Available online at www.sciencedirect.com
SCIENCE DIRECT®
Biological Conservation 122 (2005) 81–88
BIOLOGICAL CONSERVATION
www.elsevier.com/locate/biocon

Conservation of isolated Atlantic heathlands in the Mediterranean region: effects of land-use changes in the Montseny biosphere reserve (Spain)

Jordi Bartolomé [a,*], Josefina Plaixats [a], Rosario Fanlo [b], Martí Boada [c]

[a] *Departament de Ciència Animal i dels Aliments, Universitat Autònoma de Barcelona, Bellaterra 08193, Spain*
[b] *Departament de Producció Vegetal i Ciència Forestal, Universitat de Lleida, Lleida 25198, Spain*
[c] *Departament de Geografia, Universitat Autònoma de Barcelona, Bellaterra 08193, Spain*

Received 19 March 2004; received in revised form 5 May 2004; accepted 5 May 2004

Abstract

In the Mediterranean region, cycles of controlled burning combined with continuous grazing appear to have been an effective tool for maintaining isolated *Calluna vulgaris* heathlands in the form in which they occur in many places in the Atlantic region. Changes in land use and management of the mosaic of extensively exploited heathland and associated grassland over recent decades, such as bringing land into cultivation followed by its abandonment and the prohibition of fires has resulted in a process of transformation into new shrub communities with lower biodiversity. In the Mediterranean region, these changes are similar to those described in the Atlantic area, but encroachment occurs faster and could lead ultimately to afforestation by Mediterranean woodland.

In a study area of 300 ha of heathland in the Spanish Mediterranean basin (specifically, in the Montseny Natural Park and Biosphere Reserve), comparison of present and former vegetation showed that shrub cover increased from 15% in 1967 to 32% in 2000. Broom (*Cytisus scoparius*) was the main invasive species in abandoned crop fields, whereas Mediterranean holm oak forest (*Quercus ilex*) increased by 18%. The surface area of fernlands doubled and *C. vulgaris* heathlands decreased from 35% to just 9% during the same period. Intermixed grasslands also decreased moderately and progressively from 4% to 3%.

It seems probable that cycles of fires are more important in terms of shrub control and biodiversity conservation than continuous grazing alone, even at a high rate of stocking (four small ruminants per hectare per year). This encroachment process throws into relief the role that isolated habitats can play as a monitor of land use changes.

Keywords: Grazing; Fire; Grassland; *Calluna vulgaris*; Landscape

1. Introduction

Heathlands comprise a range of plant communities dominated by *Calluna vulgaris* L. (heather) or other ericaceous species, usually intermixed with acid grassland, bracken and scattered shrubs. They are widespread in western European zones with an Atlantic climate, being restricted to acidic and poor soils (Webb, 1986). It is assumed they developed as a result of forest clearances and have been sustained by grazing and burning since Neolithic times. Over the years, pastoral management has produced landscapes in which habitats and dependent wildlife communities are sustainable only through the continuation of agricultural use (Bignal and McCracken, 1993). Nowadays, heathlands are of considerable conservation interest within the European Union (Habitats Directive 92/43 ECC) and many protected areas attempt to stimulate certain traditional management

* Corresponding author. Tel.: +34-93-5811496; fax: +34-93-5811494.
E-mail address: jordi.bartolome@uab.es (J. Bartolomé).

0006-3207/$ - see front matter © 2004 Elsevier Ltd. All rights reserved.
doi:10.1016/j.biocon.2004.05.024

activities such as grazing or burning, because of their importance for maintaining biodiversity (Hanson and Fogelfors, 2000).

At present, heathlands are under threat because of a range of impacts, such as the abandonment of traditional grazing management practices or transformation into arable land. Both effects have given rise to extensive reductions in the area of these communities through a well-known process of succession, which leads in the first of these cases to woodlands, shrublands, or closed stands of bracken (Marrs et al., 1986; Mitchell et al., 1997; Webb et al., 2000). In the second case, when arable lands lying on former heathland are abandoned, ruderal communities invade the crop fields and regeneration requires artificial restoration (Marrs et al., 1998).

Outside their main distribution area, heathlands are present in some isolated uplands at heights greater than 1000 m above sea level in the Mediterranean region, such as some eastern mountains of the Iberian Peninsula (Fig. 1). In these areas, forest removal in ancient times combined with local climatic conditions and acidic or decarbonated soils favoured the establishment of heathlands belonging to the *Calluno-Ulicetea* phytosociological class (Folch, 1986). Owing to harsh soil and microclimatic conditions, these "habitat islands" contain biotic elements markedly different from those of surrounding habitats. An understanding of the effects of habitat isolation is crucial to the effective management of remnant populations with a view to conservation.

