their lack of selectivity compared to sheep. Nevertheless, caution is needed to interpret the data concerning the Hemiptera collected by pitfall traps, as this sampling method fails to detect many species living on the vegetation layer [52]. Furthermore, the subtle response of the fauna to the grazing treatments within grasslands might be related to the similar vertical complexity existing between plots, as indicated by the absence of significant effects of either grazer species or flock type on vegetation height and the inability of this vegetation variable to explain a significant amount of the variance of the fauna assemblages present on the grasslands.

Concerning the impact of the flock type on the fauna, the observed differences occurred only within shrublands. The lower shrub cover (mostly accounted for by gorse) and higher herbaceous cover under mixed than under single grazing was related to the goat grazing behaviour. Goats are known to be more willing to browse on shrublands than sheep and cattle in partially improved heathlands [6,11], thus controlling more shrub cover, height and biomass while promoting a higher regrowth of herbaceous plants [10]. Ordination analysis revealed that a relevant pull of species preferred the areas with higher herbaceous biomass. Interestingly, fewer species clearly favoured the taller shrubland areas. This was the case for *P. nigriceps*, a lycosid which prefers moister, shadier areas with taller and shrubbier vegetation [56], achieved in the absence of goats in the current study. The reason for fewer species favouring the tallest vegetation may rely on the fact that those areas had higher gorse cover and thus lower floristic diversity.

In conclusion, this study reinforces the importance of shrublands for the biodiversity in these partially improved areas and the interesting role that goats might play. The differences between vegetation types were found in terms of several exclusively collected arthropod species but also in terms of differences in vegetation structure and composition. Shrublands, presenting more different plant life forms than grasslands, held higher diversity and abundance of arthropod taxa relying on shadier environments with taller vegetation. Grasslands held their own fauna and might also fulfil the habitat requirements of certain species whose ecological demands vary during their life cycles.

The present study also showed that the abundance and diversity of most arthropod taxa were indifferent to the grazer species (cattle or sheep), and for those which responded, they were more abundant within grasslands, while no differences between cattle and sheep were observed within shrublands. By contrast, within the shrubby areas, flock type was of special relevance for both flora and fauna. Some taxa demanding taller vegetation, shadier and moister conditions, preferred monoespecific herds without goats. These ungulates enhanced the presence of herbaceous plants in the shrublands, contributing to create a patchier habitat. This may promote the coexistence of numerous arthropod species, reinforcing the interest of managing goats within mixed flocks in these partially improved areas.

Acknowledgements

We would like to thank Aida Heras, Isabel Neyra and Gregorio Pérez who helped with the field recordings. Dr. Carlos Prieto provided very valuable information concerning the Opiliones. We are also very grateful to the team dedicated to the management of the experimental station for their support and efficient work. This study was funded by the Spanish National Institute for Agricultural Research (INIA, project RTA-01-014-C2-1).

Appendix A

Abundance of arthropod species in partially improved heathlands according to vegetation type (shrubland or grassland), grazer species (cattle or sheep) and flock type (S: single; M: mixed with goats). Pooled catches of two plots per treatment (six pitfall traps per plot within each vegetation type) are indicated.

Vegetation type	Shrubland				Grassland			
Grazer species	Cattle		Sheep		Cattle		Sheep	
Flock type	S	M	S	M	S	M	S	M
O. Araneae								
Alopecosa pulverulenta (Clerck, 1758)	0	1	2	2	1	5	2	3
Pardosa monticola (Clerck, 1758)	0	0	0	0	0	1	0	0
Pardosa nigriceps (Thorell, 1856)	18	6	19	5	0	0	0	1
Pardosa proxima (C.L. Koch, 1847)	0	0	0	0	2	1	2	0
Pardosa pullata (Clerck, 1758)	4	28	14	21	38	25	57	45
Trochosa terricola (Thorell, 1856)	7	3	4	7	2	10	8	31
O. Opiliones								
Homalenotus laranderas Grasshoff, 1959	7	3	5	15	0	1	0	0
Homalenotus quadridentatus (Cuvier, 1795)	30	34	20	28	0	2	4	0
Ischyropsalis hispanica Roewer, 1953	26	0	1	3	0	1	0	1
Leiobunum blackwalli Meade, 1861	0	1	1	1	0	0	1	0
Nemastoma hankiewiczii (Kulczynski, 1909)	64	57	95	81	3	1	1	2
Odiellus seoanei (Simon, 1878)	0	0	0	1	0	0	0	0
Odiellus spinosus (Bosc, 1792)	2	28	15	16	2	1	0	0
Paroligolophus agrestis (Meade, 1855)	9	0	0	0	1	0	0	0
Phalangium opilio Linnaeus, 1761	7	2	6	2	0	0	0	0
Sabacon franzi Roewer, 1953	64	3	43	11	0	0	0	0
O. Coleoptera								
Amara equestris (Duftschmid, 1812)	0	2	5	0	0	1	0	1
Amara aenea (De Geer 1774)	0	0	0	0	0	1	0	2
Amara sp.	0	0	0	0	1	0	0	0
Bembidion lampros (Herbst, 1784)	0	0	1	0	1	2	1	2
Calathus fuscipes (Goeze, 1777)	0	0	0	0	1	0	0	0
Calathus melanocephalus (Linnaeus, 1758)	0	0	0	0	1	0	0	0
Carabus deyrollei Gory, 1839	0	1	0	0	0	0	0	0
Carabus getschmanni Lapouge, 1924	1	2	1	0	0	2	0	1
Carabus macrocephalus Dejean, 1826	101	60	44	50	9	21	11	7
Carabus melancholicus Fabricius, 1798	0	0	0	0	0	1	0	0
Carabus nemoralis O.F. Müller, 1764	0	1	0	1	0	0	0	0
Carabus purpurascens Fabricius, 1787	0	3	0	2	0	2	0	0
Harpalus affinis (Schrank, 1781)	0	0	0	0	0	1	0	0
Harpalus sp.	0	1	0	0	0	0	0	0
Iberodinodes dives Dejean, 1826	1	0	0	0	0	1	0	0
Leistus barnevillei Chaudoir, 1867	1	0	0	0	0	0	0	0
Metabletus foveatus (Geoffroy, 1785)	0	1	2	6	0	1	1	1
Notiophilus biguttatus (Fabricius, 1779)	0	0	0	0	1	0	0	0
Pterostichus cantaber (Chaudoir, 1868)	0	1	0	1	0	0	0	0
Steropus gallega (Fairmaire, 1859)	1	27	5	27	0	0	1	0
Synuchus vivalis (Illiger, 1798)	4	4	2	0	0	0	1	0
Trechus barnevillei Pandellé, 1867	0	0	5	1	2	0	10	5

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