



Review

Goat grazing, its interactions with other herbivores and biodiversity conservation issues

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ABSTRACT

Goats have developed in harmony with local conditions of climate, terrain, vegetation, and even pathogens over centuries in many areas, while they have been blamed of causing environment degradation in other ones. The paper summarizes the situation of goat's population worldwide, the status of the breeds and the multiple implications of their conservation, the interactions of goats with other animal species (wild or domestic) and the main issues regarding the consequences of goat grazing from the environmental point of view. It underlines that most of the environmentally harmful effects of goat grazing arise from improper management practices at very high grazing pressures whereas goat grazing can be a useful tool for conservation if managed adequately. Moderate grazing pressures can be compatible with high levels of biodiversity and provide externalities, whereas high intensity at short term can be a valuable tool for weed control. Goat genetic heritage is seriously threatened and requires more studies and greater support from national and international institutions, in parallel with other efforts in rural development, especially for remote areas which hold an outstanding reservoir of livestock diversity adapted to the local conditions and managed by impoverished communities. A multidisciplinary approach of scientists, policy makers, rangeland managers and local communities is required for the design of future sustainable management plans.

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1. Introduction: past, present and future of world goat populations

Goats are among the first ruminants to be domesticated and possibly the second species to be taken into the human fold after the dog (Wilson, 1991). Domestication started with the bezoar (*Capra aegagrus* (Erxleben, 1777)) in south-west Asia (Iran and Iraq) about 10,000 years ago (Mason, 1984).

The global census of this ruminant was around 920 million heads in 2010 (Table 1). Despite their global distribution, they are more abundant in the developing countries (about 98% of the total population) and around the tropics

and dry zones (Devendra, 2010), especially in Asia (60%) and Africa (33.8%). Within Asia, the greatest concentrations occur in China, India and Pakistan (39.6% of the world goat population and 66% of the continent). The rest are found mainly in Latin America, the Caribbean, Europe and Caucasus. Within the European Union (EU), around 12 million goats were recorded during 2010 and they were mostly reared in Greece (33.6%), Spain (23.5%), France (10.8%) and Italy (7.7%) (Table 1).

The world goat population growth has been constant (2.6% annual growth rate over the period 1986–2007 and 2.8% considering solely developing countries) whereas the opposite pattern is observed in Europe (Devendra, 2010; Table 1). The global increase is expected to continue (Rosegrant et al., 2009) regardless of the rapid global shift towards a monogastric livestock production which has expanded more than fourfold over the past decades (Steinfeld et al., 2006).

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Table 1
Stocks (heads) of goats in different regions and countries of the world.

Region/country	2000	2002	2004	2006	2008	2010
European Union	14,443,626	13,636,224	13,993,375	13,775,641	13,791,939	12,487,721
France	1,210,520	1,231,560	1,240,000	1,232,640	1,283,120	1,349,030
Greece	5,614,450	5,180,000	5,619,100	5,422,240	5,345,620	4,200,000
Italy	1,397,000	1,025,000	960,994	945,000	920,000	961,000
Spain	2,627,000	3,046,720	2,833,220	2,956,730	2,959,300	2,933,800
Africa	234,220,237	250,890,414	267,685,212	279,276,912	299,259,339	310,718,293
America	34,938,153	36,187,103	37,056,339	38,013,119	37,411,782	37,211,489
Asia	458,521,301	463,392,884	486,798,255	504,422,915	529,504,472	551,227,448
China	148,478,245	145,872,929	149,928,862	146,858,033	143,595,223	150,708,101
India	123,533,000	124,077,000	128,213,000	136,286,000	145,000,000	154,000,000
Pakistan	47,426,000	50,917,000	54,679,000	53,789,000	56,742,000	59,900,000
World	749,030,481	771,903,084	813,546,950	843,935,961	887,709,227	920,608,951

Source: FAOSTAT.

2. Goat breeds

The diversity of goat breeds is remarkable (they represent 12% of all the breeds within the mammals) and includes 543 local, 46 regional transboundary and 38 international transboundary breeds (FAO, 2010b). Such diversity is a result of both natural selection for fitness under varied conditions and artificial selection practised by breeders. The Saanen is the world's most widespread breed and, together with the Anglo-Nubienne, Boer, Toggenburg, Alpine, West African Dwarf, Angora and Creole, they are present in more than 24 countries (FAO, 2010a). The majority of the breeds (76%) are reared in the developing countries, mostly in Asia and Africa (42%), while another 195 local breeds occur in Europe and the Caucasus, mainly around the Mediterranean area (170 breeds) (Devendra, 2010; FAO, 2010a,b).

The flourishing of intensive livestock production systems which utilize a narrow range of breeds has contributed to the degradation of the animal genetic resources and the marginalization of the traditional livestock production ones, leading many breeds to a risk of disappearance (FAO, 2009). So far, the greatest loss of genetic resources occurs in Europe (16 out of the 19 extinct goat breeds worldwide) although, according to the European farm animal biodiversity information system (FABISnet), the status of endangerment of 86.5% of the breeds is unknown there, due to the lack of enough data to estimate it, although five European breeds are "endangered" and 13 are "critical" (Duchev et al., 2006). Notwithstanding the status of the breeds is even more poorly documented in Asia or Africa, where many of the more rarely used and best-adapted animals are found, and where many breeds face the danger of genetic erosion. Such lack of data leads to an incomplete and distorted picture of the status and trends of domestic animal breeds worldwide (Shand, 1997). Furthermore, the survival of autochthonous breeds can be associated with the survival of indigenous ethnic groups, frequently pastoralist, which are pushed, together with their livestock, to marginal areas. These trends occur in remote areas of China and India located in border states and provinces with harsh terrain and great breeds-to-people ratios (Hall and Ruane, 1993).

The FAO has a 50-year record of promoting research into livestock diversity and of advocating its conservation (FAO,

2010a,b), but there are few internationally or nationally funded projects, even within the richer nations (Hall, 2004). The Interlaken Declaration on Animal Genetic Resources already recognized the existence of serious gaps and weaknesses at national and international level which prevented an efficient inventory, monitorization and characterization of the animal genetic resources, hindering their sustainable use and conservation, and financial resources and long-term support at national and international level were urgently demanded (FAO, 2007).

We do not observe a much greater progress nowadays and the current government policies are sometimes contradictory. For example, the latest reform of the EU Common Agricultural Policy (CAP), despite including initiatives to arrest the loss of genetic resources, is expected to accelerate goat farming abandonment, and especially of those working with indigenous stock, as the decoupling process progresses (Canali, 2006; Castel et al., 2010). Therefore, we must continue stressing that the survival of the valuable genetic biodiversity would lay on the international support from institutions like FAO, on the improvement of national and international government policies, and in the case of Europe, on the efforts of the national associations related to the maintenance or establishment of goat flock books, such as the existing 19 Spanish associations, which carry on active conservation or breeding programs (e.g. Camacho Vallejo et al., 2005; Figueroa et al., 2003; Gómez et al., 1998). There is evidence of how coordinated efforts from different institutions can contribute to the conservation of endangered breeds. Once the Spanish Official Catalogue of Livestock Breeds highlighted the urgency of conservation efforts to preserve the Pitüsa or Ibicenca goat breed, endemic from two of Balearic Islands and, under evident risk of extinction, the association of producers of this breed, together with the Balearic Institute of Animal Biology and the University of Córdoba carried out an efficient rescue program following FAO's technical recommendations (Camacho et al., 2011). Apart from saving the valuable genetic heritage, a parallel plan searches for attributes that enhance its economical value to promote its expansion.