Despite the extensive literature concerning heathlands in their main oceanic distribution area, very little work has been done on these remnants in the Mediterranean region. Information about their sensitivity to fire regimes, grazing pressure, land-use and climate changes and, perhaps most importantly, the level of degradation, is very scarce.

The aims of this study were: (a) to investigate whether cycles of burning are more important than grazing pressure for the conservation of isolated heathlands in the Mediterranean region; (b) to determine if the encroachment process occurs faster than in Atlantic areas and if it implies losses in plant biodiversity; (c) to consider the question of whether reductions in the area of heathlands ultimately lead to afforestation by Mediterranean woodland.

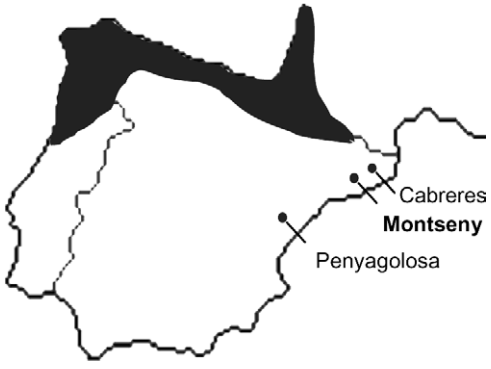

Fig. 1. Approximate distribution area of healthlands in the Iberian peninsula (shadow) and location of mountains in the Mediterranean zone wich contain isolated healthland remnants.

2. Materials and methods

2.1. Study site

The Montseny Natural Park and Biosphere Reserve contains the most extensive heathland in the eastern part of the Iberian Peninsula. During recent decades major land-use and climate changes have occurred in these mountains (Peñuelas and Boada, 2003). The total area of Mediterranean woods has increased to the detriment of temperate woodland, shrublands, arable land and pastures. Boada (2001) recorded an increase of 33% in *Quercus ilex* woodland and a decrease of 20% in land under crops from 1945 to 1995. In this Natural Park, the La Calma plateau hosts the most southerly heathland, this having been the dominant vegetation in the 1940s and 1950s (Llobet, 1947; Bolòs, 1983).

Currently, 974 ha of La Calma's surface area are covered principally by shrubs and grass, an area that represents only 56% of the pasture surface recorded in 1940s by Llobet (1947). The soil is siliceous with a pH of 4.5. The plateau has a humid Mediterranean climate, with an average annual rainfall of approximately 700 mm and a mean annual temperature of 10 °C. Fog is an additional source of moisture. The topographic emplacement and humidity circulation produces a general situation that favours the Atlantic vegetation. The value of La Calma area for biodiversity is reflected by its rich native flora, which attained a peak figure of 513 vascular plant species (Bolòs, 1986). An area of 300 ha was studied, sited in the central part of the plateau (longitude 2°18′–2°22′ east, latitude 41°44′–41°47′ north) and lying at a height of 1250–1350 m above sea level.

2.2. Land-use history

The plateau of La Calma has been used as pasture from Neolithic times (Bosch et al., 1991). In the Middle Ages, human settlement was centred on estates or *masías*, which comprised a farmhouse with paddocks, fields, woodlands and pastures (Breton, 1992). The economy was based on extensive pastoral farming (mainly involving sheep and goats) and forest products (firewood and charcoal). Some of these *masías* are still active today.

The study included two traditional *masías*, the Boscàs and Molar estates, with 61 and 175 ha of pastures,

Table 1
Livestock numbers and stocking rates for the years 1967, 1986 and 2000 in the experimental area

		1967	1986	2000
Flock B (Boscàs)	Sheep	180	190	230
	Goats	70	55	40
	Stocking rate[a]	4.1	4.0	4.4
Flock M (Molar)	Sheep	160	160	145
	Goats	100	90	95
	Stocking rate[a]	1.5	1.4	1.4

[a] Small ruminant/ha of pastureland.

respectively, in the La Calma uplands. Holm oak (*Quercus ilex* L.) forest covers the slopes and reaches 60% of the total area of both *masías*'. Field crops for winter supplies represent 14% and 2% of their surface areas, respectively. Mixed flocks of the Ripollesa breed of sheep and Murciano–Granadina breed of goats are brought back to the home paddock every evening except during summer, when they spend all their time on the plateau. The stocking rate of the two *masías* has not varied greatly during recent decades.

