Annals of Arid Zone 39(3): 305-332, 2000

The Role of Small Ruminants in Arid Zone Environments: A Review of Research Perspectives

G. Oba[1], E. Post[2], N.C. Stenseth[3] and W.J. Lusigi[4]

[1] *Noragric, Centre for International Environment and Development Studies, Agricultural University of Norway, PO Box 5001, N-1432 Ås, Norway*

[2] *Department of Biology, The Pennsylvania State University, 208 Mueller Lab, University Park, PA 16802 US*

[3] *University of Oslo, Department of Biology, Division of Zoology, PO 1050 Blindern N-0316 Oslo, Norway*

[4] *The World Bank, Washington, DC 20433*

Abstract: This article provides an overview on small ruminant-environment relations in the arid zones world-wide. We review small ruminant-environment relations under extensive, intensive and very intensive land use systems. The extensive system is common in traditional pastoral production, the intensive in commercial ranching and very intensive in crop-livestock systems. The role of small ruminants in plant community dynamics and productivity of the arid zones under these systems of production is a matter of considerable controversy. Traditionally, small ruminants have been considered to have negative effects on the environment. These views grew out of equilibrium grazing models (i.e., succession, carrying capacity) that associate stocking rates with land degradation. Alternatively, non-equilibrium grazing models (i.e., state-and-transition, rangeland health, thresholds and climate-plant-herbivore interaction) assert that unpredictable climatic events exert a greater influence on the dynamics of arid zone rangelands than do stocking rates. Here, we review extensive evidence to show that equilibrium grazing models heavily influenced grazing studies that linked small ruminants to land degradation in the arid zone. The majority of the short-term studies reviewed failed to separate the effects of climatic variability from those of grazing. By contrast, the long-term grazing studies (over 5 years) consistently revealed that fluctuating climatic conditions controlled production and vegetation cover in the arid zones (i.e., in accordance with non-equilibrium grazing models). Moreover, long-term studies documented that small ruminants promoted ecosystem stability by: 1) controlling weeds, 2) constraining bush encroachment; and 3) reducing the risk of fires. Furthermore, small ruminants contribute to ecosystem functioning by mediating the distribution of seeds and soil nutrients. Results from long-term grazing experiments on stocking rates are therefore not in agreement with the preconceived negative role of small ruminants in the arid zones. Thus, claims of land degradation by small ruminants that are based on short-term fluctuations in vegetation cover, species composition, species richness and bare soil, and bush cover that do not account for rainfall variability are of highly questionable merit. In the future, research should be undertaken with a long-term perspective, and should incorporate elements of opportunism (as in non-equilibrium grazing models), which, we suggest, will be necessary to capture the spatial and temporal variability of grazing resources in the arid zones. In addition, research in the arid zones should apply non-equilibrium models to properly interpret effects of unpredictable events, such as rainfall, on small ruminant production and their relationship to the environment. The article discusses the implications of small ruminant-environmental research for improving research technology to meet future challenges in the arid zones world-wide.

Key words: Arid zone grazing lands, equilibrium and non-equilibrium grazing models, crop-livestock integration, grazing experiments, land degradation, small ruminant-environment relations, stocking rates.

Throughout the 20th century, selective reviews of literature have created an impression that small ruminants are responsible for land degradation in arid zone grazing lands world-wide. It is estimated that about 70% of the grazing lands are affected (Squires and Glenn, 1995). In sub-Saharan Africa, where land degradation is considered an established fact (Sinclair and Fryxell, 1985; Lamprey, 1983), current estimates put the proportion at 49% (de Haan *et al.*, 1996). Land degradation is mostly blamed on goats (Staples *et al.*, 1942; Harrington, 1981; Al Martin and Huss, 1981; Malechek and Provenza, 1983). Misperception about goats is reinforced by their ability to survive in harsh environments (Silanikove, 2000) and efficiently exploit sparse vegetation (Sikosana and Gambiza, 1994). However, a proper understanding of small ruminant-environment relations in the 21st Century requires informed knowledge.

In this article, we review extensive evidence on the role of small ruminants in arid zone environments. First, we describe research themes that have implications for small ruminant-environment relations, including evidence on landscape level nutritional distribution and forage level nutrient variations. We define small ruminant-environment relations, broadly encompassing all aspects of interactions between animals and their environment through land use. Second, we provide better understanding on misperceptions about the negative role of small ruminants in arid zone environments. The importance of discussing perspectives on small ruminant-environment relations becomes evident when it is considered that the public understanding of the role of small ruminants in the arid zone has been based on anecdotal evidence. We consider research that offered different perspectives on small ruminant-environment relations, including those that assessed changes in environmental quality such as land degradation. We define land degradation as a decline in resource quality that ultimately affects the integrity of the environment including: loss of biodiversity, adverse changes in soil structure, loss of nutrients and increase in density of grazing undesirable plant species, but we do not include temporal changes in vegetation cover and composition due to climatic fluctuations (Oba, Gufu unpublished). We review the small ruminant-environment relations from the perspectives of interactions between climate, range and small stock, grazing control, stocking rates, biological agents, and animal performance and crop-livestock integration systems.

We categorize land use under extensive, intensive and very intensive systems. The extensive systems are associated with traditional land use by nomads and transhumance pastoralists. In recent decades, the latter system of land use has been transformed into semi-intensive sedentary systems in most countries. The intensive system is scale dependent but usually related to commercial ranches. The very intensive systems are associated with crop-livestock production systems in semi-arid and sub-humid zones.

Small Ruminant Production System in the Arid Zone

Small ruminants are among the principal livestock species managed in the arid zone grazing lands (Morand-Fehr and Boyazoglu, 1999). Their world-wide distribution could be explained by their adaptation to arid zone environments (Knights and Garcia, 1997; Lusigi *et al.*, 1986; Devendra and McLeroy, 1982). More than 40% of the sheep and 30% of the goats of the world are found in the arid zones (Harrington, 1981), supplying about 30% of the world's mutton market (Watanabe, 1992; de Haan *et al.,* 1996). In West Asia and North Africa, small ruminants account for 30% of the total income from agricultural production compared to sub-Saharan Africa where they contribute 10 to 15% (Wilson, 1988).

They are managed under extensive systems found in arid and semi-arid rangelands. In Central and Western Asia, Southern America and the Mediterranean regions in general, transhumance between resources at different altitudes is a regular pattern of land use (Squires and Bayan, 1992; Ehlers and Kreutzmann, 2000). In the extensive systems, livestock feed is mainly derived from natural pastures (Steinfeld *et al.,* 1996; Shinde *et al.,* 1998) compared to intensive systems where feed supplements are provided. Sheep and goats in the extensive and very intensive system are managed in mixed or separate herds on the communal grazing lands. Among the mixed herds in the traditional system, sheep:goat ratios approach 1:1.5 (Field, 1986). Herders remove, on daily basis, animals for grazing that are subsequently returned to the base camp at night (Mason, 1980; Farnworth, 1986).

By comparison, in the intensive system, management is on commercial ranches that use modern technology to improve livestock production for the global mutton and wool markets (Turner, 1991). The management system is intensively regulated by market forces. Paddocks stocked at specified animal densities are used and grazed according to fixed schedules depending on the type of grazing system (e.g., yearlong grazing, seasonal grazing, deferred grazing, deferred rotational grazing and rest-rotation grazing). Each paddock is usually supplied with water and salt licks (Heady and Child, 1994). The animals are free ranging as opposed to being herded as in the extensive system. The regions where commercial ranching is important are Australia, Southern Africa, South America and United States.

In the developing countries (e.g., sub-Saharan Africa and Southeast Asia), a greater proportion of small ruminants is managed on crop-livestock integrated systems (Steinfeld *et al.,* 1996) or very intensive systems. As opposed to the commercial ranching system, the crop-livestock system is dominated by non-market driven economies (McIntire *et al.*, 1992). Land space is limited and forage availability from natural pastures is highly constrained. Herds are small, varying from a few individuals of both sheep and goats to a few dozen animals of each species, often mixed with large ruminants and non-ruminants. Management is linked to household food security, use of crop residues, supplemental feed and farm manure for fertilizing croplands. The very intensive production system is also linked to Agroforestry and livestock-plantation production systems (Devendra, 1991).

An Overview of Research on Small Ruminant-environment Relations

The common small ruminant studies are those that deal with animal health, herd dynamics and productivity (These are not covered in the present review). The other studies concerned with small ruminant environment relationships are aimed at simulating the perceived negative role of small ruminants in arid zone environments or promoting systems of resource use that have strong regulatory tendencies. The studies misperceived the traditional system of land use such as pastoralism to be inappropriate and that a controlled system of resource is often preferred. The studies link livestock grazing to range degradation. The majority of them recommend controlled grazing or regulated stocking rates. The views will be discussed in greater detail later in the article; suffice it to mention that livestock grazing in the arid zone, if inappropriate, will have a lasting effect on the environment (Fanning, 1994; Jodha, 1995; Singh, 1995).

The greatest inadequacy of small ruminant-environment research in the arid zone is perhaps to treat livestock impacts without considering the greater overriding influence of the climate. Thus, the interpretation of small ruminant-environment relationship, using only a narrow window of opportunity that corresponds with seasonal variation of forage, but ignores the bigger picture of the effects of long-term climatic variability, has lead to misreading of the livestock-environment relationships (Turner, 1993). Indeed, despite the misperception that small ruminants contribute to land degradation (see later sections), there are only a few studies that directly investigated the problem. The studies assumed that if small ruminants are removed from the degraded land for, say, five years (the main treatment), and the response compared with areas that are continuously grazed (control), the impact may be assessed. This is done by comparing changes in plant growth, cover, browse production, twig growth and seedling regeneration (e.g., Oba, 1992, 1998; Oba and Post, 1999). Other studies related effects of regulating stocking rates on plant species composition and range productivity, plant species richness and changes in herbaceous cover (e.g., Pour and Ejtehadi, 1997).

Landscape level-grazing interactions in the extensive grazing systems

Among the studies, those that focused on relationships between grazing and landscape change are important (e.g., Posse *et al.*, 1996; Cammeraat and Imeson, 1999). Other studies integrated landscape processes with vegetation change linked to livestock grazing. The studies showed that exclusion of grazing from landscape would disrupt spatial patterns of vegetation, which ultimately have an adverse influence on ecosystem functions such as water yields, biodiversity and community production (McNaughton, 1979; Hearn, 1995; Oba *et al.*, 2000a). The research that links small ruminants grazing to the proper functioning of ecosystems showed (e.g., in

Mediterranean ecosystems) that in the absence of grazing, plant species that are tolerant to grazing disappeared, leading to a decline in biodiversity (Bartolome *et al.*, 2000). By contrast, other studies showed that protecting the environment from grazers promoted plant biodiversity (Shaltout *et al.*, 1996). However, the latter studies often failed to provide information on the effects of grazing as opposed to grazing exclusion on biodiversity conservation.

Nutritional demands in the extensive and intensive grazing systems

Among the studies that improved knowledge of the role of small ruminants in arid zone environment are those that used mixed livestock and wildlife species in an experimental portfolio. In both intensive commercial ranches and extensive traditional grazing systems, combining goats, sheep, cattle and wild ungulates showed increased economic returns per unit of land compared to managing single species (e.g., del Pozo *et al.*, 1998). The studies that investigated the complementary role of grazing by wild ungulates such as deer and goats (e.g., Etzenhouser-Mathew *et al.*, 1998) and mixed herds of domesticated ruminants showed that the conditions of rangelands are improved.