The local breeds are claimed to be superior with regard to the use of marginal lands and where feed resources are limited. That is the case of most of the indigenous breeds of semi-arid and arid areas, which utilize feed of high-fibre and low-quality content more efficiently than the exotic

ones (Silanikove et al., 1993). However, in some circumstances exotic breeds can adapt to the conditions in other areas. Cashmere goats endured the low nutritive quality of the vegetation in Cantabrian heathlands (N Spain) better than the Celtiberic local breed (Osoro et al., 2007), possibly owing to the different grazing behaviour, smaller body size and lower total maintenance requirements of the former (Silanikove, 2000). Regarding their effects on the biodiversity, the floristic richness tended to be higher in areas grazed by the locals although, after four years, evenness index dropped there due to the dominance of certain grass species (Celaya et al., 2010), while the arthropod assemblages did not differ between breeds (Jauregui et al., 2008; Rosa García et al., 2009a,b). Nevertheless, the knowledge about the effects of the different breeds on the local biodiversity should be clearly improved.

3. Interaction of goats with other livestock species

The coexistence of goats with other livestock species has been controversial as they might compete for the forage resources, while they are complementary with others, depending on multiple factors like the stocking densities, grazing behaviour of each species, vegetation, year, and season (Bartolomé, 1994; Cuartas, 1992; Rook et al., 2004; Shrestha et al., 2005). The controversy increases when they become the last available species to farmers (“the cows of the poor”) and they get involved in a vicious circle. Many of the world’s deteriorated rangelands were firstly damaged by cattle and sheep overgrazing, so the pasture left (browse or shrubs) could be used only by goats (Huss, 1972). They are also the last species that impoverished farmers can keep when they cannot afford the bigger and more demanding large herbivores, so they incorporate higher proportions of goats in their mixed flocks. Free ranging indigenous goat breeds on highly degraded grazing lands in semi-arid areas can be 2.5 times more economical than indigenous sheep (Swain, 1984). In sub-Saharan Africa, population pressure and land fragmentation forced small farms to turn to small ruminants, and particularly goats, as they were unable to support cattle, and in northern Kenya and southern Ethiopia, pastoralists claim that invasion by woody species drove them to increasingly substitute their cattle for camels and goats (Peacock and Sherman, 2010). In other cases, a switch from cattle to small ruminants occurs in arid–semiarid rangelands of East and West Africa in times of drought, when forage is scarce (Nyong et al., 2007). Therefore, rather than being drivers of desertification, goats are actually one of the most adaptable large herbivorous species to marginal mountainous or desert areas (Silanikove, 2000). It must also be stated that some of the best pastoral lands (in terms of soils and rainfall) which were converted into crop production, despite being frequently unsuitable for that activity, were later recovered by pastoralists in a much less productive state (Sidahmed, 1986). Therefore, in many cases, goats “inherit” an already “desolate” landscape which can be further depleted if not properly managed.

From another perspective, beneficial effects of goat grazing for other domestic herbivores have been observed. In improved pastures, the presence of white clover

(*Trifolium repens*) is enhanced when goats are present in the herd compared with single grazing by sheep while grass flowering stems are more consumed by goat, leading to greater percentages of green leaves in the sward. This pattern has been observed in Great Britain (del Pozo et al., 1996; Grant et al., 1984; Penning et al., 1996), Spain (Celaya et al., 2007; del Pozo et al., 1998) or New Zealand (Clark et al., 1984). These botanical and structural changes imply a higher nutritive quality of the available pasture, resulting in higher livestock performances under integrated mixed, rotational or sequential management with goats, for both sheep (Radcliffe et al., 1991; del Pozo et al., 1996, 1998) and cattle (Osoro et al., 2000). Other benefits of mixed grazing are known from semi-arid rangelands, where it might enable to decrease from 26 ha per tropical livestock unit (a TLU is equivalent to 250 kg live weight) for cattle alone to 13 ha/TLU when cattle and goats are reared together (Schwartz, 1983).

Regarding the impact on the local fauna, sheep and goats associated to similar arthropod assemblages in heather dominated areas in Cantabrian heathlands, but to different assemblages in herbaceous dominated areas, where goats enhanced herb growth while decreased shrub cover and provided more favourable conditions for certain arthropod species (Rosa García et al., 2010b). In nearby partially improved heathlands, the diversity of arthropods was higher in paddocks grazed by mixed herds of either sheep or cattle with goats than in others under monospecific grazing of cattle or sheep, especially within the shrubland areas. The local fauna benefited from the greater vegetation structural complexity resulting from the goat’s browser behaviour (Rosa García et al., 2010a, 2011).

Therefore, a profound knowledge of livestock grazing behaviour and diet selection is necessary to understand their impact on biodiversity and it can represent an interesting environmental tool.

4. Interaction of goats with wild herbivores

The relationship between livestock and native herbivores is linked to conflicts between farmers, conservationists, hunting game managers, etc., and it greatly depends on their competition for the resources. Excessive or inappropriate goat grazing has posed a threat to some native herbivores worldwide (Dawson and Ellis, 1994), while they appear complementary with others (Dawson and Ellis, 1996; Mishra et al., 2001). So far, conclusions on the impact of livestock on native ungulates are heterogeneous and highly debated, especially regarding the processes and the outcome of the interactions (e.g. Madhusudan, 2004; Mishra and Rawat, 1998; Young et al., 2005).

The competition for forage between the wild ass named kiang (*Equus kiang* Moorcroft, 1841) and livestock generates conflicts with pastoral communities in the Indian Trans-Himalaya which are linked to the loss of pastures during the Indo-Chinese war in 1962 or the increase of the cashmere production there (Bhatnagar et al., 2006).

The spatial expansion and population recovery of the tahr (*Hemitragus jemlahicus* (C.H. Smith, 1826)), and its minimal spatial overlap with the migratory herds of sheep and goats in the Himalayan Kedarnath Wildlife Sanctuary

are related to the decrease of livestock numbers, although there is a concern about its situation in nearby areas with heavy livestock grazing and poaching of tahr (Kittur et al., 2010).