Taking into account stocking density recommendations for heathlands in the United Kingdom (Williams, 2003), range management on the Boscàs farm has been based on high livestock pressure on the heathland area, while this pressure was lighter on the Molar estate (Table 1). This traditional management constitutes a natural experiment which illustrates the effects of rates of stocking on the dynamics of vegetation after important land-use changes. Specific information about grazing management, the frequency of fires and field crops in the area under study was gathered from Panareda (1978), Perrinet (1988), Belillas (1989) and local shepherds.

In the mid 20th century, a considerable part of the area under study was transformed, principally into potato fields for a short period (≈1960–1967).

In 1977, Montseny was declared a Natural Park and, in 1978, a Biosphere Reserve. This protection entailed the avoidance of fires. Controlled burning by shepherds decreased until 1982, when the study area suffered a serious fire, and thereafter was banned completely.

2.3. Vegetation types

The vegetation types were determined on the basis of physiognomic attributes. The types taken into account were:

Dry grassland: Herbaceous vegetation without shrub cover, where *Agrostis capillaris* (bent grass) and *Trifolium* sp. (clovers) used to be dominant. This vegetation type is to be found on the hilltops.

Closed stands of bracken: Herbaceous communities with seasonally dense bracken cover (*Pteridium aquilinum*). This vegetation type is usually located in valleys with deep soil.

Calluna heathland: Vegetation consisting of dwarf shrubs with slightly separated crowns of *Calluna vulgaris*. There is only one vegetation layer, with similar proportions of grass to dwarf shrubs.

Erica heathland: The shrub community is over 1.5 m in height, *Erica arborea* being the dominant species. Shrubs touch one another or are slightly separated. *C. vulgaris* is also abundant in the lower layer.

Dense Cytisus scrub: A community dominated by broom (*Cytisus scoparius*). It has a tightly packed canopy, where shrubs touch and overlap. The herbaceous stratum is discontinuous and dominated by graminoid species.

Mixed heathland: This is a community where two or more shrub species are common (*Erica arborea*, *E. scoparia* and *Juniperus communis*) and is characterized by a dense canopy. The herbaceous level is dominated by graminoids and there is a considerable amount of bare ground.

2.4. Vegetation map and remote sensing

Ortho-rectified aerial photographs taken in 1993 by the Cartographic Institute of Catalonia (ICC, 1994) were used to produce an up-to-date vegetation map. Field trips were undertaken to confirm and adjust the blocks of vegetation in 2000. Image analysis of historical aerial photographs (from 1967 to 1986) and an unpublished vegetation map drawn up by M. Perrinet (dating from 1984) were used to produce earlier vegetation maps of the study site. Three vegetation maps (1967, 1986 and 2000) were drawn using Corel DRAW 9 software (1999) and surfaces were calculated using Image Tool software (Wilcox et al., 1996).

2.5. Sampling design and data analysis

In spring 2000, two random replicate line point tracks, each 30 m long, were used to estimate the species make-up of the lower stratum (plants up to 30 cm high) for each vegetation type. All the species intercepted by a vertical pointer at 10 cm intervals were recorded along these lines. A total of 600 point contacts were recorded for each vegetation type. The occurrence of each species at the points was recorded, and the percentage of the total number of points at which a species occurred is an expression of its cover.

Measurements of the shrub and bracken cover were also based on two line point tracks, each 100 m long, where the segment projection of the canopy on the ground was recorded and expressed as a percentage.

In order to characterize species diversity in each vegetation type, the Shannon–Wiener diversity index was calculated. Diversity (H′) was determined as follows:

$$H' = -\Sigma(pi \cdot \ln pi),$$

where *p*i is the proportion of species i in the track and ln is the natural logarithm of *p*i.

3. Results

3.1. Landscape changes

In 1967 (Fig. 2), potato crops were present in the central section of the study area and *Calluna* heathland was widespread and evenly distributed. Other shrubland types (no distinction between shrubs was possible from aerial photography) were mainly located in the surrounding area, next to the forested slopes. Dry grasslands and bracken were widespread, being confined to hilltops and valleys, respectively.

By 1986, potato crops had almost disappeared. The small field that appeared on the 1986 map was a new potato field used only in 1984 and then abandoned. Crop fields were replaced by *Cytisus* scrub. This community may be seen as clearly related to former cultivated fields. *Calluna* heathland was still abundant and distributed evenly throughout the area. The other shrublands, grasslands and bracken were distributed in a similar way to 1967.

