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THE USE OF GOATS GRAZING TO RESTORE PASTURES INVADED BY SHRUBS AND AVOID DESERTIFICATION: A PRELIMINARY CASE STUDY IN THE SPANISH CANTABRIAN MOUNTAINS

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ABSTRACT

Spanish mountains have been affected by the expansion of shrubs and forests since the mid-20th century. This secondary succession in vegetation has some positive effects, but also drawbacks, such as an increase in fire risk, loss of diversity in land use, a reduction in landscape and cultural value, less water available in river channels and reservoirs, constraints on livestock farming, a reduced number of local species and loss of biodiversity. This paper analyses the potential for grazing domestic goats to help control the spread of several species of shrubs such as the common broom (*Cytisus scoparius*), red raspberry (*Rubus idaeus*) and roses (*Rosa* sp.) that are commonly found in degraded pastures in the Cantabrian Mountains of northern Spain. Using experimental plots, the effects of two levels of stocking density (4·5 and 9 goats ha^{-1} y^{-1}) are compared with other land management systems used in the region: burning, mechanical clearing and trimming. The combined use of goats with support from burning, clearing and trimming controls the spread of shrubs. The most efficient treatment was found with nine goats ha^{-1} y^{-1}. Goat grazing also changes the distribution of shrubs, transforming a dense and continuous coverage into separate clumps and thereby enabling livestock to graze more easily. Maintaining a mixed structure of shrubs and pastures is the best treatment due to the low population density of the Cantabrian Mountains, as this enhances the biodiversity, controls fire risk and enriches the landscape; it also allows extensive livestock grazing as a main economic resource. Copyright © 2013 John Wiley & Sons, Ltd.

KEYWORDS: livestock farming; goats; shrubland recovery; common broom; *Cytisus scoparius*; Cantabrian Mountains (Spain)

INTRODUCTION

Encroachment of shrubs is an environmental change found worldwide, due to climate change (Kawataba *et al*., 2001; Lucht *et al*., 2002; Turnbull *et al*., 2010), land abandonment (Lasanta *et al*., 2005; Vicente-Serrano *et al*., 2005; Arnáez *et al*., 2011; Cocca *et al*., 2012) and interactions between fire and grazing (Bachelet *et al*., 2000). Since the mid-20th century, the mountainous areas of Spain have undergone a process of production marginalisation (Lasanta, 1990a, 1990b), following a trend that began decades earlier in other mountainous regions throughout Europe (MacDonald *et al*., 2000; Gellrich *et al*., 2007; Tasser *et al*., 2007). The immediate consequences of this process include abandonment of the land, a decline in livestock farming and an intensive process of vegetation recovery with expanding areas of shrubland and forests (García-Ruiz *et al*., 1996; Poyatos *et al*., 2003; Hill *et al*., 2008; Vila Subirós *et al*., 2009). In Spain, natural grassland decreased from 6·1 to 5·5 million ha between 1973 and 2008. During the same period, forestland increased from 14·6 to 17·7 million ha. Moreover, statistics show that underbrush became denser as the number and size of trees increased and the amount of open forest receded (MAAMA, 2013).

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Woody vegetation recovery has occurred mainly in mountainous areas due to the abandonment of agricultural fields and degradation of pastures due to the lack of grazing and maintenance (Aharon *et al*., 2007). In both cases, a process of secondary succession occurs, with hillsides being initially covered with shrub and later on by forests (Mottet *et al*., 2006; Lasanta & Vicente-Serrano, 2007; Pueyo & Beguería, 2007).

The recovery of vegetation cover through the expansion of shrubs and forest has some environmental and economic benefits as follows: (i) increased absorption of CO^2 (Robert & Saugier, 2003); (ii) a temporary increase in biodiversity (Laiolo *et al*., 2004); (iii) reduced soil erosion on slopes colonised by vegetation (García-Ruiz *et al*., 2010); (iv) improvement of the water quality due to the reduction of the suspended sediment; and (v) the reduction of reservoir siltation (Navas *et al*., 2009). The enlargement of land vegetated by forest and scrublands contributes to the recovery of wildlife, especially species that need large areas for survival (Turner, 1989; Honnay *et al*., 2003; Nikolakaki, 2004). Vegetation recovery can also trigger an increase in income for the population, such as the development of forestry (Ortuño & Martín-Fernández, 2006) and tourism (de Groot *et al*., 2010).

A natural and attractive countryside remains a very important resource for the development of mountainous areas in Spain (Álvarez-Farizo & Hanley, 2002; Sayadi *et al*., 2009; Morán-Ordoñez *et al*., 2011). However, a sudden process of vegetation recovery as intense as that which has taken place in Spain over recent decades also has negative effects as follows: (i) an increased risk of wildfires (Vázquez & Moreno, 2001; Santana *et al*., 2010; Ruiz-Mirazo & Robles, 2012); (ii) a reduction in the availability of surface and groundwater (Beguería *et al*., 2003; Gallart & Llorens, 2004; García-Ruiz *et al*., 2011); (iii) loss of the cultural value of the countryside with negative consequences for tourism (Vos & Meekes, 1999; Rescia *et al*., 2008); (iv) fewer grazing areas for the development of livestock herds (Molinillo *et al*., 1997); (v) a reduction in the variety of local species (Perry, 1998; Mcadam *et al*., 2007); and (vi) a loss of flora and fauna associated with more man-made landscapes (Preiss *et al*., 1997; Suárez-Seoane *et al*., 2002).