The studies are crucial in extensive grazing systems where mixed livestock species such as camels, cattle, sheep, goats and donkeys utilized rangelands (Schwartz, 1988). Ecologists could apportion grazing resources to each species so as to determine optimal levels of grazing without degrading the range by determining dry matter intake and by considering relative animal biomass (Lusigi *et al.*, 1986; Nolan *et al.*, 1999). The limitation of the studies was that they seldom evaluated environmental consequences of grazing interactions (the exception being in wildlife studies where resource partitioning has been well established).

However, a few others linked small ruminant grazing to habitat alteration for avifauna in which loss of canopy cover was shown to increase rates of predation (e.g., Joubert and Ryan, 1999; Priddel and Wheeler, 1999). Others investigated interactions of small ruminants and the marsupials in terms of production performance (Edwards *et al.*, 1996). However, the most informative of all the studies are those that used grazing behavior of small ruminants (the ideas borrowed from wildlife studies) to improve knowledge of their response to spatial changes in feed distribution at landscape scales (see review by Vavra and Ganskopp, 1998).

Landscapes create heterogeneity in animal feed and individual landscapes have been considered as grazing resources, thereby giving them ratings in terms of grazing values (Ash *et al.*, 1995). The grazing value ratings helped managers to decide on periods of the year when grazing is optimal (Oba *et al.*, 2000b). Shifts in feed distribution between landscape patches and within vegetation strata influenced patterns and distribution of feeding that may be related to resource quality. The studies have greater relevance to the extensive and intensive grazing systems (Orihuela and Solano, 1999). However, less common but important are the studies that evaluated grazing interactions between sheep and goats and showed that selective use of forage by goats made more feed available to the sheep.

The studies reviewed showed that sheep and goats have different feeding strategies (Malechek and Provenza, 1983). Sheep, in contrast to goats, feed on herbaceous vegetation and browse (Devendra and McLeroy, 1982; Schwartz, 1988; Posse *et al.*, 1996). The diet composition of sheep typically comprises 26% browses and 38% herbs in the wet season, compared to 45% and 57%, respectively, for goats (Field, 1979). Goats consume a wide-range of plant species (Obeid and Mahmoud, 1971; Knipe, 1983; Al Martin and Huss, 1981; Becker and Lohrmann, 1992; Lu, 1988; Grünwaldt *et al.*, 1994; Fajemisin *et al.*, 1996; Silanikove, 2000). Most of their diet is dominated by browse from trees and shrubs (Boudet and Toutain, 1980; Lu, 1988; Oba, 1998; Oba and Post, 1999). In the Mediterranean areas of Europe, Africa and the Middle East, browse accounts for 35 to 40% of the feed of goats, while in tropical Africa it accounts for <20% (Le Houerou, 1980). Goats are capable of switching from one source of browse to another when main browse sources decline (Oba, 1998; Oba and Post, 1999). Moreover, their ability to travel long distances to find food makes them superior survivors in the arid zone compared to sheep (Mousa and El Kalifa, 1992; Knights and Garcia, 1997).

Nutritional demands in crop-livestock systems

On a broader scale, regional analyses of feed resources were linked to climatic variability and nutritional preferences by different ruminants (Coppock *et al.*, 1986a,b). By contrast, in the intensive systems, the studies were aimed at promoting feed banks as contingency against shortages during the dry season or winter months (Nsahlai *et al.*, 1998). Most of the studies dealing with nutritive evaluations were those concerned with feed resources in crop and agroforestry-livestock systems (see review by Nasahlai *et al.*, 1998). The studies were concerned with evaluation of feed acceptance and feed quality in relation to animal body performance. Animal productive performance such as changes in body weights, milk yield, wool production and in a few cases dressed mutton, were evaluated (Hamadeh *et al.*, 1996; Rommey *et al.*, 1996; Mishra *et al.*, 1997; Ahmed and Nour, 1997; Rai *et al.*, 1998; Rasool *et al.*, 1998; Reddy and Reddy, 1999; Ramirez, 1999; Omar *et al.*, 1999; Dutta *et al.*, 2000). Similarly, in agroforestry-related research, nutritional evaluation of browse resources was linked to small ruminant performance (Ormazabal, 1991; Roothaert and Paterson, 1997; Shahjalal and Topps, 2000). A few of the studies related nutritional variability, animal genetic performance and production of mohair and cashmere (e.g., McGregor, 1998). The studies did not, however, link small ruminants to environmental change in crop-livestock systems with the exception of a few on crop residue grazing systems that provided linkages between crop-rangeland production systems (cf. Hirata *et al.*, 1998).

Small Ruminants and Land Degradation

Positive environmental roles of small ruminants in the arid zone have often been ignored, while negative views dominated the media. Furthermore, we shall suggest that land degradation analysis has been to apportion blame to pastoralists, farmers and livestock, especially goats. Misperceptions about livestock in general, and goats in particular, have adversely influenced livestock development policy in the developing countries. Such misperceptions as overgrazing in arid lands and subsequent recommendations of de-stocking were prompted by equilibrium grazing models (such as succession and carrying capacity), which postulate a strong relationship between range productivity and animal density. Due to the ceiling placed on carrying capacity of the range (i.e., total animal biomass the range is capable of supporting without showing signs of degradation), stocking rates beyond the threshold are presumed to result in degradation as greater animal numbers compete for limited grazing resources (Caughley, 1979). Inherent in the equilibrium models is predictability in the system that allows managers to exploit rangelands by adjusting animal population against the available plant biomass to avoid population crashes (Heady and Child, 1994).

The non-equilibrium grazing models (such as state-and-transition, rangeland health and thresholds, and climate-plant herbivore interactions), by contrast, suggest that conditions in arid environments, which are under a strong influence of stochastic weather, cannot be predicted. According to the non-equilibrium grazing models, climate is the main driving force in the arid zones, influencing episodic fluctuations in animal feed and constraining animal numbers below plant production; hence, animal populations are forced to track the fluctuating range production (Sandford, 1983; Ellis and Swift, 1988). The two opposing grazing models and their ecological perspectives have been reviewed (Ellis and Swift, 1988; Westoby *et al*., 1989; Friedel, 1991; Laycock, 1991; George *et al.,* 1992; Behnke and Scoones, 1993; NCR, 1994; Dodd, 1994; Oba *et al.,* 2000a), but suffice it to add that whereas in the past the equilibrium grazing models influenced range development thinking, the failed projects, especially in developing countries, have forced scientists and decision makers to rethink (see Behnke and Scoones, 1993; Oba *et al.,* 2000a). We reviewed evidence in support of the non-equilibrium grazing models that show that the arid zones are highly resilient. This is reflected by production fluctuations from year to year and rapid recovery on the return of above-average rainfall. The inherent resilience of the arid zones provides an improved understanding of the impact on the environment over the prevailing views that suggest equilibrium tendencies between grazers and plants.

Interaction between Climate, Range and Small Ruminants

The common characteristics of the arid zones are the great annual variability of rainfall and recurrent drought. Intra-annual rainfall variability may exceed yearly variability by a large margin. Thus, soil moisture and rainfall are the main driving factors of the ecosystems. The year-to-year rainfall fluctuations induce a high variability in plant production. Land use in response to the fluctuating plant community production is by livestock grazing, which is highly opportunistic. The arid zone maintains a high diversity of landscapes and discloses diverse vegetation communities despite the harsh climatic conditions. Understanding interactions between climate, range and effects of grazing on the environment will be more rewarding than trying to separate out the role of small ruminants in arid zone environments (Oba *et al.*, 2000a). Interactions between climate and range production provides a clear picture of yearly variation (Lamprey, 1978; Breman and de Wit, 1983; Gutman and Seligman, 1995), and changes in plant species composition and richness (Omar, 1991; Oba *et al.,* 2000a). For the same reason, vegetation cover and production are highly dynamic (Breman and de Wit, 1983) with or without grazing (Ickowicz and Dassering, 1995; Hiernaux *et al.*, 1994; O'connor and Roux, 1995; Allen *et al.,* 1995). In the deserts of Kuwait, Omar (1991) showed that high variation in vegetation cover and composition in protected areas was influenced by rainfall variability. Similarly, in Australia, changes in cover and density of *Atriplex* spp. grazed by cattle, sheep and kangaroos were influenced more by rainfall variability than by grazing (Eldridge *et al.,* 1990). Yet, because of the rarity of regeneration of the *Atriplex* bush, sheep grazing induced greater mortality than was evident in the absence of grazing (Crisp, 1978). In North African rangelands, sheep and goat grazing did not reduce range production alone, but the decline was mostly related to rainfall variation (Gintzburger, 1986).

Small Ruminant Grazing and Vegetation Change

The effects of grazing are most commonly investigated by comparing centres of intensive use to those of less use (Thurow and Hussein, 1989; Lamprey and Yussuf, 1981). Environmental impact is assessed in terms of changes in vegetation cover, bare ground, litter, soil erosion, soil bulk density, and nutrient distribution (Oba, 1992; Harrison and Shackleton, 1999; Turner, 1998). Among the studies we reviewed, only a few are sufficiently long-term (i.e., >5 years) to reliably provide an understanding of the role of small ruminants in the arid zone. The following case studies illustrate the points, bearing in mind the conflicting viewpoints between the equilibrium and non-equilibrium grazing models that inherently influence interpretations of grazing studies in the arid zones. The majority of the studies are based on assumptions of equilibrium grazing models, even though responses to treatments reflect the explanations of non-equilibrium models.

For example, in the arid zone rangelands of Somalia, a 2-year rest from grazing failed to increase forage productivity compared to areas where grazing was continuous (Thurow and Hussein, 1989). After protecting pastures against grazing for 18-19 years in southern Arizona, no significant effects on range condition and trends (i.e., direction of the vegetation change) were reported (Chew, 1982). Similarly, a 20-year grazing exclusion of sheep in the Australian Mediterranean region revealed no significant effect on vegetation dynamics (Austin *et al.,* 1981), while sheep grazing control for 59 years in the salt Desert, Great Basin (USA), did not influence plant species diversity (Kitchen and Hall, 1995). Furthermore, in controlled sheep grazing experiments monitored for 17 years, greater herbaceous species richness was recorded in grazed compared to ungrazed paddocks (Thre'mont and Whalley, 1995). In the Mojave Desert (USA), no significant differences in terms of plant diversity and species richness were observed in areas trampled by sheep relative to untrampled areas (Webb and Stielstra, 1979).