Burning and cultivation had ceased in 2000 and only continuous grazing was practised. The area of *Cytisus* scrub expanded and broom is nowadays widely and evenly distributed. Bracken stands have followed a similar process of expansion. They are taking over the slopes and their areas of growth are starting to connect. Woodlands (Mediterranean *Quercus ilex* forest) have also increased on the plateau. The surface area of *Calluna* heathland has been drastically reduced. In the same way, the distribution of *Erica* heathland and dry grassland has also notably decreased.

This example of Mediterranean afforestation of heathland can be observed by following the surface evolution of vegetation types shown in Table 2. The area of woodland has increased progressively since 1967, principally in the most recent period, in which it attained its greatest surface, covering 43% of the total study area. Otherwise, losses in Atlantic vegetation were only evident after the prohibition of fires. *Calluna* heathland was close to its peak in 1967, covering 35% of the total area. This area had even increased a little (to 38%) between 1967 and 1986, when both controlled burning and grazing were still practised, but had decreased to only 9% by 2000. Associated grasslands also decreased moderately and progressively. Table 3 shows the way in which the annual percentage of reduction of area in isolated heathlands, such La Calma, in the Mediterranean region is higher (at 2.24%) than the values noted in the main zones where heathlands are found (0.60–0.95%).

The possible change of area due to grazing pressure from 1967 to 2000 for each vegetation type is shown in Fig. 3. Both estates (with high and low rate of stocking) underwent similar processes of expansion and reduction in vegetation, except for dry grassland areas,

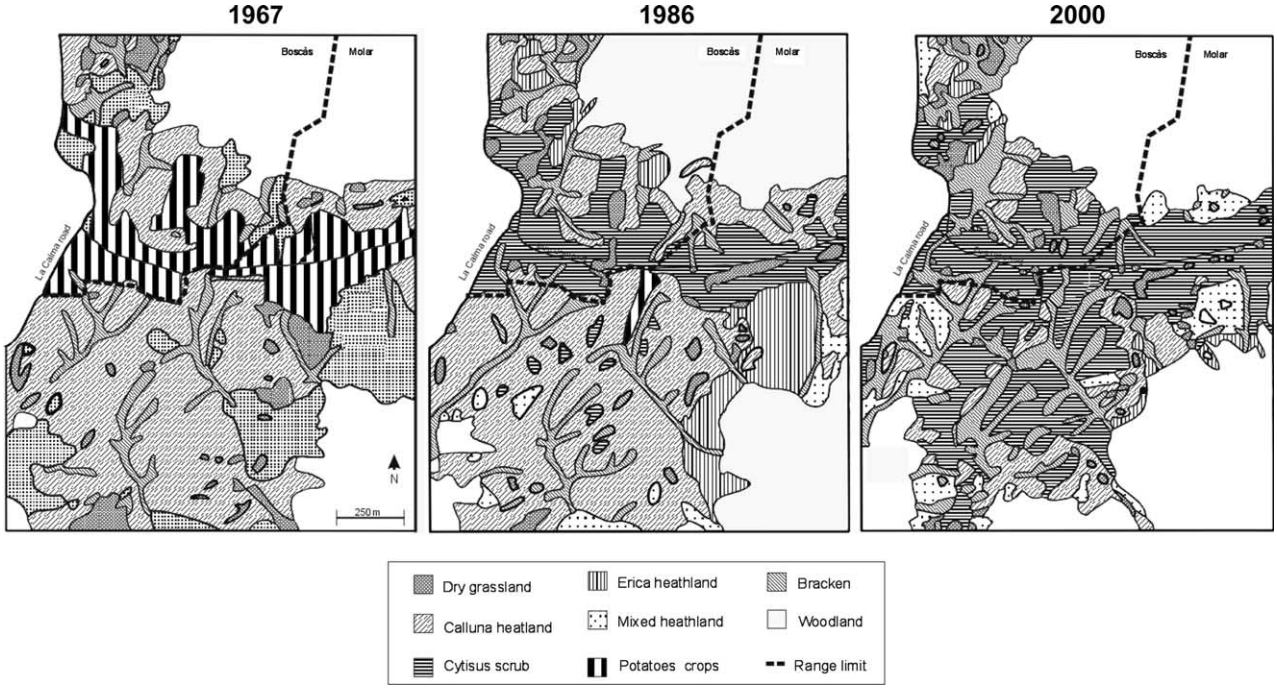

Fig. 2. Vegetation land use map in each one of the three years under study in La Calma plateau (Montseny Natural Park and Biosphere Reserve).