Livestock farming has always been an economic activity well suited to the management of mountainous areas. The abundance of natural pastures and the environmental constraints (steep terrain, cold climate and low accessibility) prevent or restrict other economic activities such as arable farming or industry. Moreover, the low population density, small proportion of active population and diversity of ecosystems make livestock farming recommendable. This type of farming can make use of the diversity in the region and needs very little labour (Gibon, 2005). Therefore, extensive livestock farming in mountainous regions is productive (sale of meat, milk, wool), has great social importance (maintenance of the population) and offers high-quality products. Moreover, livestock farming plays an important role in the countryside via its impact on crucial environmental concerns (pastures, fire control and biodiversity) (Laurent *et al*., 2003; Casasús *et al*., 2007; Riedel *et al*., 2007; Bernués *et al*., 2011). Therefore, European Union policies recognise the role of extensive livestock farming in the development and conservation of mountainous regions (Canals & Sebastià, 2000; Bernués *et al*., 2005; Gibon, 2005; Canali, 2006).

Each type of livestock is physiologically specialised in the consumption of one type of diet. Domestic ungulates found in Spanish mountainous regions (cows, sheep, goats and horses) consume different species or parts of plant, and graze in different areas (Montserrat, 1964; Morley, 1981). The goat is the most suitable species in areas where the dominant vegetation consists of shrubs. Goats can eat woody plants that are protected by thorns and anti-nutritional (potentially toxic) compounds, and so they are good at clearing areas covered by shrubs (Jones & Megarrity, 1986; Radcliffe, 1986; Valderrábano *et al*., 1996; Glasser *et al*., 2012).

Domestic species of goat are excellent at recovering areas invaded by shrub (Le Houerou, 1981; Delgado *et al*., 2004; Osoro *et al*., 2013). Goats left to graze freely with plenty of woody shrubs will always eat at least half of the shrubs, even if other types of plants are available (MacMahan, 1964; Wilson *et al*., 1975; Bourbouze & Guessous, 1977). The ability of goats to eat low-quality forages (shrubs and fibrous plants) is due to their large digestive capacity. Although sheep consume about 3·5% of their body weight each day (about 1·5 kg of dry matter (DM) goat^{-1} day^{-1}), a goat consumes 6% of its body weight. This reflects the fact that, although sheep have a digestive system that is equivalent to 15% of their body weight, the equivalent for goats is 33%. As a result, goats can compensate the low quality with larger volumes of the forage. Goats are also better at digesting than other ruminants. This is because they have a larger amount of cellulolytic bacteria in the rumen and more salivary secretion than sheep (Lu, 1988; Papachristou & Papanastasis, 1994; Barroso *et al*., 1995).

Another quality of goats that makes them that very suitable for marginal areas, as are most Spanish mountainous regions, is their low consumption of water. Goats can survive without drinking for up to 4 days, enabling them to take advantage of areas far from accessible water (Le Houerou, 1992). Goats, therefore, control and clean areas invaded by shrub and encourage the growth of grass and herbaceous material. They also facilitate grazing by other species that prefer areas without shrubs, such as sheep.

Shrubs removal is needed for livestock survival in mountainous areas. However, the use of only grazing goats cannot be sufficient to control the bush expansion. Therefore, there are examples of the combined use of grazing goats with controlled fires (Magadlela *et al*., 1995; Jáuregui *et al*., 2007; Travaud, 2009) and mechanical tools (Davis *et al*., 1975; Green & Newell, 1982; Pearson & Martin, 1991; Fernández-Santos *et al*., 1992; Lasanta *et al*., 2009a). The last one is the most feasible practice because it contributes to the recovery of the herbaceous coverage, it is the least aggressive and facilitates the development of an economic activity.

This paper analyses the potential of grazing domestic goats to help control common broom (*Cytisus scoparius*) and red raspberry (*Rubus idaeus*) and roses (*Rosa* sp.) in scrublands commonly found in abandoned pastures in the Cantabrian Mountains. Using experimental plots, we studied the effect of two stocking densities (4·5 and 9 goats ha^{-1} y^{-1}) under prescribed fires, mechanical clearing and trimming.

MATERIAL AND METHODS

The study area is located in the northern province of León, in the upper Torío river watershed. The experimental sites were selected from the sources of the Torío river to the border with Asturias, near the town of Matallana (43°03′42″N and 5°42′28″W) (Figure 1). The altitude ranges from 900 to 2189 m.a.s.l, and Pico de Braña Caballo is the highest point in the region.