Other studies also seemed to support the non-equilibrium grazing models. For example, in Somalia, a greater number of grasses and forbs were found under moderate short duration grazing and exclosure system compared to communal grazing (Thurow and Hussein, 1989; Fig. 1). The study concluded that grazing pressure decreased species diversity of grasses relative to forbs and sedges, which were influenced more by climatic variability than by grazing. No differences in terms of relative basal cover of grass, sedge and forbs along grazing gradients were disclosed, while greater grass basal cover was recorded at the very heavy grazing (79%) than at medium (48%) intensities (Herlocker and Ahmed, unpublished manuscript). Sheep grazing at moderate regimes promoted grasses compared to shifts in species composition and cover that were climate-induced (Hiernaux and Fernandez-Rivera, 1995; Alzërreca-Angelo *et al.*, 1998). In a Botswana study, Skarpe (1990) found comparable total vegetation cover between moderately grazed, ungrazed and heavily grazed pastures, while no relationship was found between shrub cover and sheep grazing intensity in a Patagonian

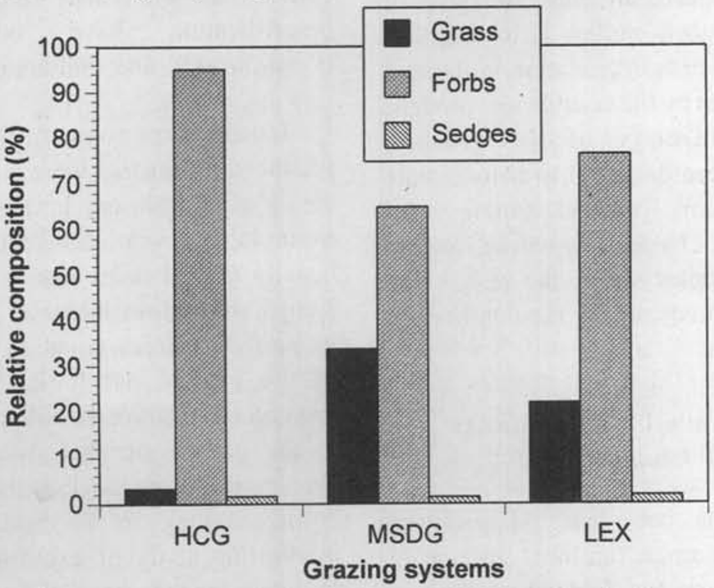


Fig. 1. Relative composition and species diversity of Heavily Communal Grazed pasture (HCG), the moderately grazed short duration pastures (MSG) and the livestock exclosure (LEX) in Somalia (Data from Thurow and Hussein, 1989). The study showed that relative composition of grass was reduced in heavily grazed communal pastures, but the fact that the exclosure composition failed to exceed those at moderate grazing intensity might suggest that grazing might have had a beneficial role. Patterns of rainfall influenced relative composition of forbs and sedges as opposed to grasses.

study (Perelman *et al.*, 1997). In Zimbabwe, no significant difference in plant basal cover was found between paddocks stocked with cattle and goats. However, differences were observed between goat grazing at light, moderate and heavy regimes. Peak biomass production showed that the changes were more related to rainfall variability rather than to grazing control (Sikosana and Gambiza, 1994). These and other studies showed that small ruminants were not responsible for widespread loss of plant biodiversity; instead grazing at moderate levels may be contributing to the persistence of arid zone vegetation (Dalibard, 1995; Perevolotsky and Seligman, 1998; Oba *et al.*, 2000a). Indeed, an important goal of the aforementioned studies is to establish criteria under which degradation in the arid zone is predicted by the equilibrium models. Thus, the majority of the grazing experiments were designed to demonstrate the link between livestock grazing and environmental change. However, as the following examples show, the results are not always as predicted by the equilibrium grazing models.

Role of Small Ruminants in Environmental Change

Investigations of land degradation associated with small ruminant grazing in extensive systems are frequently done in and around centres of livestock concentrations (Obeid and Mahmoud, 1971; Oba, 1998; Oba and Post, 1999). The centres carry animal populations that exceed average stocking densities on the range (Lamprey and Yussuf, 1981; Perevolotsky, 1991). Vegetation cover and density declined near settlements, while they increased with distance from the centre (Fig. 2a,b). In the vicinity of settlements and watering points, overgrazing removed the grass cover compared to the shrub cover, which might be increased (Harrington, 1981; James *et al.*, 1999). However, in southern Australia, reduction of *Atriplex* saltbush in and around water points resulted in soil erosion and expansion of degraded lands (Hunt, 1995). By comparison, in the Mediterranean areas of Europe and the Middle East, where small ruminants have grazed for over two millennia (Noy-Meir and Seligman, 1979; Menjli and Papanastasis, 1995), the cultural landscapes may have been transformed by grazing but claims that the small ruminants caused desertification have been disputed (Perevolotsky and Seligman, 1998).

Indeed, some controlled grazing studies produced results that were inconsistent with views of equilibrium grazing models. For example, a 5-year monitoring study of a heavily grazed range site in north-western Kenya showed an increase in bare ground in protected areas equal to that observed in the grazed paddock. The cover of *Indigofera cliffordiana* Gillet was sustained in the grazed site but disappeared from the ungrazed paddock (Oba, 1992; Oba *et al.*, 2000a). In the Sudan, a 14-year monitoring study of exclosures compared to open grazed areas showed decline in plant cover from 20% to 14% on average (Fig. 3). Bare areas increased in exclosure and open grazed treatments showing that changes in ground cover could not be attributed to livestock grazing alone but presumably to climatic variability (Suliman, 1988). Another feature of environmental impact observed is changes in soil quality.

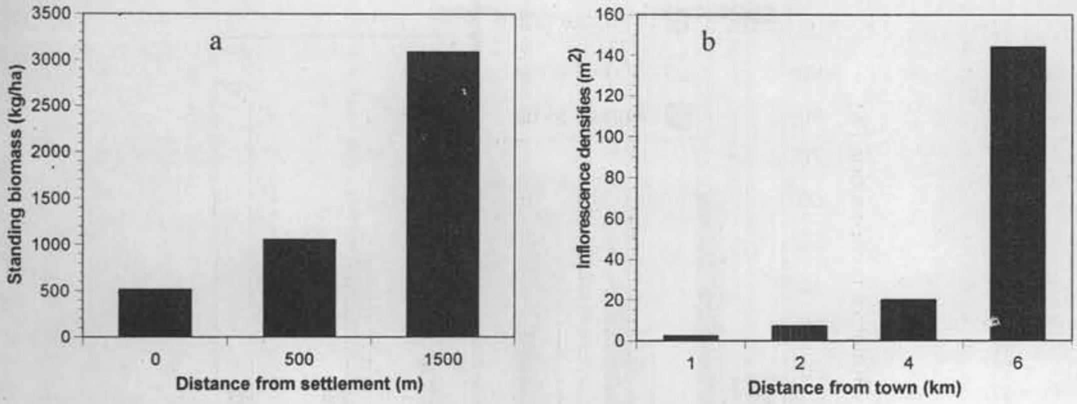


Fig. 2. (a) Above ground biomass along grazing distance from settlements showing impact of small ruminants (Data from Perevolotsky, 1991). Gradient had visible impact on vegetation cover and standing biomass from the sites of intensive use to areas of less use. This type of data has usually been used to illustrate existence of land degradation. However, such sacrifice areas as those found near water points and settlements could not be used to make generalizations about land degradation in the arid zone. (b) Inflorescence density (m^2) progressively sampled from the highly degraded centre of the town, Northern Kenya (Data from Lewis, 1977). Heavy grazing by livestock reduced plant inflorescence density in the proximity of the town, while the density increased with increasing dstance.

In South Africa's communal grazing lands, significant differences between grazed and protected areas in terms of changes in soil bulk density and nutrients were not found, while differences were related to conditions within individual landscapes (Harrison and Shackleton, 1999). In other studies, goat grazing had no effects on soil bulk density, but affected the litter cover (Severson and Debano, 1991). By contrast, heavy grazing was reported to reduce soil fertility and organic matter content (Steinfeld *et al.*, 1996) and water infiltration was greater in undegraded (6.1 cm h^{-1}) compared to degraded soils (0.8 cm h^{-1}) (Rostagno, 1989).

Other roles of small ruminants on the environment were positive such as breaking soil crusts and improving soil water and seed micro-sites (Knipe, 1983; Steinfeld *et al.*, 1996), seed dispersal and nutrient distributions (Shayo and Uden, 1998; Reid and Ellis, 1995). Small ruminants may influence soil quality in other ways. In centres of intensive use such as around settlements and watering points, livestock imported nutrients from the range (Steinfeld *et al.*, 1996), but only a few studies have analyzed nutrient budgets between areas of extraction and deposition (ILCA, 1988; Turner, 1998). Jusoff (1988) showed greater concentrations of total N

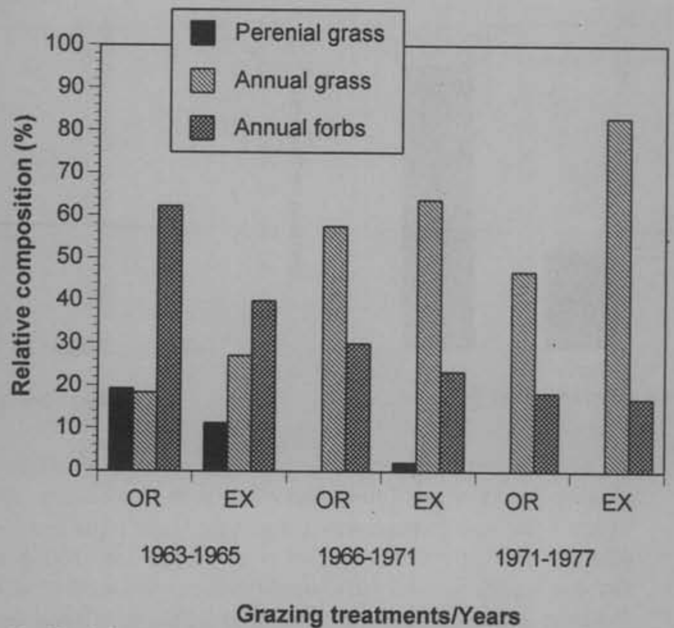


Fig. 3. Total botanical composition of protected and grazed pastures in Sudan monitored from 1963-1977 (Data from Suliman, 1988). The vegetation data clearly showed annual variability both in the open range and exclosure sites. Disappearance of grass both in exclosure and open areas in 1971-1977 showed that climatic variability was more important than grazing. Annual forbs and annual grasses were eruptive clearly related to erratic rainfall in Sudan.

and available P in grazed compared to ungrazed areas. The evidence shows that the roles of small ruminants on the environment were beneficial, even though researchers usually interpreted effects more negatively, especially at high stocking rates relative to medium or low stocking rates. These equilibrium viewpoints might have influenced range development but have not demonstrated permanent decline in range productivity in the arid zone.

Effects of Grazing Control and Stocking Rates on Vegetation

In extensive systems that functioned in accordance with non-equilibrium grazing models, stocking rates may vary from 130 animals km^{-2} (Cornelius and Schultka, 1997) to 15 animals km^{-2} (Lusigi *et al.*, 1986), while in intensive systems stocking rates were regulated according to management goals (i.e., according to equilibrium grazing models). However, in the dry lands variability in stocking rates was a feature of fluctuating rainfall. For example, in northern Kenya, greater variability in available browse during a dry compared to a wet year caused fluctuations in stocking rates due to fluctuating forage production (Fig. 4a) (Lusigi *et al.*, 1986). Small ruminant stockings at a density of 25 Tropical Livestock Unit km^{-2} (1TLU = 250 kg bovine which is equivalent to 11 goats or 12 sheep) did not show clear relationships