Table 2
Total area occupied by the several plant communities in each study year in La Calma altiplano (ha)

	1967		1986		2000	
	HSR	LSR	HSR	LSR	HSR	LSR
Potato crop	20.7	21.9	0	1.3	0	0
Cytisus scrub	I	I	22.1	14.3	23.6	49.2
Erica heathland	9.3[a]	34.5[a]	6.1	16.5	1.8	2.2
Mixed heathland	I	I	0	6.7	1.4	16.1
Calluna heathland	17.1	86.0	16.8	93.2	5.7	21.1
Closed bracken	5.1	11.2	5.0	10.5	13.7	23.8
Dry grassland	2.7	10.2	4.3	4.4	5.0	2.5
Forest	26.4	46.5	27.0	63.7	30.0	95.3

HSR, high stocking rate (Boscas estate); LSR, low stocking rate (Molar estate).
[a] Includes *Cytisus*, *Erica* and mixed heathland.

Table 3
Loss in surface area of heathland habitats in the Atlantic region (from Pakeman et al., 2003) and Mediterranean region (La Calma, Montseny biosphere reserve)

Location	Period studied	Annual loss (%)
Sweden and Denmark	1860–1960	0.70
Netherlands	1860–1960	0.95
England and Wales	1947–1980	0.81
Scotland	1940–1970	0.60
La Calma (NE, Spain)	1967–2000	2.24

which increased on the estate with the high stocking rate (Boscàs) and decreased in the farm with the low stocking rate (Molar). Considerable differences between the two appeared in the expansion of shrubland, greater in the farm with the higher rate of stocking (Boscàs), and of woodlands, greater on the estate with the lower stocking rate (Molar).

3.2. Plant diversity

The transformation of open heathland and dry grassland into dense *Cytisus* scrub, bracken stands or mixed heathland led to loss of plant diversity and changes in the abundance of species, canopy cover and bare ground (Table 4). In the area under study, a total of 91 species were recorded. Comparison among vegetation types showed the number of species ranging from 52 in the dry grassland to only 21 and 22 in the mixed heathland and dense *Cytisus* scrub, respectively. The percentage of bare ground was considerable both in the mixed heathland and in the dense *Cytisus* scrub, where it reached values of 24% and 18%, respectively. The highest diversity value for the Shannon index was noted in the dry grassland (3.14) and the lowest value among the stands of bracken (2.06).

Table 4
Structural features of each community type in 2000

	Species richness (n)	Diversity (H')	Shrub canopy cover (%)	Bare ground (%)
Dense *Cytisus*	22	2.42	95	18.4
Erica heathland	27	2.68	69	0
Mixed heathland	21	2.41	67	24
Calluna heathland	39	2.48	0[a]	0.1
Closed bracken	25	2.06	100	0.2
Dry grassland	52	3.14	0	0

[a] *Calluna vulgaris* was not included in the shrub canopy cover.

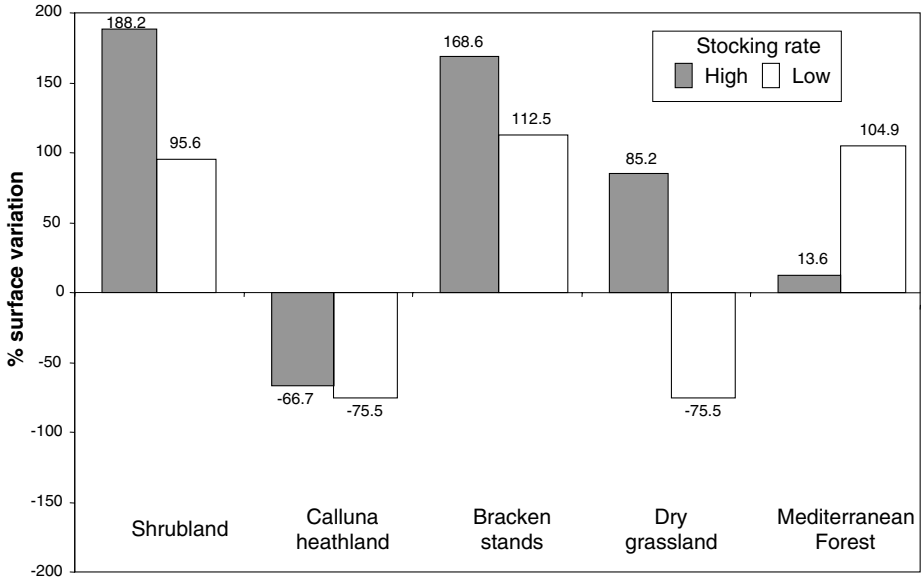

Fig. 3. Percentage change in area from 1967 to 2000 for each vegetation types under high stocking rate (Boscas estate) and low stocking rate (Molar state).