The Tibetan argali (*Ovis ammon hodgsonii* Blyth, 1841) either had a separated diet selection and habitat use from domestic goats in Nepal (Shrestha et al., 2005) or overlapped in Mongolian protected areas. The livestock–argali conflicts are associated with the flourish of the cashmere fibre production, the increase in livestock numbers, herding families and improper management (Reading et al., 2006), so the reduction of both people and livestock, antipoaching activities or controlled sport hunting is suggested to arrest its decline (Reading et al., 1997). In Western China, this species is threatened by gold mining activities, the construction of an aqueduct or its dietary overlap with livestock (Harris and Pletscher, 2002).

The growth of cashmere production also threatens the endangered Tibetan gazelle (*Procapra picticaudata* Hodgson, 1846) in the Indian Trans-Himalaya (Namgail et al., 2007, 2009). Despite its similar diet to sheep and goats in Mongolia, competition could not be inferred, but serious habitat deterioration was caused by policies which promoted a shift from a nomadic to a sedentary society (Campos-Arceiz et al., 2004).

The Himalayan blue sheep, bharal or naur (*Pseudois nayaur* (Hodgson, 1833)) overlaps its diet with goats in the Indian Trans-Himalaya (Mishra et al., 2001, 2004), whereas it is more abundant in neighbouring areas with lower livestock stocking rates (Mishra et al., 2002). It either spatially overlapped with livestock in Tibet (Schaller and Gu, 1994), or had both diet and habitat separation in this region and Nepal (Harris and Miller, 1995; Shrestha et al., 2005). Shah (2003) linked its decline in Nepal to hunting activities, diseases transmitted by livestock and genetic or environmental mishaps, coupled with predation by wild carnivores. The resource use overlap between naur and goats occurs mostly in spring and summer, when domestic stock is seasonally rotated among different pastures, a system which might also facilitate their coexistence through resource partitioning (Shrestha and Wegge, 2008). The naur uses a similar habitat type to yak (*Bos grunniens* Linnaeus, 1766) (Harris and Miller, 1995; Shrestha and Wegge, 2008) and Himalayan ibex (*Capra sibirica hemalayanus*, Hodgson, 1841) (Bagchi et al., 2004).

The Himalayan ibex deals with resource limitations imposed by migratory herds of goats and sheep around the Indian Trans-Himalayan pastures, while it is unaffected by the resident livestock as most species show habitat separation (Bagchi et al., 2004; Bhatnagar, 1997). The feeding habits and forage preferences of the Iberian ibex (*Capra pyrenaica* Schinz, 1838) are closer to feral goats (*Capra hircus* (Linnaeus, 1758)) than to domestic ones in Mediterranean mountain scrublands (Aldezabal and Garin, 2000). In the Cazorla Mountain Range (south Spain), while goats consumed mostly evergreen oak (*Quercus ilex* L.), ibex selected a mixed diet of ligneous plants, graminoids and herbaceous plants (García-González and Cuartas, 1989). Cuartas (1992) confirmed the low index of similarity in their diets, although the lowest overlap occurred between domestic goats and mouflon (*Ovis musimon* Pallas, 1762).

Goats coexist with chamois (*Rupicapra rupicapra* Linnaeus, 1758) in northern Spain, where they both have different diet selection and low similarity index (27.2%) (Aldezabal, 2001).

Although goats appeared to have negative affects on ibex in Castilla-La Mancha (Spain) by displacing it from its optimal habitat (Acevedo et al., 2007), the ibex populations were in expansion there and coexisted with other wild ungulates such as wild boar (*Sus scrofa* Linnaeus, 1758), red deer (*Cervus elaphus* Linnaeus, 1758), fallow deer (*Dama dama* Linnaeus, 1758), and roe deer (*Capreolus capreolus* Linnaeus, 1758). Later on, red deer translocations for sport hunting were also claimed to impose a threat on ibex in mountainous regions of southern Spain (Acevedo and Cassinello, 2009).

In the Isle of Rhum (Scotland), red deer selected mesotrophic communities while free-ranging goats preferred others dominated by dwarf shrubs (Gordon, 1989). Fraser and Gordon (1997) indicated that the differences in diet composition between red deer and goats grazing on different vegetation types in Scotland could be of interest to develop management protocols for vegetation communities of high nature conservation value.

White-tailed deer (*Odocoileus virginianus* (Zimmermann, 1780)) and goats responded differently to the distribution of browse plants in a Texas shallow ridge range site, with goats being more influenced by overall plant community structure whereas white-tailed deer were more affected by the distribution of their preferred forage species (Etzenhouser et al., 1998). Under rangeland conditions in Texas (USA), this deer was favoured by controlled grazing with sheep and goats, although their stocking should be carefully managed during the critical times of the year (winter, early spring) when competition might affect deer negatively (Bryant et al., 1979).

In the African savanna, goat's diet may overlap with dik-dik (*Madoqua* sp.), kudu (*Tragelaphus strepsiceros* (Pallas, 1766)), eland (*Taurotragus oryx* (Pallas, 1766)), impala (*Aepyceros melampus* (Lichtenstein, 1812)), black rhinoceros (*Diceros bicornis* (Linnaeus, 1758)), or giraffe (*Giraffa camelopardalis* (Linnaeus, 1758)) (Prins, 2000; Breebaart et al., 2002). Goats control shrub encroachment (particularly of *Acacia* species) less efficiently than dik-dik (Augustine and McNaughton, 2004) and eat more grasses than kudu and gazelle, but less than impala (Owen-Smith and Cooper, 1985; Hoppe et al., 1977). While foraging at similar height as eland (although they generally consume different species), goats do it at different one to giraffe (Breebaart et al., 2002).

The inconsistent pattern among different studies might relay on local adaptations of the ungulates within their geographical ranges and the changes in the phenology, and hence quality, of forage plants between areas (Shrestha et al., 2005).

The presence of humans may obscure natural interactions between wild and domestic ungulates, acts as a displacement factor and can reduce their habitat overlap as it influences the foraging behaviour of wild ungulates (Namgail et al., 2007), so it might be considered in addition to exploitative competition patterns (Bagchi et al., 2004; Harris and Loggers, 2004). The presence of both small

ruminants (mainly sheep) and people contributed to reduce the distribution area for chamois in northern Spain, forcing them to move (Aldezabal, 2001), although a vertical natural migration of chamois is already known (Pérez Barbería, 1994) and it is greatly influenced by the cover and the depth of the snow (García-Gonzalez et al., 1990). Mongolian gazelles (*Procapra gutturosa* (Pallas, 1777)) had a consistent feed composition among different areas while sheep and goat varied, maybe mediated by herding management, which turned important for the conservation of the wild ungulate (Yoshihara et al., 2008). Furthermore, the human-adapted strategy of seasonally rotating domestic herds across different areas to optimize the use of limited feed resources might have facilitated their coexistence with naur through partitioning of resources (Shrestha and Wegge, 2008).

The situation of livestock vs. wild ungulates regarding nature conservation in the Mediterranean landscapes has evolved since the 1960s. Whereas livestock numbers are declining, wild ungulate populations have increased as a result of rural abandonment, the expansion of protected areas and the outstanding growth of big game hunting demand. For example, the annual Spanish harvest of wild boar has increased by tenfold during the last 35 years (Bueno et al., 2009) and red deer numbers have also grown at an exponential scale (Milner et al., 2006).