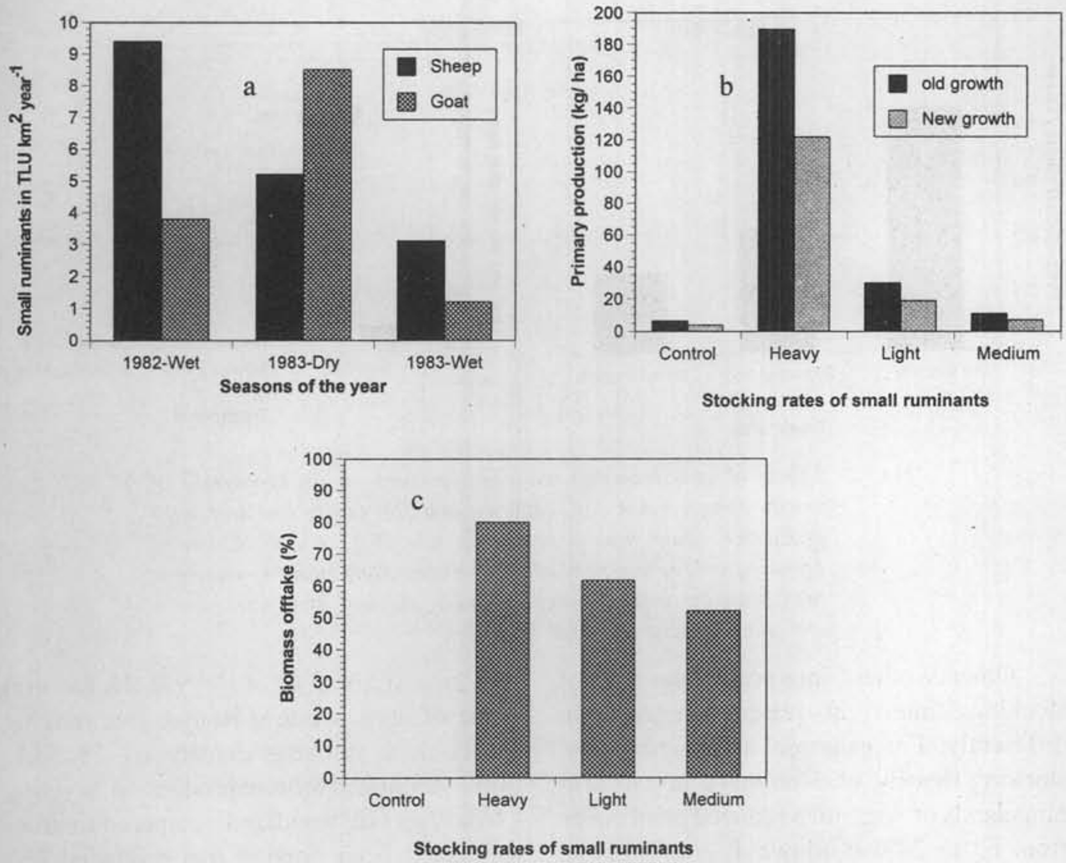
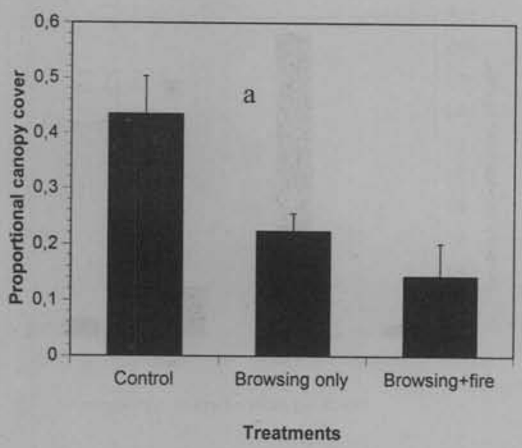


Fig. 4. (a) Small ruminants stocking variations on communal rangelands in northern Kenya showing that stocking rates were in response to fluctuating range production. In controlled grazing effects of small ruminant stocking rates on (b) primary productivity and (c) biomass offtake in arid range sites in Northern Kenya (Data from Lamprey and Yussuf, 1981). The greater offtake at the heavy stocking rate may have reflected greater availability of the forage. Lower production at the light and control sites was a reflection of landscape variation than grazing. Thus, studies of this nature might falsify the results if the conclusions are that the heavy stocking demonstrated desertification.

with standing vegetation (Fig. 4b). The study used biomass offtake (Fig. 4c) measured before and after grazing as evidence of desertification (Lamprey and Yussuf, 1981). The results regarding the contribution of stocking rates to desertification were, however, inconclusive. Rather, greater primary productivity was found at high stocking density in that study, implying that greater biomass offtake was due to greater availability before treatments as opposed to being the product of treatments.



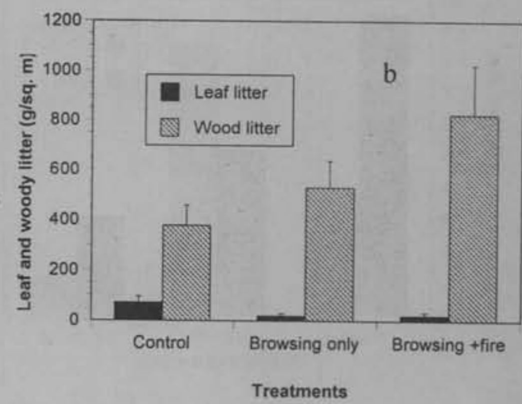


Fig. 5. Effects of goat browsing and fire treatment on (a) proportion of woody canopy cover (M^2) affected and (b) woody and leaf litter production (Data from Scogings et al., 1995). A combination of browsing and fire was more effective in controlling bush encroachment than browsing alone. However, woody and leaf litter were not in any way reduced by goat browsing.

Other workers interpreted the role of stocking rates in range degradation differently. For example, a four-year goat stocking density of 3 animals ha^{-1} in arid rangelands of Argentina reduced plant cover from 62 to 24% (Grûnwaldt *et al.*, 1994), while in California stocking rates of 600 Spanish goats ha^{-1} in a single day reduced vegetation cover by 48%, fuel by 33% and litter by 27% (Tsiouvaras *et al.*, 1989). Similarly, grazing small ruminants at stocking levels of 47 animals ha^{-1} led to drastic decline in herbage production (Ndamukong *et al.*, 1994). Yet, none of the studies showed that the changes were permanent. On the contrary, in cattle grazing experiments mixed with goats, Staples *et al.* (1942) did not observe adverse effects on vegetation that could be attributed to goat browsing. Further, in grazing experiments comparing effects of different stocking rates, no clear trends in canopy cover of *Acacia berlandieri* Benth was reported (Ekblad *et al.*, 1993). In the arid zone of north-western Kenya, free ranging goats at a stocking density of 13 TLU km^{-2} stimulated browse production in young *Acacia tortilis* woodland compared to areas protected from grazing that produced less browse over a period of 5 years (Oba, 1998; Oba and Post, 1999). Goat-stocking rates were not related to mortality of *Eremophila forresti,* which is unpalatable, whereas mortality of the palatable *E. mairlandii* was greater in grazed treatments. However, shrub mortality was influenced more by rainfall variability than goat herbivory (Watson *et al.*, 1997). Furthermore, goat-stocking rates had no significant effects on perennial herbs (Michalk *et al.*, 1976), relative to year-to-year variations in composition, which was controlled by rainfall (Hiernaux and Fernandez-Rivera, 1995). Nevertheless, the effects of small ruminants on vegetation may be directly related to above-and-below ground biomass dynamics (Michalk *et al.*, 1976; Dagar, 1987). Another interpretation of the effects of stocking rates was in terms of tree, shrub and grass regeneration. The studies produced varied results from none to negative effects.

Effects of stocking rates on plant regeneration

Small ruminants reduced understorey herbaceous vegetation cover, but they did not influence the regeneration and mortality of eucalypt plantations (Couto *et al.*, 1994). Moreover, removing grazing from *Atriplex* shrub pastures did not influence shrub population dynamics, recruitment and mortality, suggesting that a shrub population under grazing or in the absence of grazing was highly dynamic (Eldridge *et al.*, 1990). In Patagonia, sheep grazing did not influence survival of mature shrubs, while seedling mortality resulted from environmental desiccation (Fernández *et al.*, 1992). In comparison to these studies, some workers have reported reduced plant basal areas in grasses (e.g., Orr and Phelps, 1995) as well as lowered regeneration rates in chenopod shrub lands that were heavily grazed by goats (e.g., Tiver and Andrew, 1997), while browsing by feral goats hindered tree regeneration compared to protected management (Scowcroft and Hobdy, 1987). In arid Karoo, sheep grazing reduced shrub canopy cover, but had no influence on survival (Milton, 1994). By comparison, grazing by sheep and goats promoted tillering in grass (Hiernaux *et al.*, 1994) relative to those of cattle grazing that produced less tillers (O'reagain and Grau, 1995).

Small Ruminants as Biological Control Agents of Noxious Weed

Grazing by small ruminants is often used as part of a wider biological control programs aimed at removing undesirable plant species from the range (Kirby *et al.*, 1997; Lym, 1998; Lunginbuhl *et al.*, 1999; Gardner *et al.*, 1999). Control of noxious weeds is usually done in intensive systems linked to commercial ranches. The treatments combined grazing with clearing or, grazing in mixed herds of small ruminants and cattle. In the extensive systems, pastoralists combined fire and grazing to control noxious weeds. The strategy uses small ruminants' dietary preferences (O'reagain and Grau, 1995; Fajemisin *et al.*, 1996) but the studies we review produced varied results. For example, eradication of leafy spurge (*Euphorbia esula* L.), a common noxious weed in North American rangelands, is usually achieved by sheep and goat grazing (Olson *et al.*, 1997; Kronberg and Walker, 1999). However, because the sheep eat seeds of leaf spurge they are responsible for dispersing them and, consequently spreading the weeds (Olson *et al.*, 1997). Thus, the effectiveness of sheep control of leafy spurge might be increased if the grazing was done before plants produced seeds (Popay and Field, 1996). In comparison, goats were effectively used in weed control (Walker *et al.*, 1995). In the Karoo, sheep grazing reduced seed production of the shrub *Pteronia emetrifolia* relative to the noxious *P. pallens*, which was unaffected (Milton, 1995). In weed grazing, therefore, the critical factor concerns decisions to adjust grazing periods to correspond with time of phenology that could be used to effectively control the noxious plant species (Popay and Field, 1996).

Control of bush-encroachment

Bush cover poses a serious threat to grazing lands in the tropics (Oba *et al.*, 2000b). Generally, goat browsing is more effective in bush control than is sheep grazing (Holmgren and Hutchins, 1972; Knipe, 1983; Riggs *et al.*, 1988; Casey and Van Niekerk, 1988; El Aich and Waterhouse, 1999). However, the treatments are more effective when mixed herds of sheep, cattle and goats are used, rather than any of them alone (Papachristou, 1997; del Pozo *et al.*, 1998). In Californian shrub lands, Tsiouvaras *et al.* (1989) reported that heavy goat grazing reduced fire hazard and promoted current shrub growth, thereby increasing browse productivity on wildlife range (Riggs and Urness, 1989).

Goats break shrub canopy and promote vegetation patchiness, which increases herbaceous vegetation in their diets (Papachristou and Nastis, 1993). The scheme has been widely used in Mediterranean *Quercus coccifera* bush lands where fire is a recurrent problem (Papanastasis and Liacos, 1980; Papatheodorou *et al.*, 1993). In the semi-arid savannah of South Africa, a 12-year period of grazing by goats combined with or without fire modified the structure of bushes and grass fuels (Scogings *et al.*, 1995). The combination of goat and fire treatments showed significantly greater responses unapparent in treatments of either of them alone. By comparison, goat grazing did not alter wood and leaf litter (Figs. 5a,b).

Goats have, however, been shown to degrade some plant communities that resource managers wished to conserve. For example, in the Addo Elephant National Park in South Africa where the endemic succulent *Portulacaria afra* is protected, goat browsing adversely affected the shrub cover (Stuart-Hill, 1992; Moolman and Cowling, 1994). In Kiboko, Kenya by contrast, herbaceous cover, but not woody cover, was reduced at heavy goat browsing intensity (Stuth and Kamau, 1990). Overall, the studies on bush control showed that goat browsing promoted ecosystem stability in arid zone landscapes through seed dispersal (Perevolotsky, 1991; Schutka and Cornelius, 1997), increased environmental heterogeneity (El Aich and Waterhouse, 1999) and reduced fire hazards (Knipe, 1983; Hulme *et al.*, 1999). The studies were concerned less with improving animal performance, but more on understanding the impacts of small ruminants on the environment.