4. Discussion

A rapid replacement process has occurred in the La Calma area over recent decades as a result of various changes in land use and management.

Cultivation has had the greatest impact on vegetation characteristics. Even though crop fields were left to regenerate naturally under the effects of grazing, agricultural use drastically altered the composition and abundance of heathland species which were formerly present. Probably because cultivation implies a gradual loss of heather seeds from the seed bank, subsequent abandonment of crop fields led to a *Cytisus* invasion rather than *Calluna* heathland recuperation. No heather regeneration was recorded on the former arable sites, in agreement with the results of Walker et al. (2004) This change was due to abandoned fields being managed only by continuous grazing, and because fire was no longer used in the area under study (Perrinet, 1988).

According to these results, it is evident that grazing pressure on its own, without controlled burning, is not a tool capable of regenerating *Calluna* heathland after a short cultivation period and is similarly not enough to stop invasion by shrubs and woodland. However, continuous high or low pressure can influence the successional process. On the Atlantic pasturelands of La Calma, the Boscàs and Molar ranges maintained a constant high (around four small animals per hectare per year) and low (around 1.5 small animals per hectare per year) rate of stocking, respectively, for the whole period under consideration (Table 1). Pakeman et al. (2003) reported a number of studies indicating a wide range of stocking levels considered sustainable for grazing heathlands (0.7–2.7 sheep per hectare per year), all of them smaller than on the Boscàs estate. However, according to them, the sustainability of heathlands must be related to heather utilization rather than to the rate of stocking. On those lines, livestock on both Boscàs and Molar consumed a small proportion of annual heather production, at 29% and 16%, respectively (Bartolomé et al., 2000). Grant et al. (1978) proposed a threshold of 40% utilization of annual green shoot production which heather can tolerate before damage occurs. This implies that the impact of livestock in the area under study is much closer to undergrazing than overgrazing in its effects and decreased *Calluna* heathland cover is mainly a consequence of shrub invasion, rather than grazing pressure.

Dry grassland surfaces increased by 85% on the estate with the high stocking rate (Boscas) and decreased by 75% on the farm with the low rate of stocking (Molar) (Fig. 3). This suggests that relatively high grazing pressure was able to maintain and even expand the small patches of dry grassland. These patches showed dominance of *Agrostis capillaris* which is usually favoured by heavy grazing pressure (Welch, 1984). On the other hand, low grazing pressure led to smaller, fragmented patches of grassland in the area of abandoned crop fields (Fig. 2). Moreover, woodland expansion was lower in Boscàs (14%) than in Molar (105%), indicating that a high stocking rate can restrain this process. This is particularly true when the dominant woody species, *Quercus ilex*, is heavily grazed by flocks (Bartolomé et al., 1998) so tree seedlings and saplings can be severely damaged. This is an important difference with respect to Atlantic areas, where the cessation of turf-cutting and controlled fire management on heathland resulted in a rapid growth of trees, regardless of whether grazing animals were absent or present (Kuiters, 2002).

The major expansion of shrubland in Boscàs (188%) compared with Molar (96%) has to be considered carefully. It reflects the higher proportion of potato fields in 1967 (25% in Boscàs compared to 10% in Molar) that were invaded by *Cytisus* by 1986. However, on the Boscàs estate this shrub invasion did not increase greatly between then and 2000 (Table 2). On the Molar estate, shrub invasion was mainly the consequence of a strong invasion by *Cytisus* of abandoned crop fields and a later expansion into areas of other vegetation types during both periods (1967–1986 and 1986–2000). This may imply that although a high stocking rate can not prevent *Cytisus* invasion of abandoned fields, it can at least reduce its expansion into other communities.

The reductions in *Calluna* heathland areas and the expansion of closed bracken were very similar on both estates, indicating limited influence from the rate of stocking on either process. These results are in partial agreement with the findings of Siebel and Piek (2002), who stated that a low stocking density of one sheep per hectare is inadequate to stop the encroachment of *Calluna* heathland, and that a higher stocking density, of more than two sheep per hectare, can lead to overgrazing and deterioration of heather.