A hillside near the hamlet of Coladilla (1200 m) was chosen for the experimental area. In this sector, the climate is ‘cool temperate Mediterranean’, sub-region VI temperate-wet (Papadakis, 1966). The main rock types are dolomite, limestone and marly limestone. The soil has a high pH and little organic matter or nitrogen. The phosphorus content is very variable, and the levels of potassium, calcium and magnesium are medium to high (Álvarez-Martínez, 1995).

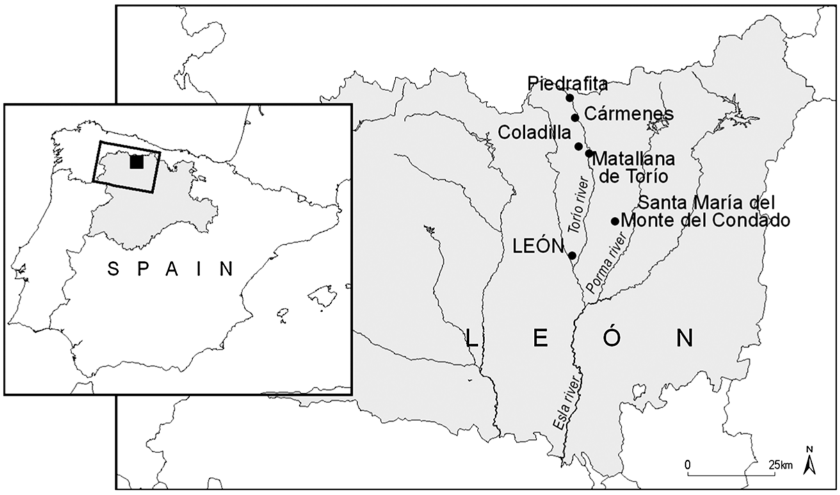

Figure 1. The study area.

The potential vegetation is pyrenean oak, *Quercus pyrenaica* (Rivas-Martínez *et al*., 1987).

The population of the area fell sharply throughout the 20th century, mostly after the 1960s. The village of Vegacervera, which includes the hamlet of Coladilla, had 940 inhabitants in 1900, but only 169 inhabitants remained in 2010, of which 68 live in the urban area of Coladilla. The loss of more than 80% of the inhabitants and an ageing population resulted in abandonment of the agricultural land, which allowed the vegetation to recover. A secondary floristic succession with a massive expansion of common broom (*C. scoparius*), accompanied by red raspberry (*R. idaeus*), rose (*Rosa* sp.), pyrenean oak (*Q. pyrenaica*), as well as the occasional presence of broom (*Genista florida*) and blackthorn (*Prunus spinosa*) is found in the study region. Note that mature formations of *C. scoparius* can cover wide areas, as clumps join together and thus completely cover the land. This provides connectivity to the vegetation and promotes the spread of forest fires. Another characteristic is that the average height of common broom is 170 cm, and so several layers of the other types of shrub can grow below (small growths of *Q. pyrenaica*, *R. idaeus* or *Rosa* sp.).

The sample plots were located on a hillside farm where crop farming was abandoned in the middle of the last century, and grazing was subsequently abandoned in the 1970s. This hillside is typical of the southern part of the Cantabrian Mountains, where abandoned fields are now mostly covered not only by *C. scoparius* but also by *Rosa* sp., *R. idaeus* and *Q. pyrenaica*. Four plots of 224 m^2 (28 × 8 m) were created for various treatments: burning, clearing, trimming and finally, a control plot. A low severity prescribed fire was conducted in mid-April (maximum temperature between 400 and 600 °C) and the remains were left in the field. Clearing was performed with a manual brush cutter disc, with the brush cut to the ground and the resulting biomass removed. Trimming consisted of cutting the vegetation higher than 70 cm with a sickle and the subsequent removal of the biomass.

The plots were arranged in parallel, with a separation of 1 m. In each plot, the effect of the two stocking densities single stocked (4·5 goats ha^{-1} y^{-1}) and double stocked (9 goats ha^{-1} y^{-1}) was analysed. These two densities represent the two extreme values used for free grazing in the study area. Each plot was subdivided into three subplots as follows: two with an area of 96 m^2 (12 × 8 m) for each stocking density and a third subplot of 32 m^2 (4 × 8 m) served as a control and was left unstocked (Figure 2). In total, we had 12 sampling subplots and 48 goats for each grazing event. Each of the 12 subplots was fenced with a two-m high mesh structure made from galvanised iron (fenced). The goats were set to graze at two different times of the year: in early June when the *C. scoparius* begins to flower and in late July when the leaves fall and the fruiting period for the shrubs begins to end. The goats were kept in each plot for two consecutive days, grazing from 9 to 19 h in spring and from 7 to 20 h in summer.

Sampling was conducted for 4 years and was aimed at exploring the composition and structure of the ground flora, shrubs and biomass eaten by the goats. To achieve this, it was necessary to take two vegetation samples from each grazing event: one before and another after grazing.