Wild ungulates might assume part of the traditional contribution of livestock to rural development and to the conservation of cultural landscapes and insect fauna (Theuerkauf and Rouys, 2006), but they also require an adequate management, especially of those species of hunting interest like wild boar or red deer, whose over-expansion is already generating conflicts with the local communities, threatening the environment and increasing herbivory pressure, and even affecting negatively other wild species such as Iberian ibex in certain areas (Acevedo and Cassinello, 2009; Bueno et al., 2009). According to Zamora et al. (2001) and Gómez et al. (2003), the conservation and restoration of forests of most Mediterranean mountains require the proper management of both wild and domestic ungulates.

5. Goat grazing and habitat conservation

Goats are defined 'the black sheep' among livestock by consuming almost everything edible and they have been blamed for causing habitat degradation (Peacock and Sherman, 2010). Feral goats are considered a pest in semi-arid rangelands in Australia (Parkes et al., 1996), where their commercial harvest is suggested as an economic opportunity, but also as a tool to minimize their negative impacts on both agricultural production and native species and habitats (Choquenot et al., 1998). Goats have been eradicated from at least 120 islands worldwide (Campbell and Donlan, 2005) where their introduction has frequently resulted in ecosystem degradation and biodiversity loss (Coblentz, 1978; Schofield, 1989). Within the Aldraba Island (Seychelles), a World Heritage site, their eradication started once their numbers increased and prompted concern for the future of the local biota (Coblentz et al., 1990). The intense goat grazing in various Galapagos Islands

affected the native vegetation severely over many decades (Hamann, 1979) and the posterior population control programs seemed to contribute to the recovery of birds like rails (*Laterallus* sp.) (Donlan et al., 2007). Although invertebrate diversity increased in Volcán Alcedo (Galápagos) after a severe grazing by introduced feral goats which temporarily increased habitat heterogeneity, its conservation value was questioned, and the species naturally occurring in the scrub and groves, as well as others from humid open habitats, were expected to disappear unless the situation was reversed (Desender et al., 1999). Conversely, moderate goat grazing is considered valuable for the conservation of pastures dominated by native or endemic species in Tenerife Island (Fernández-Lugo et al., 2009), and negative effects on plant diversity are expected after goat grazing abandonment in pastures which sustain endemic plant species in La Gomera Island (Arévalo et al., 2011).

Most of the abovementioned examples highlight that it might not be goats per se that is the real culprit, but their mismanagement, frequently by overgrazing. Furthermore, goats having a potential positive impact on vegetation regeneration and biodiversity improvement (El Aich and Waterhouse, 1999), they have returned to several unmanaged grasslands around Europe with aims of conservation of the biodiversity (Ferrer et al., 2001; Muller, 2002). They can also contribute to preserve ecosystems like heather, moor, marsh wet meadow and other unique biotops present in protected areas (Martyniuk and Olech, 1997).

Within calcareous grasslands in the Franconian Jura, small ruminant grazing periods are adjusted to the life cycle of the butterfly *Parnassius apollo* (Linnaeus, 1758). Its conservation has been enhanced by including goats into the sheep herds to allow new growth of *Sedum album*, the feed-plant it requires (Dolek and Geyer, 2002). Grazing by small ruminants in these areas becomes a central option for long-term conservation, once the timing, intensity and spatial distribution are planned, and the infrastructure and social conditions required by the herders to keep grazing practicable are provided (Dolek and Geyer, 2002). Traditional rough grazing with sheep and goats was also the most favourable tool for the preservation of the Duke of Burgundy butterfly (*Hamearis lucina*, 1758) in German calcareous grasslands (Fatmann, 2006). Balanced management of goat, sheep and rabbit populations is also among the prescriptions to preserve the shrubland habitat needed for the survival of the butterfly *Plebejus argus* (Linnaeus, 1758) in north Wales (Dennis, 2004).

Within Los Filabres area in SE Spain, a retrospective analysis revealed that the abandonment of cereal mountainous practices and the posterior development of goat grazing practices, far from leading to the degradation of the area, contributed to the restoration of the plant canopy, revealing that the comparison of grazing with degradation should be questioned (Robles et al., 1997).

Goat production and management in agro-forestry systems are also related to habitat conservation. The very complex, species-rich and traditionally managed homegardens are sustainable agro-forestry systems, frequently include goat grazing, and are considered neglected hotspots of agro-biodiversity and cultural diversity (Galluzzi et al.,

2010). The silvopastoral systems are another agro-forestry combination where woody fodder species can be key sources of nutrients for livestock (e.g. Papachristou and Papanastasis, 1994; Rigueiro-Rodríguez et al., 2005). Goat grazing can benefit the production of trees (oil palms, rubber trees, coffee, etc.), but also carbon sequestration (Ørskov, 2011) because goats can help to restore the cycling of plant nutrients sequestered by woody species, as observed in Black Kettle National Grassland (Oklahoma), where available N, P and K increased on the soil after three years of goat grazing of shinnery oak (*Quercus havardii* Rydb.) (Hart, 2001). It can also improve soil fertility through nutrient recycling and C sequestration after long term goat grazing, without additional soil management practices, in loblolly pine-goat (*Pinus tadea* L.) silvopastures in Southeast USA, making the system both environmentally and economically sustainable (Nyakatawa et al., in press).

The *Dehesa* (in Spanish) or *montado* (in Portuguese) is a traditional Mediterranean silvopastoral system which has evolved under extensive mixed livestock grazing (including goats) and supports an extraordinary biodiversity, including highly endangered species such as the Iberian lynx (*Lynx pardinus* (Temminck, 1827)), the imperial eagle (*Aquila adalberti* Brehm, 1861) or the cinereous vulture (*Aegypius monachus* (Linnaeus, 1766)). The conservation programs of these species require management practices which preserve their habitat and provide the resources (e.g. rabbits) they need (González and San Miguel, 2004).

As it will be explained further on in this manuscript, silvopastoral methods which include goats are also a powerful tool for habitat conservation through the prevention of fire risks by an efficient control of the accumulation of flammable woody vegetation (Etienne et al., 1996; Jáuregui et al., 2009; Rigueiro-Rodríguez et al., 2005).

6. Bush encroachment and fire risk reductions

The bush encroachment is caused by various factors, including fire frequency, under-utilization of the bushes and overgrazing of herbaceous vegetation (Smit et al., 1999). According to the FAO, fires affect an estimated 350 million hectares of land worldwide every year and cause losses of lives, enormous ecological and economic damage in forests and agriculture areas and contribute to global warming, air pollution, desertification and loss of biodiversity.