Changes in land use have contributed to differentiating communities, such that canopy recovery increased while biodiversity decreased. Dry grasslands have the highest biodiversity value, followed by the two rather similar formations, *Calluna* and *Erica* heathlands. These three formations have reduced in area since 1967, despite their value for pastoral farming as a source of animal forage (Bartolomé et al., 1998) and their status as vegetation easy to walk through.

The abandonment of potato growing and the prohibition of controlled burning have favoured the other three shrub formations. Botanical composition analysis of mixed heathland suggests that it would be an intermediate step, in terms of plant succession, between *Erica-Calluna* heathlands and holm oak forest. Some of its bushes, such as juniper (*J. communis*), act as a shield against livestock for holm oaks, and their "nursemaid" effect contributes to the replacement of Atlantic heathland by Mediterranean woodland, perhaps even

stimulated by the climate change factor. Bracken stands and widespread, dense blocks of *Cytisus* showed the greatest susceptibility to invasion after land-use changes. In terms of landscape conservation, dense *Cytisus* stands present low biodiversity, impenetrability and a high fire hazard. Bracken stands are next to those formations and present similar attributes.

5. Conclusion

Cycles of controlled burning combined with continuous grazing appear to have been an effective tool for maintaining isolated heathlands in the Mediterranean region, such as Montseny Natural Park, for a long time in the form in which they occur in many places in the Atlantic region.

Changes in this sustainable management over a short period of time, such as bringing land into cultivation followed by its abandonment, determined plant succession toward the current Mediterranean woodland, *Cytisus* scrub and bracken stands. However, this process was also influenced by another major change, which was the prohibition of fires. Both promoted considerable encroachment by shrubs and an expansion of forest and stands of bracken to the detriment of more diverse grasslands and heather pastures. In the Mediterranean region, these changes are similar to those described in the Atlantic area, but encroachment is faster and could lead ultimately to invasion by Mediterranean woodland. This process throws into relief the role that isolated habitats can play as monitor of global change.

After the end of cultivation and burning, only animal pressure acted in the opposite direction and it seems that the high rate of stocking (four small animals per hectare per year) might determine the maintenance of small patches of grassland within an area of shrubland. The practice of continuous year-long grazing with a similar stocking rate can also restrain the expansion of shrubs and woodland, but cannot stop it. On the other hand, grazing alone, whether at a high or low rate of stocking, is not enough to stop or to restrain the expansion of stands of bracken and the shrinkage of *Calluna* heathland.

In designated conservation areas such as the La Calma upland, where traditional human activities are still maintained, the promotion or restoration of a mosaic of extensively-used heathland and associated grassland is an urgent issue that needs to be addressed in order to preserve the diverse and partly open landscape. Techniques intended to reverse the encroachment process, including cropping, burning, or application of heather propagules, need to be brought into play to improve the conservation profile of these areas.

Acknowledgements

We thank Isabel Alonso, Salvador Català, W.S. Dodd, Francesc Grau, Oriol Lecina, Zenón G. López, Josep Masnou, Harriet Marshall, Josep Peñuelas, Michele Perrinet, Joan Pujal, Emili Ramirez, Sònia Sànchez and Ramón Vila for their collaboration. Financial assistance was provided by the Spanish Government (REN2002-03827) and the Natural Parks Service of the Barcelona Provincial Council.

References

Bartolomé, J., Plaixats, J., Franch, J., Seligman, N., 1998. Diet selection by sheep and goats on mediterranean heath-woodland range. J. Range Manage. 51 (4), 379–384.

Bartolomé, J., Franch, J., Plaixats, J., Seligman, N., 2000. Grazing alone is not enough to maintain landscape diversity. Agr. Ecosyst. Environ. 77, 267–273.

Belillas, M.C., 1989. Balance de nutrientes y efecto del fuego en cuencas de landa, La Calma, Montseny. Thesis, Autonomous University of Barcelona, Spain, p. 131.

Bignal, E., McCracken, D., 1993. Nature conservation and pastoral farming in the British uplands. Brit. Wildlife 4 (6), 367–376.

Boada, M., 2001. Manifestacions del canvi global al Montseny. Ph.D. Thesis, Autonomous University of Barcelona, Spain, p. 430.

Bolòs, O. de, 1983. La vegetació del Montseny, Ed. Diputació de Barcelona, Servei de Parcs Naturals, Barcelona, p. 170.

Bolòs, O. de 1986. Flora vascular del Montseny. In: El patrimoni biològic del Montseny. Ed. Diputació de Barcelona. Servei de Parcs Naturals, Barcelona, pp. 41–92.