Ten square samples (50 × 50 cm) were distributed within each plot, having a separation of 3 m among them (Figure 2). These squares were identified and fixed to the ground with large nails so that samples were always taken from the same location in subsequent years. In each sampling square, a calculation was made, before and after grazing, of the absolute abundance of herbaceous species, percentage of ground covered by herbaceous vegetation, percentage of ground covered by each species of shrub and by all the shrubs, the maximum height of each shrub, percentages of bare and stony ground and percentage of fallen leaves, droppings and other organic material. The canopy coverage was estimated visually.

As the main objective was to understand the effects of grazing on the shrubs, the number of shrubs was counted

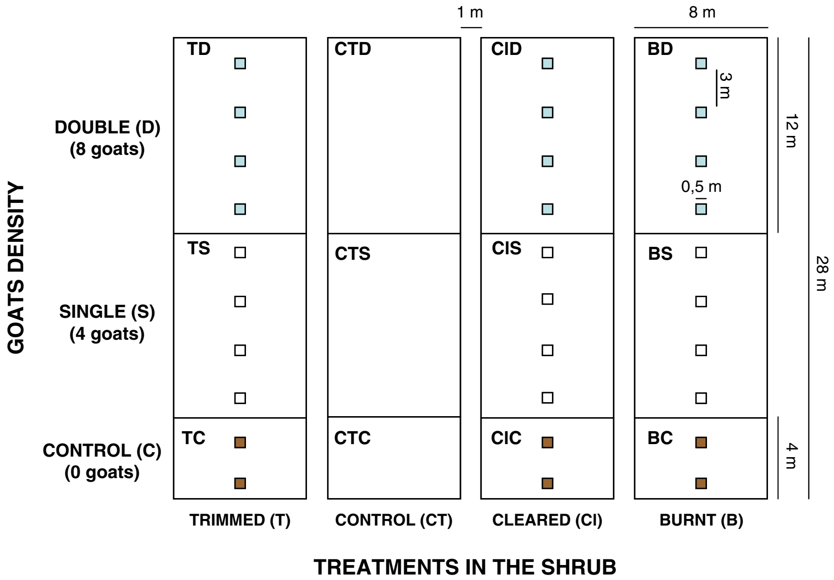

Figure 2. Experimental design of the plots to the study of the interaction between vegetation and grazing goats. Location of the sampling squares (50 × 50 cm) is indicated.

in each plot and their location was mapped before and after each grazing event. Each live and dead branch in the different plots was also counted. Moreover, we measured annually the shrub growth in five *C. scoparius* shrubs in the trimmed and control plots, and we calculated the total shrub loss by goats grazing.

To know plant biomass consumption by goats, we cut vegetation from two squares (30 × 30 cm) randomly distributed in each plot, before and after each grazing. The cut was made at ground level in order to estimate how much a goat could have eaten. The sampled plants were gathered into plastic bags and placed in a refrigerator. The cuttings were then sent to a laboratory and weighed without further treatment. The DM was subsequently determined by drying in a forced air oven at 60 °C for 48 h, which is the sufficient time for the herbaceous vegetation to dry without any change in composition. The value of biomass from each plot was calculated as the arithmetic average of the weights taken from the two squares. Data is expressed in g/m^2 of DM.

RESULTS

Evolution of C. Scoparius after 4 Years of Grazing

Grazing dramatically reduces the number of shoots of *C. scoparius*, especially after clearing and burning (Table I). This effect is particularly evident with double stocking (nine goats) and was more pronounced in the cleared plot than the burnt plot. After 4 years of sampling and eight grazing sessions, only 9% of the shrubs survived in the burnt plot and 18·4% in the cleared plot. Single stocking (four goats) grazing also reduced the number of shrubs in both treatments: 43·4% survived in the burnt plot and 79% in the cleared plot. No variation in the number of shrubs was observed for clearing and burning treatments in the control plots (without grazing). After 4 years, the number of shrubs was the same as before burning or clearing.

In the trimmed and control plots, the number of shrubs fell considerably. Trimming with double stocking eliminated 20% of the initial shrubs, whereas all shrubs survived with single grazing. In the control plot, double stocking caused a reduction of 7·7% in the number of shrubs, whereas there was no reduction in the number of shrubs with single grazing (Table I).

Figure 3 shows the evolution in the number of shrubs in the two plots showing the greatest impact after grazing: the burnt and cleared plots. Note that with double stocking, the number of shrubs fall after each grazing event, whereas with single stocking, there was slight recovery by some shrubs. It can be seen that the greatest reduction in the number of shrubs occurs during the early years.