Among ruminants, goats are able to reduce bush cover more efficiently than sheep or cattle (Sineiro, 1982; Benavides et al., 2009). They reduced it from 45 to 15% in one year on hill pastures of the Appalachians, whereas sheep required 3 years to bring the same results (Magadlela et al., 1995). Although Fajemisin et al. (1996) questioned the potential of Spanish goats for woody plant control in good condition sagebrush steppe pastures, other authors reported that they were more willing to eat browse than Angora goats (Pritz et al., 1997; Warren et al., 1984), or that they reduce it more than Cashmere ones (Celaya et al., 2010). In Cantabrian heathlands, gorse (*Ulex gallii*) biomass was more efficiently controlled with goat than with sheep grazing, favouring herbaceous presence and turning goats

a valuable tool to reduce fire risk (Benavides et al., 2009; Celaya et al., 2007; Jáuregui et al., 2009).

In the Sacramento River and Stone Lakes National Wildlife Refuges (northern California), goats are also used to reduce overgrown vegetation in areas at risk of wildfire and maintain the critical habitat for migratory birds along the Pacific Flyway (see <http://www.fws.gov/fire/news/ca/goats.shtml>). In New Hampshire they are used by an electric company to clear under the powerline in an ecologically friendly manner (Hart, 2001). They have also been utilized to control the highly flammable shrubs of the southern California chaparral (Green and Newell, 1982; Sidahmed et al., 1981), they assisted in controlling bush encroachment in savannas (Mahanjana and Cronje, 2000; Ward, 2005), in woody plant control in Tanzania's Massailand (Martin and Huss, 1981) or in western Texas (Ueckert, 1980). They also contributed in reducing Gambel oak (*Quercus gambielii*) sprouts in Colorado (Davis et al., 1975) and in biological control efforts in Australia and New Zealand (Gray, 1984; Holmst, 1980; Radcliffe, 1985). The woody encroachment of previously cultivated areas of the pre-Alps mountains (SE France) and Corsica increased fire risk considerably and concerns about whether the remaining animal husbandry can make a sustainable use of the natural ligneous plants rose. The Livestock Farming Systems (LFS) research programs carried out by the INRA explored the capacity of adapting small ruminant grazing management for preventing fire risk (Flamant et al., 1999). Such capacity is confirmed in Spain, where goats have been successfully managed for controlling bushes with high ignition capacity (Valderrábano and Torrano, 2000) and clearing fuel breaks (Martín et al., 2011), while contributing to integrate livestock breeders in sustainable initiatives (Ruiz Mirazo et al., 2009).

Finally, the environmental concerns and the economic costs of chemical and mechanical methods for clearing and maintaining firebreaks provide an opportunity to utilize biological control methods such as goats for these purposes (Green and Newell, 1982; Launchbaugh, 2006). In the case of mechanical methods, it provides an alternative in remote areas or with steep slopes, and it would also contribute to reduce the use of fuel and therefore, the environmental pollution.

7. Use of crop residues and crop by-products

The use of crop wastes as feed facilitates the return of nutrients to the soil via the production of manure and urine, which, carefully managed can result in improved soil fertility and structure, and higher humus levels, thereby increasing crop production (FAO, 2009). Although sometimes relatively indigestible for goats, plant residues from vegetable crops, tuberous crops, green stover of corn, sorghum and millet can be excellent feeds when fed green. They have been traditionally used by nomads or transhumant pastoralists during the dry period but, as these activities are ceasing, further research is needed to integrate pastoralism with cropping, conservation and forage production, especially during that period (Wilson, 1991).

Some crop by-products such as rice or wheat bran, cassava chips, peanut, sunflower or linseed cake and sugar-cane tops have also been used as low-cost feed supplements for goats (Peacock, 1996). Their utilization during summer, when perennial forage plants are less available, could contribute to easing grazing pressure on vegetation and reduce its degradation, as reported from the Tehuacán-Cuicatlán Valley in Mexico (Baraza et al., 2010) or the northern mountainous areas of Oman (Schlecht et al., 2009).

8. Weed control

The impacts of noxious weed invasion include loss of biodiversity (Tyser and Key, 1988), increased soil erosion (Lacey et al., 1989), loss of wildlife habitat (Wallace et al., 1992) or reductions of the carrying capacity for domestic livestock (Hein and Miller, 1992). The role of goats as biological control agents is becoming more important due to environmental concerns and elevated costs of other control methods such as mechanical cutting or herbicide application (Magadela et al., 1995), as already mentioned for firebreaks. According to Launchbaugh (2006), the problem with invasive weeds in the Western USA resulted from declining small ruminant numbers during the past 20 years, as many of the worst weeds, like leafy spurge (*Euphorbia esula*), yellow starthistle (*Centaurea solstitialis*) and spotted knapweed (*Centaurea maculosa*) are palatable and nutritious for them. The goat eradication in Round Island (Mauritius), Carnac Island (Australia) and Channel Islands (USA) also led to long-term increasing influence by undesirable exotic plants (Abbott et al., 2000; Bullock et al., 2002; Halvorson et al., 1988). The suitability of goats for weed control involves numerous species (Table 2). They are useful to maintain pastures through the control of dock (*Rumex obtusifolius*) in Japan (Sakanoue et al., 1995), gorse (*Ulex europaeus* or *Ulex gallii*) in New Zealand (Radcliffe, 1985), Tasmanian midlands (Harradine and Jones, 1985) or Spain (Sineiro, 1982; Celaya et al., 2007), soft rush (*Juncus effusus*) in Great Britain (Merchant, 1993), spotted knapweed (Williams and Prather, 2006) and yellow starthistle (Goehring et al., 2010) in Idaho, or for general bush clearing in Texas (Merrill and Taylor, 1981) and California (Adams and Hughes, 1977). They have also been used to control invasive woody plants such as juniper (*Juniperus* sp.) and mesquite (*Prosopis glandulosa*) on rangelands in SW USA (Brock, 1988; Hanselka and Paschal, 1992) and to renovate pastures dominated by herbaceous weeds, brush and multiflora rose bushes imported from Japan in the Appalachian region (Luginbuhl et al., 1999). Together with acetic acid (vinegar), goat grazing seemed as cost effective as single application herbicides to control certain weed species while posing fewer concerns over impacts on human and ecosystem health in northern Canadian communities (Booth and Skelton, 2009). Compared to other livestock species, goats control spiny or poisonous brush weeds like gorse or poison ivy (*Toxicodendron radicans*) better than sheep or cattle (Popay and Field, 1996; Celaya et al., 2007). They also control leafy spurge (Lym et al., 1997) better than the other livestock species and, because of their lower dietary overlap with cattle, they might be

preferred by cattle rangers over sheep for their mixed herds to reduce the weed enough to allow cattle grazing (Lym, 1998; Olsen and Hansen, 1977). In perennial pastures infested with nodding thistle (*Carduus nutans*), goats selectively consumed thistle capitula throughout the flowering period and controlled its spread (Holst et al., 2004). All these works on weed control by goat grazing reveal their potential for mixed grazing with other herbivores due to the high complementary on different pastures.