Conversely, it is usual to expect (i.e., according to the equilibrium grazing models) that animal performance and stocking rates are interrelated (Galina and Russel, 1994; Sikosana and Gambiza, 1994; Grünwaldt *et al.*, 1994; de Pozo *et al.*, 1998). Destocking is advocated to manage "quality" animals due to the perceived links between range stocking rates and animal performance. However, as the following examples show, empirical evidence is lacking to support such views. It is, therefore, important to realize that animal performance is the sum of environment and management as opposed to stocking rates alone.

Assessment of Animal Performance in Response to Stocking Rates

Some of the studies we reviewed reported greater goat weight losses at heavy stocking rates than at medium and/or low stocking rates (Sikosana and Gambiza, 1994; Grünwaldt *et al.,* 1994). By contrast, dwarf ewes (Ndamukong *et al.,* 1994) and goats grazed at light or heavy stocking rates showed no significant differences in weights (Riggs *et al.,* 1988), even though pasture contamination by helminth increased with stocking rates (Ndamukong *et al.,* 1994). Moreover, weanling production by goats was greater at moderate stocking densities than at heavy stocking rates in goat-cattle mixed production systems (Sikosana and Gambiza, 1994). However, dry-matter intake and the amount of water consumed by yankasa sheep (Aganga *et al.,* 1988) and sheep and goats fed on *Atriplex halimus* L. showed no significant differences under different stocking rates (Valderra'bano *et al.,* 1996). Other workers showed that increased stocking rates were followed by increased dry-matter consumption from unpalatable forage species (e.g., Malechek and Provenza, 1983). The correlative relationship between animal performance and stocking rates have greater relevance to crop-livestock production systems in semi-arid and sub-humid zones than in grazing of natural pastures in the arid zones. These will be briefly highlighted in the following sections.

Crop-livestock Systems in the Semi-arid Zones

On-farm research rarely focused on environmental impacts while nutritional improvements in animal feed and nutrient transfers linked to crop-livestock production were emphasized (Devendra, 1991; Peters, 1999). In the developing countries, a greater proportion of small ruminants are produced in crop-livestock mixed systems (Tiedeman *et al.,* 1998). These are of two types; first, the agro-pastoralists allowed livestock on their land for part of the year to use livestock manure to fertilize cropland while the livestock used crop residues (Means, 1997). Second, farmers maintained small herds of sheep and goats as a source of meat and milk and to transfer nutrients on garden plots (Otchere *et al.,* 1987; McIntire *et al.,* 1992). In the crop-livestock systems, because of the direct relation between management of crop residues and transfer of animal manure, changing one system affected the other (Bayer *et al.,* 1999). Thus, the greatest source of environmental impact is when exhaustion of crop residues leads to nutrient depletions (Ehui *et al.,* 1998).

Furthermore, in semi-arid zones, management of small ruminants is linked to agroforestry, both in mixed fodder-livestock systems (Jabbar *et al.,* 1996) and livestock-plantation management systems (Hussain *et al.,* 1983; Devendra, 1991). Small ruminants utilized the under-canopy vegetation in tree plantations without adversely affecting tree fruit production (Peters and Deichert, 1984). The effects are beneficial to the plantations because of increased soil fertility and weed control (Devendra, 1991; Sa'nchez, 1995). However, in the semi-arid zone, where cropping has taken over the key resources from grazing, conflicts between the two systems have adversely influenced animal performances during drought years. Thus, intensification of resource use may require balancing livestock needs on the one hand and introducing technologies to protect the environment on the other hand (Peters, 1999). We might add that under conditions of altered land use the management features in the very intensive crop-livestock systems reflect those described by equilibrium grazing models. However, because of the paucity of data on small ruminant-environment interactions in crop-livestock systems, it remains to be seen if the role of small ruminants in cropping systems is viewed in negative perspectives similar to those in the extensive systems.

Implications for Technology Transfer

In this article, we have reviewed wide-ranging studies that have implications for small ruminant-environment relations. Despite the myths about their negative role in the arid zone, scientific evidence to support the notion that small ruminants degrade grazing lands is lacking. What is needed is to properly understand that small ruminants' grazing is only part of a larger land use system in the arid zones world-wide (Bayer *et al.,* 1999). But under changing land use systems induced by population pressures, impact on the arid zones will be greater in the future. The changes would demand that researchers become more imaginative to tackle environmental issues. Research on small ruminant-environment relations in the future should, therefore, be focused on the central role of livestock-range production, bearing in mind the global climate change scenarios. For example, what is the contribution of grazing land to carbon sinks (i.e., carbon sequestration) as mitigation to global warming? What will be the effects of livestock grazing on carbon sequestration? If overgrazing as perceived contributes to land degradation, then how would it affect the capacity of grazing lands to sequester carbon? Or what would be the effects of intensifying livestock production on increased emissions of methane and other green house gases? In northern environments, for example, it is estimated that the contribution of large herbivores to carbon sequestration, acting through nitrogen fertilization of grazed and browsed habitats, far exceeds the annual response of vegetation to rising CO_2 and temperatures (Post *et al.*, unpublished). These are issues that future research needs to investigate by using appropriate models in the arid zones world-wide.

Moreover, the shifts from research preoccupied with the "overgrazing syndrome" (i.e., the view that herbivore grazing leads to deterioration of the range) to that of understanding sustainable land use systems and taking into consideration the dynamic nature of the arid zones is needed. However, research on small ruminant-environment relations in the arid zones should be aware that common approaches would not necessarily be appropriate for all the arid zones. Rather, the arid zones being highly diverse and local conditions being more important than global, research on small ruminant- environment relations needs to work towards diversity of ideas. The type of research will vary according to the system of grazing and priorities of the countries concerned (Fitzhugh, 1998). Research should be more applied and adaptive by evolving new ideas to confront the challenging environmental and production problems in the future (Gibson *et al.,* 1995).

Indeed, traditional field-based range science techniques are inadequate to capture the production dynamics over huge areas while the development of remote sensing and the use of Geographical Information System (GIS) has made it possible to link the ground-based to the remotely sensed monitoring. The techniques are sufficiently sensitive to allow monitoring of small ruminant-environment relations over extensive areas of the range. Time series data on vegetation greenness index (NDVI) are currently available for all the arid zones of the globe. The data can be downloaded and analysed to understand changes in range productivity in long-term perspectives (Tueller, 1995).

More importantly, future technology transfer needs to be aware of the indigenous knowledge of the resource users, especially the pastoralists. Furthermore, research should recognize the human environmental complex, which exists in the arid zones, and concentrate on how to accommodate inevitable changes in environment and society (e.g., loss of territory, population increase, climate change, change in societies socio-political structure, globalization, etc.) without being disruptive to long-standing fabrics of the traditional pastoral production systems. Research should, therefore, look at the environmental perceptions of pastoral societies and their outlook towards the landscape as key resources. In this regard, we shall suggest that research in the future establishes local perceptions of the optimal conditions of landscapes and try to define resource value in these terms. For example, stocking levels of the range in the arid zones must take these perceptions into account, as the landscape is not dominated by a single vegetation type.

Another important factor that future research should take cogniance of is that the small ruminants are a part of complex livestock management system that includes large ruminants such as cattle and camels. However, their specific role within the complex system should be appreciated both in terms of landscape use, culture and survival. Small ruminant is contributing to more than just the normal survival and become the main exchangeable commercial product of the arid zones. These evolving roles of the small ruminants are also influencing the producers' perceptions of environment and how to manage it best. Moreover, technology transfer should look at the inevitable need for intensification of land use due to reduction in land resources and population growth. Appropriate technologies must exist but the producers need to be given a chance to reflect on these technologies in terms of their needs and perceptions. This means that appropriate technologies should be developed "with" them, rather than "for" them.

Conclusions

In this article we have reviewed wide-ranging research themes directly or indirectly related to the role of small ruminants in the arid zones world-wide. Small ruminants were preferred in grazing experiments, even though their role in environmental degradation has been exaggerated. The equilibrium grazing models that greatly influenced range science during the previous century prompted the controversy about the role of small ruminants in arid zone environments. The theories have been influential in attracting research funding and subsequently affecting policy in range development, especially in the developing countries.

The equilibrium as opposed to the non-equilibrium grazing models failed to acknowledge the fact that rainfall variability controlled events in the arid zones and influenced range production more than livestock populations. Another failure was that of relying on short-term findings to generalize conditions in the arid rangelands. The short-term studies failed to capture cycles of wet and dry years that characterize the arid zones. Indeed, research done during years of exceptional rainfall might show one pattern while that done during a dry year shows another. Since scientists relied on glimpses of climatic cycles, which are unpredictable, the conclusions from such studies were incomplete and any reliance on single event may mislead development. The studies reviewed in this article were in support of the non-equilibrium grazing models. The studies showed that stocking rates did not by themselves influence range production; plant cover, diversity and animal performance, rather interactions with rainfall had greater influence in majority of the cases. The equilibrium grazing models on the other hand advocated rigid systems where controlling stocking rates was the guiding principles, but they resulted in project failures. In the future, research in arid zones needs to apply non-equilibrium grazing models that incorporate elements of opportunism and climatic variability in grazing experiments and test hypotheses that might improve understanding of the role of small ruminants in the arid zone world-wide.

Acknowledgements

The work on the article was supported by Noragric (to G.O.), NSF (to E.P.) and NFR (to N.C.S). We thank Ola Syrastad and Arve Lund for their comments on the earlier version of the paper.

References

Aganga, A.A., Umunna, N.N., Oedipe, E.O. and Okoh, P.N. 1988. Seasonal variations in water requirement and influence of intermittent watering on grazing Yankasa sheep. *Small Ruminant Research* 1: 381-386.

Ahmed, M.M.M. and Nour, H.S. 1997. Legume hays as a supplement for dairy goats during the dry season. *Small Ruminant Research* 26: 189-192.

Allen, R.B., Wilson, J.B. and Mason, C.R. 1995. Vegetation change following exclusion of grazing animals in depleted grassland, central Otago New Zealand. *Journal of Vegetation Science* 6: 615-626.

Al Martin, J.A. and Huss, D.L. 1981. Goats much maligned but necessary. *Rangelands* 3: 199-201.

Alze'rrecca-Angelo, H., Schupp, E.W. and Kitchen, S.G. 1998. Sheep grazing and plant cover dynamics of a shadscale community. *Journal of Range Management* 51: 214-222.

Ash, A.J., McIvor, J.G., Corfield, J.P. and Winter, W.H. 1995. How land condition alters plant-animal relationships in Australia's tropical rangelands. *Agriculture Ecosystems and Environment* 56: 77-92.

Austin, M.P., Williams, O.B. and Belbin, L. 1981. Grassland dynamics under sheep grazing in Australian Mediterranean type climate. *Vegetatio* 47: 201-211.

Bartolome, J., Franch, J., Plaixats, J. and Seligman, N.G. 2000. Grazing alone is not enough to maintain landscape diversity in the Montseny Biosphere Reserve. *Agriculture Ecosystems and Environment* 77: 267-273.

Bayer, W., Von Lossau, A. and Schrecke, W. 1999. Livestock husbandry and the environment in the drylands. *Agriculture and Rural Development* 1: 48-51.

Becker, K. and Lohrmann, J. 1992. Feed selection by goats in tropical semi-humid rangeland. *Small Ruminant Research* 8: 285-298.

Behnke, R. and Scoones, I. 1993. Rethinking range ecology: Implications for rangeland management in Africa. In *Range Ecology at Disequilibrium: New Models of Natural Variability and Pastoral Adaptation in African Savannas* (Eds. R., Behnke, I. Scoones and C. Kerven), London, ODI, IIED/Commonwealth Secretariate, London.