When the goats are faced with closed formations of shrubs, such as in the control and trimmed plots, their strategy is to create divisions and fragment the coverage. This strategy increases their access to the herbaceous vegetation. Figure 4 shows the spatial evolution of *C. scoparius* in trimmed plots. It can be seen how, with single stocking in the early sessions, the goat herd breaks the shrubs cover but that it later recovers and spreads further. However, with

Table I. Percentage of shrubs (*Cytisus scoparius*) that survive after eight grazing sessions

Treatment	Stocking level: Single	Stocking level: Double	Without grazing Control plots
Cleared	79·0	18·4	100
Burnt	43·4	9·0	100
Trimmed	100	80·0	100
Control	100	92·3	100

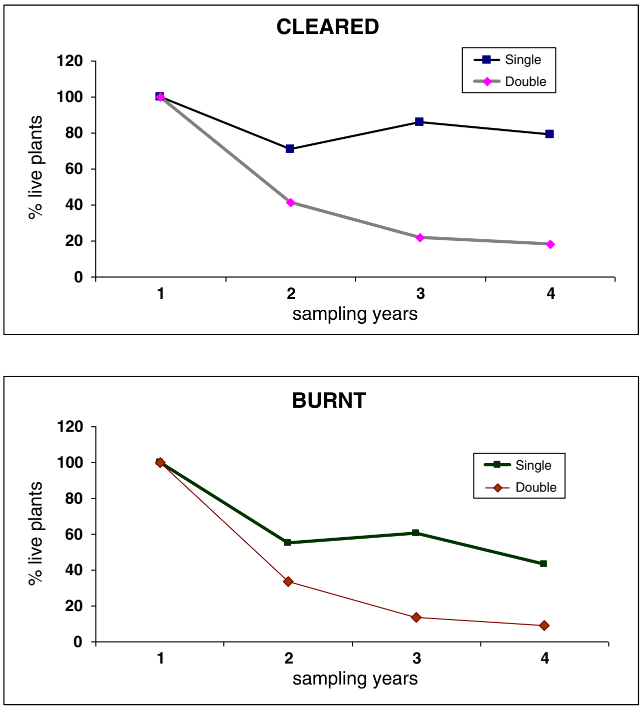

Figure 3. Evolution (%) of the number of live plants of *Cytisus scoparius*.

double stocking, the goats manage to control the expansion of *C. scoparius*. It should be highlighted that grazing also controlled the other shrubs and achieved a reduction of more than 50% in clumps of *Q. pyrenaica*, *Rosa* sp. and *R. idaeus*.

Recovery of the Shrubs in the Absence of Grazing

Table II shows the evolution of the coverage in the control plots (no grazing) during the sampling period. The effect of the treatments was to increase herbaceous coverage, especially in the cleared plot where the herbaceous coverage reached nearly 90% during the first year. Herbaceous coverage is much less pronounced in the burnt (60%) and trimmed plots (15·8%). The subsequent evolution shows slight fluctuations for the following three treatments: herbaceous coverage remaining broadly the same during the 4 years of experimentation in the cleared and burnt plots. However, in the trimmed plot, there was a substantial increase between the first and second years (from 15·8% to 56·3%) followed by a decline during the third and fourth years (41·8% and 32·8%, respectively).

The response of all the shrubs (the sum of *C. scoparius*, *R. idaeus*, *Rosa* sp and *Q. pyrenaica*) differs according to the treatment. It can be seen that clearing most effectively controls these shrubs, and coverage is reduced in the first year to 21·3%; whereas coverage is reduced to 53% in the burnt plot and 79·3% in the trimmed plot. The evolution over the next 3 years shows clear differences, with shrubs recovering very slowly in the cleared plot (coverage in the fourth year is just 27%); whereas shrubs in the trimmed plot show a total recovery in the third year (100%) and even reach 116·8% in the fourth year, thereby showing the revitalisation effect of trimming shrubs. The response in the burnt plot also shows a rapid recovery by the shrubs, with 92% coverage in the third year.

With respect to the height of the shrubs, the results show that, in the trimmed plot in the fourth year, they had regained 85% of their previous height, compared with 57% in the burnt plot and 47% in the cleared plot.

The results by species show that *C. scoparius* and *R. idaeus* had greater capacity for recovery in the trimmed and burnt plots than in the cleared plot, where even red raspberry showed a slight negative trend over the years (Table II). Bare and rocky ground showed an inverse