Bosch, A., Llorens, J.M., Rueda, J.M., 1991. La Feixa Llarga (Arbúcies): un testimoni de la presència de comunitats ramaderes prehistòriques al Montseny. Monografies del Montseny 6, 107–116.

Breton, F., 1992. El territori del mas en el Montseny. Aixa, 5. Revista anual de La Gabella, Museu Etnològic del Montseny, pp. 29–64.

Corel Corporation and Corel Corporation Limited, 1999. Corel DRAW Graphics Suits, User Guide (Ottawa, Canada, Dublin, Ireland).

Folch, R., 1986. Historia Natural del Països Catalans. Ed. vol. 7, Enciclopèdia Catalana, S.A. Vegetació. p. 442.

Grant, S.A., Barthram, G.T., Lamb, W.I.C., Milne, J.A., 1978. Effects of season and level of grazing on the utilization of heather by sheep. 1. Responses of the sward. J. Brit. Grassland Soc. 33, 289–300.

Hanson, M., Fogelfors, H., 2000. Management of a semi-natural grassland: results from a 15-year-old experiment in southern Sweden. J. Veg. Sci. 11 (1), 31–38.

Institut Cartogràfic de Catalunya, 1994. Ortofotomapa de Catalunya, 1:25.000. Generalitat de Catalunya, Departament de Política Territorial i Obres Públiques.

Kuiters, A.T., 2002. Hoofed animals in nature areas: theory and practice versus research. Vakblad Natuurbeheer 41, 21–23.

Llobet, S., 1947. El Medi i la Vida al Montseny. Ed. Consejo Superior de Investigaciones Científicas, Barcelona, p. 486.

Marrs, R.H., Hicks, M.J., Fuller, R.M., 1986. Losses of lowland heathland through succession at four sites in Breckland, East Anglia, England. Biol. Conserv. 36, 19–38.

Marrs, R.H., Snow, C.S.R., Owen, K.M., Evans, C.E., 1998. Heathland and acid grassland creation on arable soils at Minsmere: identification of potential problems and a test of cropping to improverish soils. Biol. Conserv. 85, 69–82.

Mitchell, R.J., Marrs, R.H., Le Duc, M.G., Auld, M.H.D., 1997. A study of the succession on lowland heaths in Dorset, southern England: changes in vegetation and soil chemical properties. J. Appl. Ecol. 34, 1426–1444.

Pakeman, R.J., Hulme, P.D., Torvell, L., Fisher, J.M., 2003. Reabilitation of degraded dry heather (*Calluna vulgaris* (L.) Hull) moorland by controlled sheep grazing. Biol. Conserv. 114, 389–400.

Panareda, J.M., 1978. L'estructura i la dinàmica del paisatge actual al Montseny: els impactes humans sobre els sistemes naturals. Thesis, University of Barcelona, Spain, p. 436.

Peñuelas, J., Boada, M., 2003. A global change-induced biome shift in Montseny mountains (NE Spain). Global Change Biol. 9, 131–140.

Perrinet, M., 1988. Etude des landes acides de la montagne catalane (Montseny, Barcelone) en relation avec l'action du feu et les autres facteurs ambiants. consequences pour l'amenagement. Ph.D. Thesis, University of Barcelona, Spain, p. 80.

Siebel, H, Piek, H, 2002. New views on grazing among site managers. In: Grazing and grazing animals. Vakblad Natuurbeheer 41, 6–10.

Walker, K.J., Pywell, R.F., Warman, E.A., Fowbert, J.A., Bhogal, A., Chambers, B.J., 2004. The importance of former land use determining successful re-creation of lowland heath in southern England. Biol. Conserv. 116, 289–303.

Webb, N.R., 1986. Heathlands. Collins, London.

Webb, N.R., Rose, R.J., Clarke, R.T., Traynor, C.H., 2000. Heathland changes in dorset, England, between 1987 and 1996. Biol. Conserv. 93, 117–125.

Welch, E., 1984. Studies in the grazing of heather moorland in northeast Scotland. II. floristics. J. Appl. Ecol. 21, 209–225.

Wilcox, D., Dove, B., McDavid, D., Greer, D., 1996. Image Tool for Windows (v.2.00). The University of Texas Health Science Center in San Antonio, USA.

Williams, B., 2003. A comparison of heathland management practices, approaches and mechanisms in the UK and the Netherlands, National Trust, Arkell Fellowship.