9. Seed dispersers

Livestock appears to be one of the primary vectors of seed dispersal with positive or negative consequences attending to several factors. In the case of goats, the rate of passage and viability of the noxious weed seeds they consume are low (Launchbaugh, 2006). They also preferentially consume seeds in an immature stage and prefer seedling stems, reducing the spread and perpetuation of weeds by seed (Hart, 2001). Goats appear to be poor dispersers of invasive plants such as mesquite, but also of non-invasive ones, as it occurs with different fodder grasses in Mongolian rangelands (Bläß et al., 2010). On the contrary, they acted as efficient seed dispersers of diverse plant species in the Biosphere Reserve of the Tehuacán-Cuicatlán Valley (Baraza and Valiente-Banuet, 2008) but also of certain leguminous shrubs native of the Mediterranean Basin which are considered useful plants for recovering degraded shrublands (Robles et al., 2005). Mancilla-Leytón et al. (2011) observed that the number of seeds retrieved by goats differed between the four common Mediterranean shrub species they were fed with, and it should be taken into account for the design of future management plans which aim either to prevent shrub invasion of undesired plants, or to spread populations of desirable shrub species.

10. Landscape conservation

In many regions the evolution of landscapes has been intimately related with animal activity, and landscape management addresses various situations where grazing animals may provide services to the environment. It includes grazing “social fallows” and any other uncultivated or waste lands in order to control succession and to provide easy access for the public for recreation and leisure. The restoration of traditional landscapes like permanent pastures in Haut-Verdon, France (Decaix, 1994), or rural landscapes in Extremadura, Spain (Blázquez et al., 1995; Gallego et al., 1995) was successfully done through the use of small ruminants, which contribute with their grazing besides being a part of the local culture, providing entertainment and special animal products for tourists. Nevertheless, the promotion of extensification and fallowing in western European countries as a consequence of EU policy has resulted in increasing areas of uncultivated land which threaten the maintenance of the landscape if proper national/regional policies are not adopted (Martyniuk and Olech, 1997).

Table 2

Summary of plant species considered weeds and which are palatable to goats.

Scientific name
Acacia aneura
Acacia escelsa
Acacia farnesiana
Acacia karoo
Acacia mearmsii
Acacia nilotica
Acacia homalophylla
Acacia paradoxa
Acaena ovina
Acetosa sagittata
Acroptilon repens
Aesculus spp.
Agapanthus spp.
Agave spp.
Agerantina adenophora
Ageratum houstonianum
Ageratum riparia
Agrostis avenacea
Ailanthus altissima
Alhagi pseudalhagi
Allium triquetrum
Allium vineale
Alternanthera pungens
Amaranthus spp.
Amaryllis belladonna
Ambrosia artemisiifolia
Ambrosia confertiflora
Ambrosia psilostachya
Ambrosia tenuifolia
Ammi majus
Amsinckia spp.
Andropogon virginicus
Angophora spp.
Anredera cordifolia
Amthemiscotula
Apophyllum anomalum
Araujia hortorum
Arctotheca calendula
Aristida spp.
Atalaya hemiglauca
Atriplex spp.
Avena spp.
Baccharis halimifolia
Bambusa spp.
Bidens spp.
Brachychiton populneus
Brassica tourneforti
Bromus diandrus
Bromus tectorum
Bryophyllum spp.
Bursaria spinosa
Buxus spp.
Calandrina spp.
Calicotome spinosa
Callitris columellaris
Callitris endlicheri
Calotropis procera
Caninia quinquefaria
Cannabis sativa
Capparis mitchellii
Capsella bursa-pastoris
Cardaria draba
Cardiospermum spp.
Carduus nutans
Carduus pycnocephalus
Carex spp.
Carthamus lanatus
Carthamus leucocaulos
Cassia artemisioides

Table 2 (Continued)

Cassia barclayana
Cassia floribunda
Cassia obtusifolia
Cassia occidentalis
Cassinia arcuata
Cassinia quinquefaria
Casuaria cristata
Cenchrus echinatus
Centaurea biebersteinii
Centaurea diffusa
Centaurea maculosa
Centaurea melitensis
Centaurea nigra
Centaurea solstitialis
Cestrum spp.
Chamaecytisus proliferus
Cheilanthes spp.
Chenopodium album
Chenopodium nitriacem
Chloris spp.
Chondrilla juncea
Chrysanthemoides monilifera
Cichorium intybus
Cineraria lyrata
Cinnamomum camphora
Cirsium arvense
Cirsium palustre
Cirsium vulgare
Citrullus colocynthis
Citrullus lanatus
Codonocarpus spp.
Coleogyne ramosissima
Conium maculatum
Convolvulus arvensis
Conyza albida
Coreopsis lanceolata
Cortaderia spp.
Cotoneaster spp.
Cotula australis
Craspedia spp.
Crataegus spp.
Crotalaria spp.
Cryptostegia grandiflora
Cucumis myriocarpus
Cuscuta spp.
Cycas spp.
Cynara cardunculus
Cynodon dactylon
Cynoglossum officinale
Cyperus aromaticus
Cyperus rotundus
Cytisus scoparius
Danthonia spp.
Diplotaxis tenuifolia
Discaria toumatou
Ditrichia graveolens
Dodonaea attenuata
Dodonaea viscosa
Echium plantagineum
Echium vulgare
Eleusine indica
Emex australis
Equisetum arvense
Equisetum pratense
Eragrostis australasia
Eragrostis curvula
Eremophila longifolia
Eremophila mitchellii
Erodium spp.
Erythrina spp.
Erythroxylum coca
Eucalyptus albens

Table 2 (Continued)

Eucalyptus cladocalyx
Eucalyptus melliodora
Eucalyptus polyanthemus
Eucalyptus populnea
Euphorbia esula
Foeniculum vulgare
Froelichia floridana
Fragaria virginiana
Galenia pubescens
Gastrolobium spp.
Gaura parviflora
Geijera parviflora
Genista linifolia
Genista monspessulana
Gleditsia triacanthos
Gnaphalium spp.
Gomphrena globosa
Gorteria personata
Haloragis aspera
Heliotropium europaeum
Hedera spp.
Heterodendrum oleifolium
Hibiscus trionum
Hieracium spp.
Hirschfeldia incana
Homeria spp.
Hordeum leporinum
Hydrangea spp.
Hyparrhenia hirta
Hypericum androsaemum
Hypericum tetrapterum
Hypericum triquetrifolium
Hypochaeris radicata
Ilex spp.
Imperata cylindrica
Ipomoea lonchophylla
Ipomoea plebeia
Ipomoea purpurea
Iva axillaris
Juncus acutus
Juncus effusus
Juncus gregiflorus
Juniperus coahuilensis
Juniperus virginiana
Juniperus spp.
Laburnum spp.
Lactuca serriola
Lantana camara
Laurel spp.
Lavandula stoechas
Lepidium latifolium
Leucaena spp.
Leucanthemum vulgare
Ligustrum lucidum
Ligustrum sinense
Lolium spp.
Lomandra longifolia
Lonicera japonica
Lycium ferocissimum
Maclura pomifera
Maireana spp.
Malva parsiflora
Marvella leprosa
Marrubium vulgare
Medicago falcata
Medicago sativa
Melia azedarach
Melilotus albus
Mentha spp.
Muehlenbeckia adpressa
Muehlenbeckia cunninghamii
Muhlenbergia schreberi