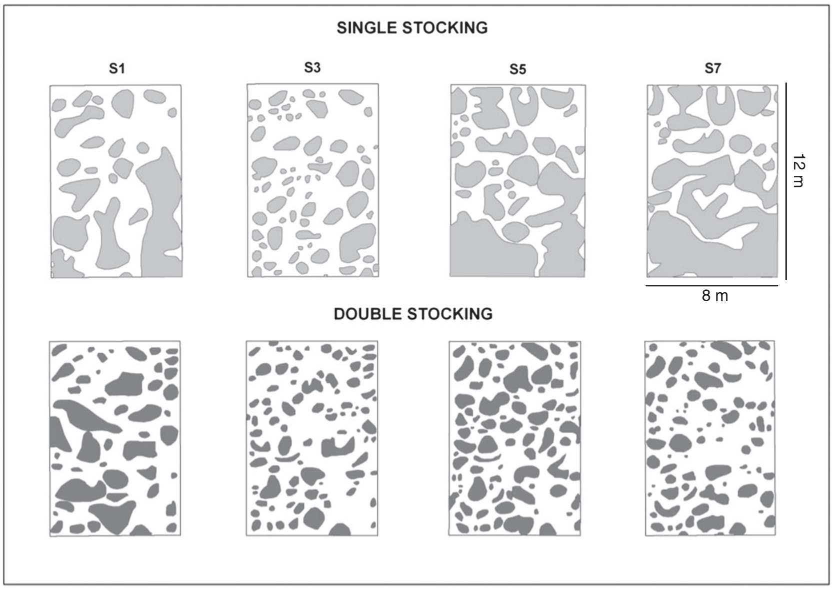

Figure 4. Spatial distribution of the *Cytisus scoparius* plants in the pruned plots, according to the stocking. Four samplings were represented (S1, S3, S5 and S7), carried out before the grazing each of the 4 years of experimentation. The map was done by dividing the plots in squares of 2 × 2 m.

Table II. Changes in absolute coverage (in %) in the control plots

Years	Herbaceous	Shrubs	*Cytisus*	*Rubus*	*Quercus*	*Rosa*	Bare soil	Rocky ground
TRIMMED								
1	15·8	79·3	56·0	19·0	4·3	0	12·5	2·5
2	56·3	79·1	51·3	27·8	0	0	18·8	1·3
3	41·8	100	62·5	37·5	0	0	15·0	0
4	32·8	116·8	77·5	39·3	0	0	20·5	0
CLEARED								
Years	Herbaceous	Shrubs	*Cytisus*	*Rubus*	*Quercus*	*Rosa*	Bare soil	Rocky ground
1	87·5	21·3	10·0	10·0	0	1·3	6·5	13·5
2	76·3	18·9	8·8	8·8	1·3	0	7·8	2·5
3	88·8	22·6	17·5	3·8	1·3	0	8·5	0·3
4	77·5	27·1	19·5	4·0	2·8	0·8	9·5	0
BURNT								
Years	Herbaceous	Shrubs	*Cytisus*	*Rubus*	*Quercus*	*Rosa*	Bare soil	Rocky ground
1	60·0	53·0	7·5	45·0	0	0·5	30·0	15·0
2	46·3	56·3	21·3	35·0	0	0	15·0	8·8
3	59·5	92·0	37·5	44·5	0	10·0	17·5	7·5
4	57·0	83·4	43·8	39·3	0	3·3	19·5	1·5

evolution to vegetation coverage, which became less common over the years.

Production and Consumption of Vegetation

Table III provides data on the production and consumption of vegetation in the various plots during spring and summer and shows that herbaceous production in the three plots is higher in spring than in summer and tends to be higher with single stocking than double stocking – although production in the trimmed plot is slightly higher with single stocking (160 g/m^2 DM) than with double stocking (132·6 g/m^2 DM). Clearing provides the greatest production values as follows: 310·2 g/m^2 DM with single stocking and 239·8 g/m^2 DM with double stocking. The burnt plot also shows high-production levels that are very similar with both stocking groups: 275·9 g/m^2 DM with single and 260·4 g/m^2 DM with double stocking. Production is lower in the trimmed plots: two to three times less than the burnt and cleared plots with single stocking. This is because the shrub coverage limits the sunlight reaching herbaceous levels. In summer, the differences are less pronounced, but production does not reach 50% of the burnt and cleared plot levels with single stocking. However, it is noteworthy that the low production of herbaceous vegetation in the trimmed plots is partly offset by the consumption by the goats of *C. scoparius*. The contribution of broom is especially important in the summer and when combined with the herbaceous production (290·7 g/m^2 DM with single stocking and 241·7 g/m^2

Table III. Production and consumption of vegetation (average values) in the various plots; standard error between parentheses

Treatment	Cleared		Trimmed		Burnt	
	Production DM (g/m^2)	Consumption DM (g/m^2)	Production DM (g/m^2)	Consumption DM (g/m^2)	Production DM (g/m^2)	Consumption DM (g/m^2)
Single stocking						
Herbaceous (Spring)	132·6 (14·4)	48·5 (25·8)	310·2 (9·2)	106·4 (26·5)	275·9 (54·3)	96·1 (35·6)
Herbaceous (Summer)	94·4 (17·9)	21·2 (7·2)	194·0 (31·6)	32·5 (25·3)	199·5 (33·4)	62·9 (24·43)
Cytisus (Spring)	86·8 (40·1)	38·0 (5·7)				
Cytisus (Summer)	196·3 (24·8)	71·1 (5·1)				
Double stocking						
Herbaceous (Spring)	160·0 (15·5)	90·3 (31·8)	239·8 (7·3)	108·3 (24·3)	260·4 (55·4)	112·3 (36·3)
Herbaceous (Summer)	88·5 (16·0)	36·5 (22·1)	125·3 (27·2)	28·6 (7·8)	139·1 (36·7)	50·3 (20·1)
Cytisus (Spring)	36·3 (17·7)	22·9 (1·5)				
Cytisus (Summer)	45·4 (1·5)	32·1 (8·3)				

DM, dry matter.