Boudet, G.C. and Toutain, B. 1980. The integration of browse plants within pastoral and agropastoral systems in Africa. In *Browse in Africa* (Ed. H.N. Le Houërou). The current state of knowledge. pp. 427-432. ILCA Addis Ababa.

Bradford, G.E. and Berger, Y.M. 1988. Breeding strategies for small ruminants in arid and semi-arid areas. In *Proceedings of a workshop held at International Centre for Agricultural Research in the Areas* (Eds. E.F. Thomson and F.S. Thomson), pp. 95-109. Aleppo, Syria. 30 November to 3 December 1987. Kluwer Academic Publ. Dordrecht.

Brady, W.W., Stromberg, M.R., Aldon, E.F., Bonham, C.D. and Henry, S.H. 1989. Response of a semidesert grassland to 16 years of rest from grazing. *Journal of Range Management* 42: 284-289.

Breman, H. and de Wit, C.T. 1983. Rangeland productivity and exploitation in the Sahel. *Science* 221: 1341-1347.

Cammeraat, L.H. and Imeson, A.C. 1999. The evolution and significance of soil-vegetation patterns following land abandonment and fire in Spain. CATENA 37: 107-127.

Casey, N.H. and Van Niekerk, W.A. 1988. The Boer goat. 1. Origin, adaptability, performance testing, reproduction and milk production. *Small Ruminant Research* 1: 291-302.

Caughley, G. 1979. What is this thing called carrying capacity? In *North American Elk: Ecology, Behaviour and Management* (Eds. M.S. Boyce and L.D. Hayden-Wing), pp. 2-8. Laramie, Wyoming, University of Wyoming.

Chew, R.M. 1982. Changes in herbaceous and suffrutescent perennials in grazed and ungrazed desertified grassland in Southern Arizona, 1958-1978. *The American Midland Naturalist* 108: 159-169.

Coppock, D.L. Ellis, J.E. and Swift, D.M. 1986a. Livestock feeding ecology and resource utilization in a nomadic pastoral system. *Journal of Applied Ecology* 23: 573-583.

Coppock, D.L., Swift, D.M. and Ellis, J.E. 1986b. Seasonal nutritional characteristics of livestock diets in a nomadic pastoral system. *Journal of Applied Ecology* 23: 585-595.

Cornelius, R. and Schultka, W. 1997. Vegetation structure of a heavily grazed range in northern Kenya: ground vegetation. *Journal of Arid Environments* 36: 459-474.

Couto, L., Roath, R.L., Betters, D.R., Garcia, R. and Almeida, J.C.C. 1994. Cattle and sheep in eucalypt plantations: silvopastoral alternative in minas grerais, Brazil. *Agroforestry Systems* 28: 173-185.

Crisp, M.D. 1978. Demography and survival under grazing of three Australian semi-desert shrubs. *Oikos* 30: 528-530.

Dagar, J.C. 1987. Species composition and plant biomass of an ungrazed and a grazed grassland at Ujjain, India. *Tropical Ecology* 28: 208-215.

Dalibard, C. 1995. Livestock's contribution to the protection of the environment. *World Animal Review* 84/85: 104-112.

de Haan, C., Steinfeld, H. and Blackburn, H. 1996. *Livestock and the Environment: Finding a Balance*. EC Directorate. General for Development and Natural Resources-WREN Media, Fressingfield, Suffolk, UK.

del Pozo, M., Osoro, K. and Celaya, R. 1998. Effects of complementary grazing by goats on sward composition and on sheep performance managed during lactation in perennial rye grass and white clover pastures. *Small Ruminant Research* 29: 173-184.

Devendra, C. 1991. Potential integration of small ruminants with tree-cropping systems in Asia and the South. *World Animal Review* 66: 13-22.

Devendra, C. and McLeroy, G. B. 1982. *Goat and Sheep Production in the Tropics*. Longman, London.

Dodd, J.L. 1994. Desertification and degradation in sub-Saharan Africa. *BioScience* 44: 28-34.

Dutta, N., Sharma, K. and Hasan, Q. Z. 2000. Effect of feed allowance on selection, intake and nutrient utilization of green maize (*Zea mays*) by goats. *Asian-Australasian Journal of Animal Science* 13: 483-486.

Edwards, G.P., Croft, D.B. and Dawson, J.J. 1996. Competition between red kangaroos (*Macropus rufus*) and sheep (*Ovis aries*) in the arid rangelands of Australia. *Australian Journal of Ecology* 21: 165-172.

Ehlers, E. and Kreutzmann. H. 2000. *High Mountain Pastoralism in Northern Pakistan*. Franz stein Verlag, Stuttgart.

Ehui, S., Li-Pun, H., Mares, V. and Shapiro, B. 1998. The role of livestock in food security and environment protection. *Outlook on Agriculture* 27: 81-87.

Ekblad, R.L., Stuth, J.W. and Owens, M.K. 1993. Grazing pressure impacts on potential foraging competition between Angora goats and white-tailed deer. *Small Ruminant Research* 11: 195-208.

El Aich, A. and Waterhouse, A. 1999. Small ruminants in environmental conservation. *Small Ruminant Research* 34: 271-287.

Eldridge, D.J., Westoby, M. and Stanley, R.J. 1990. Population dynamics of the perennial rangeland shrubs *Atriplex vercaria, Maieana astrotrich* and *Pyramidala* under grazing, 1980-1987. *Journal of Applied Ecology* 27: 502-512.

Ellis, J.E. and Swift, D.M. 1988. Stability of African pastoral ecosystem: Alternative paradigms and implications for development. *Journal of Range Management* 41: 450-459.

Etzenhouser-Mathew, J., Owens, O., Keith, M., Sparlinger, D.E. and Murden, S.B. 1998. Foraging behavior of browsing ruminants in a heterogeneous landscape. *Landscape Ecology* 13: 55-64.

Fajemisin, B., Ganskopp, D., Cruz, R. and Vara, M. 1996. Potential for woody plant control by Spanish goats in the sagebrush steppe. *Small Ruminant Research* 20: 99-107.

Fanning, P. 1994. Long-term contemporary erosion rates in an arid rangelands environment in Western New-south Wales, Australia. *Journal of Arid Environments* 28: 173-187.

Farnworth, J. 1986. The Burri (dharmnai) sheep. *World Animal Review* 58: 51-54.

Fernandez, R.J., Nuñez, A.H. and Soriano, A. 1992. Contrasting demography of two Patagonian shrubs under different conditions of sheep grazing and resource supply. *Oecologia* 91: 39-46.

Field, A.C. 1979. *Impact of sheep-goats on the vegetation in the arid zone*. UNEP-MAB-IPAL, Technical Report E2. UNESCO-Nairobi.

Field, C.R. 1986. Smallstock: Introduction. In *Smallstock and Cattle Productivity, Nutrition and Disease in Northern Kenya*. UNESCO-IPAL Technical Report Number E-8. pp. 1-7. UNESCO, Nairobi.

Fitzhugh, H.A. 1998. Global agenda for livestock research. In *Food, Lands and Livelihoods-setting Research Agendas for Animal Science* (Eds. M. Gill, T. Smith, G.E. Pollott, E. Owen and T.L.J. Lawrence), pp. 11-17. Occasional Publ. No. 21. British Society of animal Science, Edinburg, UK.

Friedel, M.H. 1991. Range condition assessment and concepts of thresholds: A viewpoint. *Journal of Range Management* 44: 422-426.

Galina, C.S. and Russel, J.M. 1994. Transfer of research findings in the tropics: How are researchers transferring information to livestock producers? *World Animal Review* 80/81: 3-12.

Gardner, D.R., James, L.F., Panter, K.E., Pfister, J.A., Palps, M.H. and Stegelmeier, B.L. 1999. Ponderosa pine and broom snakeweed: Poisonous plants that affect livestock. *Journal of Natural Toxins* 8: 27-34.

George, M.R., Browsn, J.R. and Clawson, W.J. 1992. Application of non-equilibrium ecology to management in Mediterranean grasslands. *Journal of Range Management* 45: 436-440.

Gibson, R.S., Allen, W.J. and Bosch, O.J.H. 1995. Condition assessment concepts and their role in facilitating sustainable range management. *Annals of Arid Zone* 34: 179-189.

Gintzburger, G. 1986. Seasonal variation in above-ground annual and perennial phytomass of an arid rangeland in Libya. *Journal of Range Management* 39: 348-353.

Grûnwaldt, E.G., Pedrani, A.R. and Vich, A.I. 1994. Goat grazing in the arid piedmont of Argentina. *Small Ruminant Research* 13: 211-216.

Gutman, M. and Seligman, N. 1995. Long term plant community dynamics in a grazed Mediterranean grassland. In *Proceedings of the Fifth International Rangeland Congress* (Ed. N.E. West), Vol. 1., pp. 193-194. Salt Lake City, Utah.

Hamadeh, S. K., Shomo, F., Nordblom, T., Goodchild, A. and Gintzburger, G. 1996. Small Ruminant production in Lebanon's Bekaa Valley. *Small Ruminant Research* 21: 173-180.

Harrington, G.N. 1981. Grazing arid and semi-arid pastures. In *Grazing Animals* (Ed. F.H.W. Morley). pp. 181-201. World Animal Science, B1. Elsevier Scientific Publishing Co. Amsterderm.

Harrison, Y.A. and Shackleton, C.M. 1999. Resilience of south African communal grazing lands after the removal of high grazing pressure. *Land Degradation and Development* 10: 225-239.

Heady, H.F. and Child, D. 1994. *Rangeland Ecology and Management*. Boulder (CO). Westview Press.

Hearn, K.A. 1995. Stock grazing of semi-natural habitats on Natural Trust land. *Biological Journal of the Linnean Society* 56: 25-37.

Hiernaux, P., De Leeuw, P.N. and Diarra, L. 1994. Modelling tillering of annual grasses as a function of plant density: application to the Sahelian rangelands productivity and dynamics. *Agricultural Systems* 46: 121-139.

Hiernaux, P. and Fernandez-Rivera, S. 1995. Grazing effects of goats-sheep mixes on vegetation structure and productivity of old fallow in the Sahel. In *Proceedings of the Fifth International Rangeland Congress* (Ed. N.E. West) Vol. 1, pp. 230-231. Salt Lake City, Utah, USA.

Hirata, M., Fujta, H. and Miyazaki, A. 1998. Changes in grazing areas and feed resources in a dry area of northeastern Syria. *Journal of Arid Environments* 40: 319-329.

Holmgren, R.C. and Hutchins, S.S. 1972. Salt desert shrub response to grazing use. In *Wildland Shrubs: Their Biology and Utilization* (Eds. C.M. McKell, J.P. Blaisdel and J.R. Goodin), pp. 153-164. USDA, Utah, USA.

Hulme, P.D., Pakeman, R.J., Torvell, L., Fisher, J.M. and Gordon, I.J. 1999. The effects of controlled sheep grazing on the dynamics of upland *Agrostis festuca* grassland. *Journal of Applied Ecology* 36: 886-900.

Hunt, L.P. 1995. Spatial variation in the dynamics of an arid zone perennial shrub under sheep grazing. In *Proceedings of the Fifth International Rangeland Congress* (Ed. N.E. West), Vol. 1, pp. 255-256. Salt Lake City, Utah, USA.

Hussain, M.Z., Naidu, I., Tuvuki, I. and Singh, R. 1983. Goat production and development in Fijii. *World Animal Review* 48: 25-32.

Ickowicz, A. and Dassering, O. 1995. Dynamics of forage avaialbility and consumption on Sahelian pasture in Chad. In *Proceedings of the Fifth International Rangeland Congress* (Ed. N.E. West), Vol. 1, pp. 260-261. Salt Lake City, Utah.