Table 2 (Continued)

Myagrimum perfoliatum
Myoporum spp.
Nassella neesiana
Nassella trichotoma
Nicandra physalodes
Nicotiana glauca
Olea europaea
Olearia elliptica
Onopordum acanthium
Onopordum acaulon
Onopordum illyricum
Opuntia inermis
Opuntia stricta
Owenia acidula
Oxalis latifolia
Oxalis pes-caprae
Paraver seminiferum
Parkinsonia aculeata
Parthenium hysterophorus
Pennisetum clandestinum
Pennisetum acourum
Pennisetum villosum
Pentzia suffruticosa
Pinus halepensis
Persicaria spp.
Phalaris minor
Pharagmites australis
Phyla canescens
Physalis virginiana
Physalis viscosa
Phytolacca octandra
Pinus halepensis
Pinus radiata
Pinus spp.
Poa labillardieri
Polygonum aviculare
Polypogon monspeliensis
Portulaca oleracea
Proboscidea louisianica
Prosopis cineraria
Prosopis glandulosa
Prosopis juliflora
Prunus persica
Pteridium esculentum
Pueraria montana
Pyracantha spp.
Quercus havardii
Quercus marilandica
Ranunculus spp.
Raphanus raphanistrum
Rapistrum rugosum
Reseda spp.
Rhododendron spp.
Ricinus communis
Robinia pseudoacacia
Romulea rosea
Rosa canina
Rosa micrantha
Rosa multiflora
Rosa rubiginosa
Rubus discolor
Rubus fruticosus agg.
Rubus oklahomas
Rumex acetosella
Rumex brownii
Rumex obtusifolius
Rumex brownii
Rumex conglomeratus
Rumex crispus
Rumex obtusifolius
Rumex pulcher
Salsola kali

Table 2 (Continued)

<i>Salvia reflexa</i>
<i>Schinus</i> spp.
<i>Sclerolaena birchii</i>
<i>Sclerolaena muricata</i>
<i>Scolymus hispanicus</i>
<i>Senecio jacobaea</i>
<i>Senecio madagascariensis</i>
<i>Senecio pterophorus</i>
<i>Senecio quadridentatus</i>
<i>Senecio vulgaris</i>
<i>Senna artemisioides</i>
<i>Senna barclayana</i>
<i>Sericea lespedeza</i>
<i>Sida acuta</i>
<i>Sida cordifolia</i>
<i>Sida rhombifolia</i>
<i>Silybum marianum</i>
<i>Sisymbrium officinale</i>
<i>Solanum carolinense</i>
<i>Solanum elaeagnifolium</i>
<i>Solanum mauritanium</i>
<i>Solanum nigrum</i>
<i>Soliva pterosperma</i>
<i>Sonchus</i> spp.
<i>Sorghum halepense</i>
<i>Sporobolus caroli</i>
<i>Sporobolus indicus</i>
<i>Sporobolus pyramidalis</i>
<i>Stachys arvensis</i>
<i>Stypantra glauca</i>
<i>Stevia eupatoria</i>
<i>Stipa caudata</i>
<i>Swainsona</i> spp.
<i>Syncarpia glomulifera</i>
<i>Taeniatherum caput-medusae</i>
<i>Tagetes minuta</i>
<i>Tamarix ramosissima</i>
<i>Taraxacum officinale</i>
<i>Thunbergia grandiflora</i>
<i>Toxicodendron diversilobum</i>
<i>Toxicodendron vernix</i>
<i>Toxicodendron radicans</i>
<i>Toxicodendron succedaneum</i>
<i>Tribulus terrestris</i>
<i>Trifolium</i> spp.
<i>Typha</i> spp.
<i>Ulex europaeus</i>
<i>Ulex gallii</i>
<i>Ulmus</i> spp.
<i>Urochloa panicoides</i>
<i>Urtica incisa</i>
<i>Ventilago viminalis</i>
<i>Verbascum thapsus</i>
<i>Verbena tenuisecta</i>
<i>Verbesina encelioides</i>
<i>Watsonia bulbifera</i>
<i>Xanthium occidentale</i>
<i>Xanthium orientale</i>
<i>Xanthium spinosum</i>

Source: Popay and Field (1996), Simmonds et al. (2000), and Launchbaugh (2006).

11. Climate change, water use and global warming

Climate change and future water shortages are some of the most serious challenges facing the human race. The relevance of goats rises during periods of cyclical and unpredictable feed shortages, such as droughts. For example, the replacement of cattle by dromedaries and of sheep

by goats in the Sahel followed the droughts of the 1980s (Hoffmann, 2010). After severe droughts, goat's populations recover faster than other ruminants due to factors such as their shorter gestation period or their lower mortality rate, providing food (e.g. milk) even before other resources (e.g. cereals) are available (Wilson, 1991).

The livestock sector demands 8% of the global human water use, mostly for the irrigation of feedcrops (Steinfeld et al., 2006). For example, 500 L of water is needed in Kenya to produce \$2 income from growing grain whereas it takes 4 L of water to produce \$2 income from goat milk (Peacock and Sherman, 2010).

Livestock accounts for about 37% of all anthropogenic methane emissions related to the global warming (Steinfeld et al., 2006), and it is greatly related to the expansion of beef production (Peacock and Sherman, 2010). Furthermore, most of the emissions from manure derive from pigs, beef cattle feedlots and dairy farms, where manure is stored in anaerobic conditions (Steinfeld et al., 2006; FAO, 2009), which is seldom the case in goat systems.

12. Goats as a feed resource for other species

Small ruminants are some of the major components of the diet of certain carnivores and scavengers. Domestic goats made up to 43% of the total depredation cases of the Eurasian lynx (*Lynx lynx* Linnaeus 1958), listed as "near threatened" by the International Union for Conservation of Nature (IUCN) in Pakistan (Din and Nawaz, 2010). They represented around 32% of the prey for wild predators in India, mainly by the Tibetan wolf (*Canis lupus chanco* Gray, 1863), "vulnerable" according to the IUCN, and the snow leopard (*Uncia uncia* (Schreber, 1775)), a "highly endangered" species (Namgail et al., 2007). Domestic animals can also be an important target for wolves, a carnivore which is increasing in numbers in both Europe and North America and is beginning to reoccupy semi-wilderness and agricultural lands (Boitani, 2003). Livestock predation has caused human-wildlife conflicts in many places, especially in the Alpine zones of the world where livestock rearing is the major source of income (Din and Nawaz, 2010).