DM with double stocking) exceeds production levels achieved in the cleared (194 g/m^2 DM with single stocking and 125·3 g/m^2 DM with double stocking) and burnt plots (199·5 g/m^2 with single stocking and 139·1 g/m^2 DM with double stocking).

It can be seen in Table III that herbaceous consumption in spring is twice that of summer, with the exception of the burnt plot with single stocking. It can also be seen that there is little difference in consumption of herbaceous vegetation in spring, with values close to 100 g/m^2 DM. An exception is the trimmed plot with single stocking, where consumption was only 48·5 g/m^2 DM. There are two reasons for this low level of consumption: the lower volume of herbaceous biomass produced because of the higher coverage by shrubs; and the substantial contribution made by shrubs to the diet of the goats.

DISCUSSION

Land abandonment during the 20th century in Spain's mountainous regions has led to a decline in extensive livestock farming and fewer farms. This has, in turn, led to processes of secondary succession. In the Cantabrian Mountains, plant colonisation has led to a rapid, massive invasion of shrubs (Morán-Ordoñez *et al*., 2012), the most dominant of which is *C. scoparius*, whereas others include *R. idaeus*, *Rosa* sp. and *Q. pyrenaica*. The encroachment of shrubs has some positive effects (CO^2 sequestration, soil erosion control and improvement in water quality), but there are also negative effects, including the loss of pastures, wildfires and loss of the millennia old cultural landscape (Antrop, 1993, 2003; Lasanta *et al*., 2006; Martínez *et al*., 2009).

These results should be considered as a case study that cannot be generalised to other areas. Nevertheless, our date demonstrate that goats are necessary to keep the growth of *C. scoparius* under control, as it shows high survival rates in all three treatments. It can be concluded that prescribed fires, cleaning and trimming treatments without grazing are useless for controlling shrub growth. All of the shrubs in the study area had been recovered after 4 years. After being subjected to low-severity prescribed fires, as demonstrated in our experiments, many of the shrubs (including *C. scoparius*) regenerate after very few years (Hanes, 1971; Trabaud, 2002; Cerdà & Lasanta, 2005; Pérez-Cabello *et al*., 2012). Recovery is quicker after clearing and even more so after trimming (Lécrivain & Beylier, 2004; Heineman *et al*., 2005).

The exclusive use of grazing on the control plot also has little effect in converting areas of shrub to pasture. The analysis shows that 100% of *C. scoparius* shrubs survive with single stocking and 92·3% survive with double stocking after 4 years. In the central Spanish Pyrenees, experiments were carried out with goat grazing on slopes covered by *Genista scorpius* (a yellow flowering thorny shrub), and it was found that the survival rate of the shrubs was very high, 69%, after spring grazing, and 49% after autumn grazing (Valderrábano & Torrano, 2000). The same authors suggest that autumn is the best season for removing *G. scorpius* because of the phenological state of the shrub. Bartolomé *et al*. (2000) concluded that grazing with goats and cows is deficient in itself to support herbaceous vegetation in the shrublands of the Montseny Biosphere Reserve in Spain. The action of livestock is more effective in preventing the expansion of shrubs. Casasús *et al*. (2007) showed that, in the Garcipollera Valley, in the Spanish Pyrenees, cattle grazing prevents the expansion of shrubs. There, the ungrazed areas shown an increase in the shrub biomass of 528·3 kg of digestible matter ha^{-1} y^{-1} ($p < 0{\cdot}001$), whereas there was no increase in the grazed areas.

The combined use of grazing goats with support from other practices (burning, clearing and trimming) can contribute to the transformation of areas of shrubland into pastureland, as well as preventing the advance of shrubs. The effect achieved is highly dependent on stocking density, with double stocking being more effective than single stocking. The number of *C. scoparius* shrubs was reduced after 4 years of experimentation to just 9% of the initial number after burning and 18% after clearing. Coverage is also very much affected, because few shrubs survive. Valderrábano & Torrano (2000) reached similar conclusions after observing grazing in areas covered by *G. scorpius*.

Repeated grazing creates major changes in the distribution of shrubs and continuous coverage becomes a series of individual clumps that enable goats to gain access to more vegetation. The contribution of *C. scoparius* to the diet of goats is especially important in the trimmed plot with single stocking (4·5 goats ha^{-1}), as twice as many shoots are obtained as in the control plot. However, the number of shoots falls dramatically with double stocking (9 goats ha^{-1}). This demonstrates that combining trimming and grazing is a too aggressive strategy for the shrubs to recover. After the clearance of *G. scorpius* shrubs in the southeast of the Iberian System Mountains in Spain, it was found that fodder production increased from 19·9 kg DM ha^{-1} y^{-1} to 2488·9 kg DM ha^{-1} y^{-1} (Delgado *et al*., 2004). This leads us to suggest, first, that shrubland can be very attractive for intensive grazing; and second, to maintain the balance between shrub cover and open spaces, it is advisable to use a medium level of stocking.