ILCA 1988. *Sustainable Production from Livestock in Sub-Saharan Africa: ILCA's Programme Plans and Funding Requirements 1989-1993*. Addis Ababa.

Jabbar, M.A., Larbi, A. and Reynolds, L. 1996. *Alley Farming for Improving Small Ruminant Productivity in West Africa: ILRI's Experiences. Socioeconomics and Policy Research.* Working Paper No. 20, ILRI. Addis Ababa.

James, C.D., Landsberg, J. and Morton, S.R. 1999. Provision of watering points in the Australian arid zone: A review of effects on biota. *Journal of Arid Environments* 41: 87-121.

Jodha, N.S. 1995. Grazing lands and biomass management in Western Rajasthan: Microlevel field evidence. *Annals of Arid Zone* 34: 209-226.

Joubert, D.F. and Ryan, P.G. 1999. Differences in mammal and bird assemblages between commercial and communal rangelands in the succulent karoo, South Africa. *Journal of Arid Environments* 43: 287-299.

Jusoff, K. 1988. Influence of sheep grazing on soil chemical properties and growth of rubber (*Hevea brasiliensis*) in Malaysia. *Agroforestry Systems* 7: 115-120.

Kirby, D.R., Hanson, T.P. and Sieg, C.H. 1997. Diets of angora goats grazing leafy spurge (*Euphobia esula*) infested rangeland. *Weed Technology* 11: 734-738.

Kitchen, S.G. and Hall, D.B. 1995. Diversity and sheep grazing-induced compositional shifts in salt desert communities (USA). In *Proceedings of the Fifth International Rangeland Congress* (Ed. N.E. West), Vol. 1, pp. 292-293. Salt Lake City, Utah.

Knights, M. and Garcia, G.W. 1997. The status and characteristics of the goat (*Capra hircus*) and its potential role as a significant milk producer in the tropics. A Review. *Small Ruminant Research* 26: 203-215.

Knipe, O. D. 1983. Effects of Angora goat browsing on burned-over Arizona chaparral. *Rangelands* 5: 252-255.

Kronberg, S.L. and Walker, J.W. 1999. Sheep preference for leafy spurge from Idaho and North Dakota. *Journal of Range Management* 52: 39-44.

Lamprey, H.F. 1978. The integrated Project on aridlands (IPAL). *Nature and Resources* 14: 2-11.

Lamprey, H.F. 1983. Pastoralism yesterday and today: the overgrazing problem. In *Tropical Savannas* (Ed. F. Bourliere), Vol. 13, pp. 643-666. Ecosystems of the World,

Lamprey, H.F. and Yussuf, H. 1981. Pastoralism and desert encroachment in Northern Kenya. *Ambio* 10: 131-134.

Laycock, W.A. 1991. Stable states and thresholds-of range condition North American rangelands: a viewpoint. *Journal of Range Management* 44: 427-433.

Le Houërou, H.N. 1980. Browse in northern Africa. In *Browse in Africa. The Current State of Knowledge* (Ed. H.N. Le Houërou), pp. 55-82. ILCA Addis Ababa.

Lewis, J. G. 1977. *Report of a short-term Consultancy on the Grazing Ecosystem in the Mt Kulal Region, Northern Kenya.* IPAL Technical Reports Number E-3. UNEP-MAB, Integerated Projects in Aridlands, Nairobi.

Lu, C.D. 1988. Grazing behavior and diet selection of goats. *Small Ruminant Research* 1: 205-216.

Lunginbuhl, J.M., Harvey, T.E., Green, J.T. Jr., Poore, M.H. and Mueller, J.P. 1999. Use of goats as biological agents for the renovation of pastures in the Appalachian region of the United States. *Agroforestry Systems* 44: 241-252.

Lusigi, W.J., Nkurunziza, E.R., Awere-Gyekye, K. and Masheti, S. 1986. *Range resource assessment and management strategies for south-western Marsabit, Northern Kenya.* UNESCO-IPAL Technical Report No. D-5.

Lym, R.G. 1998. The biology and integrated management of leafy spurge (*Euphobia esula*) on North Dakota rangeland. *Weed Technology* 12: 367-373.

Malechek, J.C. and Provenza, F.D. 1983. Feeding behaviour and nutrition of goats on rangelands. *World Animal Review* 47: 38-48.

Mason, I.L. 1980. Sheep and goat production in the drought polygon of North East Brazil. *World Animal Review* 34: 23-28.

McGregor, B.A. 1998. Nutrition, management and other environmental influences on the quality and production of mohair and cashmere with particular reference to Mediterranean and temperate climatic zones: A review. *Small Ruminant Research* 28: 199-215.

McIntire, J., Bourzat, D. and Pingali, P. 1992. *Crop-livestock Interaction in sub-Saharan Africa.* The World Bank, Washington DC.

McNaughton, S.J. 1979. Grazing as an optimizing process: Grass ungulate relationships in the Serengeti. *The American Naturalist* 113: 691-703.

Means, R. 1997. Livestock and environment: potential for complementarity. *World Animal Review* 88: 2-14.

Menjli, M. and Papanastasis, V. 1995. Impact of pastoralism on desertification on Psilonites Mountain in Crete, Greece. In *Proceedings of the Fifth International Rangeland Congress* (Ed. N.E. West), Vol. 1, pp. 361-362. Salt Lake City, Utah.

Michalk, D.L., Bryness, C.C. and Robards, G.E. 1976. Effects of grazing management on natural pastures in a marginal area of southeastern Australia. *Journal of Range Management* 29: 380-383.

Milton, S. J. 1994. Growth, flowering and recruitment of shrubs in grazed and in protected rangeland in the arid Karoo, South Africa. *Vegetatio* 111: 17-27.

Milton, S. J. 1995. Effects of rain, sheep and tephritid flies on seed production of two arid Karoo shrubs in South Africa. *Journal of Applied Ecology* 32:137-144.

Mishra, A.S., Santra, A., Chatuvvedi, O.H., Prasad, R. and Karim, S.A. 1997. Comparative nutrient utilization in sheep and goats on *Cenchrus* (*Centhrus ciliaris*) based diet. *Indian Journal of Animal Nutrition* 14: 250-253.

Moolman, H.J. and Cowling, R.M. 1994. The impact of elephant and goat grazing on the endemic flora of South African succulent thicket. *Biological Conservation* 68: 53-61.

Morand-Fehr, P. and Boyazoglu, J. 1999. Present state and the future outlook of the small ruminant sector. *Small Ruminant Research* 34: 175-188.

Morse, D. 1995. Environmental considerations of livestock producers. *Journal of Animal Science* 73: 2733-2740.

Mousa, H.M. and El Kalifa, M.Y. 1992. Effects of water deprivation on dry matter intake, dry matter digestibility, and nitrogen retention in Sudan desert lambs and kids. *Small Ruminant Research* 6: 311-316.

National Research Council (NCR) 1994. *Rangeland Health: New Methods to Classify, Inventory, and Monitor Rangelands*. National Academy Press, Washington DC.

Ndamukong, K.J.N., Mbomi, S.E. and Killanga, S. 1994. Stocking rate of sheep and survival of helminth infective larvae on Brachiaria pastures. In *Small Ruminant Research and Development in Africa*. Proceedings of the second Biennial Conference of the African Small Ruminant Research network. pp. 127-131. AICC, Arusha, Tanzania, 7-11 Dec. 1992. ILCA/CTA.

Nolan, T., Pulina, G., Sikosana, J. L. N. and Connolly, J. 1999. Mixed animal type grazing research under temperate and semi-arid conditions. *Outlook on Agriculture* 28: 117-128.

Noy-Meir, I. and Seligman, N. 1979. Management of semi-arid ecosystems in Israel. In *Management of Semi-arid Ecosystems* (Ed. B.H.Walker), pp. 113-160. Amsterdam, Elservier Science.

Nsahlai, I.V., Bonsi, M.L.K., Umunna, N.N., Sileshi, Z. And Bediye, S. 1998. Feed utilization strategies for improved ruminant production in the arid region. *Annals of Arid Zone* 37: 283-310.

Oba, G. 1992. Effects of controlled grazing on a degraded dwarf shrub annual grass semi-desert vegetation type of northwestern Kenya. *Land Degradation and Rehabilitation* 3: 199-213.

Oba, G. 1998. Effects of excluding goat herbivory on *Acacia tortilis* woodland around pastoralist settlement in northwest Kenya. *Acta Oecologica* 19: 395-404.

Oba, G. and Post, E. 1999. Browse production and offtake by free-ranging goats in arid zone, Kenya. *Journal of Arid Environments* 43: 183-195.

Oba, G., Stenseth, C.N. and Lusigi, W.J. 2000a. New perspectives on sustainable grazing management in arid zones of sub-Saharan Africa. *BioScience* 50: 35-51.

Oba, G., Post, E., Syvertsen, P.O. and Stenseth, N.C. 2000b. Bush cover and range condition assessments in relation to landscape and grazing in southern Ethiopia. *Landscape Ecology* 15: 535-545.

Obeid, M. and Mahmoud, A. 1971. Ecological studies in the vegetation of the Sudan. II The ecological relationships of the vegetation of Khartoum Province. *Vegetatio* 23: 177-198.

O'connor, T.G. and Roux, P.W. 1995. Vegetation changes (1949-71) in a semi-arid, grassy dwarf shrubland in the Karoo, south Africa: influence of rainfall variability and grazing by sheep. *Journal of Applied Ecology* 32: 612-626.

Olson, B.E., Wallander, R.J. and Kott, R.W. 1997. Recovery of leafy spurge seed from sheep. *Journal of Range Management* 50: 10-15.

Omar, S.A.S. 1991. Dynamics of range plants following 10 years of protection in arid rangelands of Kuwait. *Journal of Arid Environments* 21: 99-111.

Omar, S.S., Shayo, C.M. and Uden, P. 1999. Voluntary intake and digestibility of mulberry (*Morus alba*) diets by goats. *Tropical Grasslands* 33: 177-181.

O'reagain, P.J. and Grau E.A. 1995. Sequence of species selection by cattle and sheep on south African sourveld. *Journal of Range Management* 48: 314-321.

Orihuela, A. and Solano, J.J. 1999. Grazing and browsing times of goats with three levels of herbage allowance. *Applied Animal Behavior Science* 61: 335-339.

Ormazabal, C.S. 1991. Silvopastoral systems in arid and semiarid zones of northern Chile. *Agroforestry Systems* 14: 207-217.

Orr, D.M. and Phelps, D.G. 1995. Rainfall and grazing influence cohort development in Astrebla grasslands. In *Proceedings of the Fifth International Rangeland Congress* (Ed. N.E. West), Vol. 1, pp. 418-419. Salt Lake City, Utah.

Otchere, E.O., Ahmed, H.U., Adenowo, T. K., Kallah, M.S., Bawa, E.L.K., Olorunju, S.A. and Vohr, A.A. Jr. 1987. Sheep and goat production in the traditional Fulani agropastoral sector. *World Animal Review* 64: 50-55.

Papachristou, T.G. 1997. Foraging behaviour of goats and sheep on Mediterranean kermes oak shrublands. *Small Ruminant Research* 24: 85-93.

Papachristou, T.G. and Nastis, A.S. 1993. Diets of goats grazing oak shrublands of varying cover in northern Greece. *Journal of Range Management* 46: 220-226.

Papanastasis, V.P. and Liacos, L.G. 1980. Productivity and management of kermes oak brushlands for goats. In *Bowse in Africa*. (Ed. H.N. Le Houe'rou), pp. 375-381. ILCA, Addis Ababa.