In Picos de Europa National Park (northern Spain), domestic small ruminants have been a feed resource for wolves and several species of scavenger birds such as bearded vultures (*Gypaetus barbatus* Linnaeus, 1758), Eurasian griffon vultures (*Gyps fulvus* Hablizl, 1783) and Egyptian vultures (*Neophron percnopterus* Linnaeus, 1758). They are threatened birds in Europe (Annex I, EU Wild Birds Directive 79/409/EEC, Appendix II of the Bern Convention, Bonn Convention and CITES) which require conservation priorities based on favouring extensive livestock practices. In the case of Eurasian griffon and Egyptian vulture, there is a clear relationship between the available biomass of sheep and goats and the density of these species (Margalida et al., 2007). Furthermore, the reintroduction program of the bearded vulture in northern Spain greatly depends on whether mountainous pastures and extensive livestock grazing (of small ruminants) are preserved (Báguena et al., 2007). Finally, a contradictory situation occurs in the Canary Islands (Spain), where introduced goats are responsible for the near-extinction of some endemic plants,

whereas their populations support native scavengers and predators which include three endangered endemic sub-species of birds (Gangoso et al., 2006).

13. Future perspectives

The goat systems will have to face different global trends from the socio-economic and environmental points of view. They will have to respond to the increasing demand of a growing population in developing countries, who have aspirations and dietary choices closer to the developed countries, but also to maintain sustainable systems under new scenarios influenced by the global warming and the environmental degradation, while coping with the rising costs of non-renewable energy or grain (Peacock and Sherman, 2010). In addition, the developing and the developed areas have to confront different difficulties. The poorer areas require an improvement of the social and political conditions to ensure a long term sustainable application of environmentally friendly management strategies. For example, the restoration of the cashmere trade in Afghanistan after years of war and prolonged droughts could contribute to the recovery of the economy while minimizing adverse environmental consequences, only if economic and socio-political decisions in the future attend to reasonable grazing strategies. Mongolia and China had responded to an increasing market demand for cashmere with increasing government subsidies and goat numbers to a point beyond the carrying capacity of rangelands, so desertification emerged and the viability of the enterprises dropped (Osnos, 2006), exemplifying how incorrect and irrational policy decisions can affect environmental sustainability.

Adequate strategies to provide both environmental and social and economical benefits are known in other areas. Improved grazing and feeding schemes are recommended in northern mountainous areas of Oman to reduce the pressure on the natural vegetation, taking also into account local property rights, herding skills and the potential recovery of the vegetation (Schlecht et al., 2009). Similarly, Baraza et al. (2010) propose goat management strategies in the Mexican Biosphere Reserve of the Tehuacán-Cuicatlán Valley to improve the quality of life for the people living in the reserve without increasing anthropogenic environmental impact.

Within the developed countries, sustainable development based on environmental criteria is on the agenda of the most influential European governments and it has clearly carried weight on EU agricultural policy. Nevertheless, the income provided by ecologically sustainable low-input goat systems may be insufficient to sustain the next generation, so there is a greater risk of becoming marginalized (e.g. de Rancourt et al., 2006; Dýrmondsson, 2006; Peacock and Sherman, 2010). In addition, further increases of the productivity in certain areas are limited by the carrying capacity of the land, nutritive quality of the vegetation and sustainability, environmental protection, animal health, animal welfare or product quality (Dýrmondsson, 2006). Nevertheless, goat systems might have a chance in new niche markets that demand high

quality products such as cheese, yogurt, goat-milk soap, and high quality textile fibre, which may also help to maintain traditional farming in harmony with the needs of landscapes and habitat conservation (Boyazoglu and Morand-Fehr, 2001; Lu et al., 2010). In addition, small ruminant management should also be compatible with recreational, cultural, or scientific purposes (Ronchi and Nardone, 2003). The organic goat production might achieve a great part of these goals, as it can protect the environment, improve animal welfare and sustain rural live styles. This sector has increased substantially during the past decade and its demand is expected to continue growing at a rate of 10–30% per year. This activity is especially promising to increase the income of goat producers operating in marginal lands as results of incomes from externalities, but it still requires more research on alternative nutrition and alternative treatments for disease prevention (Lu et al., 2010).

14. Concluding remarks

This paper has reviewed some of the most important issues concerning the environmental impacts of goat grazing worldwide and some of the main challenges that are to be confronted in a politically, socioeconomically and climatologically changing world where sustainable management strategies should be encouraged. The urgency of confronting these challenges has been highlighted during the IGAs' Meeting, (Dubeuf, 2011) or in the Global Plan of Action for Animal Genetic Resources (FAO, 2007), but the current knowledge is not summarized for many issues although it could provide basic guidelines for future projects.

Most of the environmentally harmful effects of goat grazing are linked to improper management practices and various examples of how it can be a powerful and environmentally friendly tool if managed adequately to the environmental and socioeconomic context of each area are mentioned.

More efforts to preserve and study the genetic heritage associated to goat breeds are needed, starting from the agricultural policy makers at both national and international level. Such efforts should run in parallel with rural development, especially in remote areas where rural communities endure adverse conditions managing for their survival an outstanding reservoir of livestock diversity mostly unknown to us.

One of the most effective tools to guarantee the persistence of any management or conservation program relies on the participation of scientists, policy makers, rangeland managers and local communities or farmers. In full agreement with Dubeuf (2011), local know-how has to be considered a valuable tool to be incorporated in new methodologies which will be enriched with the academic knowledge. The results of this fusion must be disseminated on two ways, to the scientist community and to the local communities to help them to manage their livestock in a sustainable way. In summary, the information from different sources must be put together and participation and education should be prioritized.

The multidisciplinary approach should be extended to the scientific community when analysing the implications of management strategies as they tend to be focused either on environmental, socioeconomical or production perspectives, while they are rarely considered simultaneously and that would be highly desirable to define sustainable strategies. This would allow meeting those goals of the Interlaken Convention which considered necessary a co-management of the various components of biological diversity, including soils, crops, rangelands and pastures, fodder crops and wildlife (FAO, 2007).

One of the strategies which have already proved to be efficient is the management of mixed flocks of goats with other livestock under moderate grazing pressure. It will contribute to the diversification of the production and to enhance animal performance of other domestic herbivores, landscape biodiversity by reducing fire risk and the economic conditions in marginal areas as suggested by Osoro et al. (1999).

Low input goat systems which provide high quality products and organic goat production are among the best options to develop sustainable management alternatives which are also environmentally friendly.

As a summary, this manuscript highlights that the consideration of goats in general as harmful for the environment is erroneous. Numerous studies prove that moderate grazing pressures can be compatible with high levels of biodiversity and can provide externalities which support population, whereas high grazing pressures can be valuable tools for weed control. The conservation of the genetic heritage has multiple implications as many autochthonous breeds better adapted to resist pathogens than exotic ones are threatened together with the local communities which manage them despite their relevance as a precious reservoir of biodiversity to confront the impending climatological and socioeconomical challenges.

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