Goats also play a key role in controlling other shrubs (*R. idaeus*, *Rosa* sp. and *Q. pyrenaica*). Double stocking almost completely eliminates these shrubs (average consumption over 80%) and with single stocking, they are reduced to 40%. In contrast, these shrubs quickly recovered in the control plots. Remarkably, despite the fact that the leaves and young shoots of these shrubs are almost entirely eaten, their capacity to regrow easily means that they continue to offer forage in the following years.

The three applied treatments gave the goats access to herbaceous material growing under shrubs. The average productivity of herbaceous biomass ranges from 227 g DM m^2 y^{-1} on the trimmed plot with single stocking to 504·2 g DM m^2 y^{-1} on the cleared plot with single stocking. These levels of production are similar to those obtained in other Spanish mountainous areas: Álvarez-Martínez *et al.* (1990) stated average outputs of 290 g DM m^2 y^{-1} in the Porma valley (Cantabria); Alfageme *et al.* (1994), stated 450 g DM m^2 y^{-1} in Campóo (Cantabria); Marinas & García-González (2008) stated values of between 100 and 500 g DM m^2 y^{-1} depending on the type of pasture in the Central Spanish Pyrenees. In plots that have been affected by clearing and burning, the biomass production is significantly lower for double stocking than single stocking, both in spring and summer. This may be due to the effects of the goats trampling, as well as increased consumption, thereby making the plant regrowth difficult, and triggering sheet and rill erosion due to the lack of vegetation cover and trampling by goats. For trimming, however, the effect of stocking levels is different, because production is greater with double stocking. This is because double stocking opens more clearings, and this action provides more sunlight for the herbaceous layer. It can also be seen that plant recovery after spring grazing is more pronounced in the trimmed plot than in the cleared or burnt plots. This is due to the effect of the shrub canopy, which results in reduced evapotranspiration underneath and favours the renewal of the herbaceous vegetation cover (Belsky, 1986).

The grazing preferences of goats depend on the initial relation between available herbaceous material and shrub biomass and the time of year. When the plot offers unlimited shrubs (*C. scoparius* coverage above 50%), occuring in the control and trimmed plots, the most consumed resource in the spring is the herbaceous material; whereas in summer, the goats prefer the shrubs because of the loss of quality in the herbaceous material caused by the spring graze and summer drought. Various authors have shown how goats selectively graze the most nutritious parts of shrubs or herbaceous plants (Hoffman, 1988; Kronberg & Walker, 1993; Jáuregui *et al.*, 2007). This suggests that maintaining a complex structure of shrubs and herbaceous grasses may be very beneficial for feeding goats, as well as benefiting the countryside, reducing erosion and increasing biodiversity. In the NW of the Spanish Iberian System, it has been found that the selective clearing of *G. scorpius* leads to a doubling of pastoral productivity – from 6666 MJ ha^{-1} y^{-1} to 12 983 MJ/ha^{-1} y^{-1} and a multiplication by four (2435 MJ ha^{-1} y^{-1} to 9741 MJ ha^{-1} y^{-1}) if the clearing was made in abandoned fields that are covered by rock rose (*Cistus laurifolius*) (Lasanta *et al.*, 2009a). In the same study area, it was shown that selective clearing produced a more fragmented and diverse landscape (the Shannon diversity index increased from 0·96 to 1·15 after clearing), as well as a decrease in fires and area burnt (Lasanta *et al.*, 2009b). The beneficial effect of grazing on the control of fires is a widely noted in the literature (Tsiouvaras *et al.*, 1989; Magadlela *et al.*, 1995; Kramer *et al.*, 2003; Torrano & Valderrábano, 2005; Ruiz-Mirazo *et al.*, 2011).

The loss of fertility, floristic diversity and increased erosion after repeated fires is well known (Cerdà & Doerr, 2005). Similarly, Tárrega *et al.* (2009) have shown that clearing shrubs, when not followed by livestock grazing, causes a loss of species, mainly those that produce fodder. Moreover, the rapid recovery of shrubs makes this approach ineffective for reducing the risk of fire. Livestock grazing, by itself, is unable to eliminate shrubs unless the stocking density is very high (Bartolomé *et al.*, 2000), which encourages erosion (Evans, 2005; Thornes, 2007).

CONCLUSIONS

Traditional practices such as prescribed fires, clearing and trimming are unable to control the shrub cover in abandoned mountainous terrain in north of Spain. Shrubs sprout and recover easily after treatments, which are expensive and raise environmental concerns. The results obtained in this study indicate that goat grazing, combined with other practices, can be a powerful tool for transforming areas of shrubland to grassland or for limiting the growth of shrubs. This research verifies that extensive livestock grazing can be a productive activity in mountainous areas, as well as fulfilling environmental functions, improving the structure of the countryside, and reducing the risk of fire.

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