Papatheodorou, E., Pantis, J.D. and Stamou, G.P. 1993. The effects of grazing on growth, spatial pattern and age structure of *Quercus coccifera*. *Acta Oecologica* 14: 589-602.

Perelman, S.B., Lëon, R.J.C. and Bussacca, J.P. 1997. Floristic changes related to grazing intensity in a Pantagonian shrub steppe. *Ecography* 20: 400-406.

Perevolotsky, A. 1991. Goats or scapegoats-the overgrazing controversy in Piura, Peru. *Small Ruminant Research* 6: 199-215.

Perevolotsky, A. and Seligman, N.G. 1998. Role of grazing in Mediterranean rangeland ecosystems. *BioScience* 48: 1007-1017.

Peters, K.J. 1999. Livestock production and food security-consequences for the environment? *Agriculture and Rural Development* 1: 43-47.

Peters, K.J. and Deichert, G. 1984. Pattern of goat production in low-income economic units of Peninsular Malaysia. *World Animal Review* 51: 44-50.

Popay, I. and Field, R. 1996. Grazing animals as weed control agents. *Weed Technology* 1: 217-231.

Posse, G., Anchorena, J. and Collantes, M.B. 1996. Seasonal diets of sheep in the steppe region of Tierra del Fuego, Argentina. *Journal of Range Management* 42: 24-30.

Priddel, D. and Wheeler, R. 1999. Malleefowl conservation in New South Wales: A review. *Zoologische Verhandelingen Leiden* 327: 123-141.

Pour, H.Z. and Ejtehadi, H. 1997. Grazing effects on diversity of rangeland vegetation: A case study in Mouteh plain, Iran. *Acta Botanica Hungarica* 40: 271-280.

Rai, P., Solanki, K.R., Deb, R.R. and Singh, R. 1998. Performance of lambs and kids on silvipastoral system and effects of grazing on constituent vegetation. *Indian Journal of Animal Sciences* 68: 973-975.

Ramirez, R.G. 1999. Feed resources and feeding techniques of small ruminants under extensive management conditions. *Small Ruminant Research* 34: 215-230.

Rasool, E. Khan, M.F., Nwaz, M. and Rafiq, M. 1998. Utilization of sunflower crop residues as feed in small Ruminants. *Asian-Australasian Journal of Animal Sciences* 11: 272-276.

Reddy, M.R. and Reddy, G.V.N. 1999. On-farm performance of sheep and goats under intensive rearing. *Indian Journal of Animal Nutrition* 16: 164-166.

Reid, R.S. and Ellis, J.E. 1995. Impacts of pastoralists on woodlands in south Turkana, Kenya-livestock mediated tree recruitment. *Ecological Applications* 5: 978-992.

Riggs, R.A. and Urness, P.J. 1989. Effects of goat browsing on gambel oak communities in northern Utah. *Journal of Range Management* 42: 354-360.

Riggs, R.A., Urness, P.J. and Hall, T.A. 1988. Diets and weight responses of Spanish goats used to control Gambel oak. *Small Ruminant Research* 1: 259-271.

Rommey, D.L., Sendalo, D.S.C., Owen, E., Mtenga, L. A., Penning, P.D., Mayes, R.W. and Hendy, C.R.C. 1996. Effect of tethering management on feed intake and behaviour of Tanzanian goats. *Small Ruminant Research* 19: 113-120.

Roothaert, R.L. and Paterson, R.T. 1997. Recent work on the production and utilization of tree fodder in East Africa. *Animal Feed Science and Technology* 69: 39-51.

Rostagno, C.M. 1989. Infiltration and sediment production as affected by soil surface conditions in a shrubland of Patagonia, Argentina. *Journal of Range Management* 42: 382-385.

Sánchez, M., 1995. Integration of livestock with perennial crops. *World Animal Review* 82: 50-57.

Sandford, S.1983. *Management of Pastoral Development in the Third World*. Chichester, John Wiley & Sons.

Schultka, W. and Cornelius, R. 1997. Vegetation structure of a heavily grazed range in northern Kenya: Tree and shrub canopy. *Journal of Arid Environment* 36: 291-306.

Schwartz, H. J. 1988. Improving utilization of natural pastures in arid areas of Africa through multiple species grazing systems. In *Highlights of German*

Research Projects in the Tropics and Subtropics (Ed. J.H. Weginer), pp. 33-44. ICT-Internation cooperation and transfer GMbH.

Scogings, P.F., Trollope, W.S.W. and O'connor, T.G. 1995. The impact of browsing and burning on savanna vegetation. In *Proceedings of the Fifth International Rangeland Congress* (Ed. N.E. West), Vol. 1, pp. 498-499. Salt Lake City, Utah.

Scowcroft, P.G. and Hobdy, R. 1987. Recovery of goat-damaged vegetation in an insular tropical montane forest. *Biotropica* 19: 208-215.

Severson, K.E. and Debano, L.F. 1991. Influence of Spanish goats on vegetation and soils in Arizona chaparral. *Journal of Range Management* 44: 111-117.

Shahjalal, M. and Topps, J.H. 2000. Feeding Sesbannia leaves as a sole feed on growth and nutrient utilization in goats. *Asian-Australasian Journal of Animal Sciences* 13: 487-489.

Shaltout, K.H., El Halawany, E.F. and El Kady, H.F. 1996. Consequences of protection from grazing on diversity and abundance of the coastal lowland vegetation in Eastern Saudi Arabia. *Biodiversity and Conservation* 5: 27-36.

Shayo, C.M. and Uden, P. 1998. Recovery of seed of four African browse shrubs ingested by cattle, sheep and goats and the effect of ingestion, hot water and acid treatment on the viability of the seeds. *Tropical Grasslands* 32: 195-200.

Shinde, A.K., Karim, S.A., Sankyan, S.K. and Bhatta, R. 1998. Seasonal changes in biomass growth and quality and its utilization by sheep on semi-arid *Cenchrus ciliaris* pasture of India. *Small Ruminant Research* 30: 29-35.

Sikosana, J.L.N. and Gambiza, J. 1994. Goat production in a mixed cattle-goat system: Effects of stocking and substitution rate on redsoil thornveld stability. In ILCA/CTA Small ruminant research and development in Africa. *Proceedings of the second Biennial Conference of the African Small ruminant research network*, pp. 43-46. AICC, Arusha, Tanzania, 7-11 December 1992.

Silanikove, N. 2000. Review: The physiological basis of adaptation in goats to harsh environments. *Small Ruminant Research* 35: 181-193.

Sinclair, A.R.E. and Fryxell, J.M. 1985. The sahel of Africa: Ecology of a disaster. *Canadian Journal of Zoology* 63: 987-994.

Singh, P. 1995. Rangelands and their improvement in India. *Annals of Arid Zone* 34: 157-161.

Skarpe, C. 1990. Shrub layer dynamics under different herbivore densities in an arid savanna, Botswana. *Journal of Applied Ecology* 27: 873-885.

Squires, V. and Bayan, O. 1992. Biology and ecology of sheep raising on the desert fringe: A case study from Xinjiang, China. In *Current Natural Resources Development Activities in Developing Nations* (Eds. G.K. Pierrier and C.W. Gay), pp. 118-125. Proceedings of the 1992 International rangeland Development Symposium-Society for Range Management. Spokane, WA-February 11-12 1992. Department of Range Science Utah State University Logan, UT.

Squires, V.R. and Glenn, E.P. 1995. Creating an economic linkage between fossil fuel burning, climate change and rangeland restoration. In *Proceedings of the Fifth International Rengeland Congress*. Vol. 1, pp. 531-532. Salt Lake City, Utah.

Staples, R.R., Hornby, H.E. and Hornby, R.M. 1942. A study of the comparative effects of goats and cattle on a mixed grassbush pasture. *East African Agriculture & Forestry Journal* 8: 62-70.

Steinfeld, H., de Haan, C. and Blackburn, H. 1996. *Livestock-environment interactions: Issues and option.* Commission of the EC Directorate-General for Development, WREN Media Fressingfield, Suffolk, UK.

Stuart-Hill, G.C. 1992. Effects of elephants and goats on the Kaffararian succulent thicket of the eastern Cape, South Africa. *Journal of Applied Ecology* 29: 699-710.

Stuth, J.W. and Kamau, P.N. 1990. Influence of woody plant cover on dietary selection by goats in *Acacia senegal* savanna of East Africa. *Small Ruminant Research* 3: 211-225.

Suliman, M.M. 1988. Dynamics of range plants and desertification monitoring in the Sudan. *Desertification Control Bulletin* 16: 27-31.

Thre'mont, R.M. and Whalley, R.D.B. 1995. The effects of grazing on plant diversity of rangelands on the northern table lands of New South Wales, Australia. In *Proceedings of the Fifth International Rangeland Congress* (Ed. N.E. West), Vol. 1. pp. 570-571. Salt Lake City, Utah.

Thurow, T.L. and Hussein, A.J. 1989. Observations on vegetation responses to improved grazing systems in Somalia. *Journal of Range Management* 42: 16-18.

Tiedeman, J., Boulanouar, B., Christiansen, S. and Derkaoui, M. 1998. Sheep production on medic and weedy pasture in semi-arid Morocco. *Journal of Range Management* 51: 288-292.

Tiver, F. and Andrew, M.H. 1997. Relative effects of herbivory by sheep, rabbits, goats and kangaroos on recruitment and regeneration of shrubs and trees in eastern south Australia. *Journal of Applied Ecology* 34: 903-914.

Tsiouvaras, C.N., Havlik, N.A. and Bartolome, J.W. 1989. Effects of goats on understory vegetation and fire hazard reduction in the coastal forest in California. *Forest Science* 35: 1125-1131.

Tueller, P.T. 1995. Remote sensing in the management of rangelands. *Annals of Arid Zone* 34: 191-207.

Turner, H.N. 1991. Sheep production research: the development of small ruminants in the developing countries. *World Animal Review* 66: 3-12.

Turner, M. 1993. Overstocking the range-a critical analysis of the environmental science of Sahelian pastoralism. *Economic Geography* 69: 402-421.

Turner, M.D. 1998. Long-term effects of daily grazing orbits on nutrient availability in Sahalian Africa. 1. Gradients in the chemical composition of rangeland soils and vegetation. *Journal of Biogeography* 25: 669-682.

Valderra'bano, J., Munoz, F. and Delgado, I. 1996. Browsing ability and utilization by sheep and goats of *Atriplex halimus* L. shrubs. *Small Ruminant Research* 19: 131-136.

Vavra, M. and Ganskopp, D. 1998. Grazing behaviour in ungulates: Current concepts and future challenges. *Annals of Arid zone* 37: 319-335.

Walker, J.W., Kronberg, S.L., Al-Rowaily, S.L. and West, N.E. 1995. Comparison of sheep and goat preferences for leaf spurge. *Journal of Range Management* 47: 429-434.

Watanabe, S. 1992. ILCA's strategy for improving the output of livestock in sub-Saharan Africa based on six research thrusts. In *Proceedings of the 25th International Symposium on Tropical Agricultural Research Tsukuba, Japan.* pp. 92-103. Tropical Agriculture Research Series No. 25 TA RC. Tsukuba, Ibaraki, 305, Japan.

Watson, I.W., Westoby, M. and Holm, A. McR. 1997. Demography of two shrub species from an arid grazed ecosystem in Western Australia. *Journal of Ecology* 85: 815-832.

Webb, R.H. and Stielstra, S.S. 1979. Sheep grazing effects on Mohave desert vegetation and soils. *Environmental Management* 3: 517-529.

Westoby, M., Walker, B.H. and Noy-Meir. I. 1989. Opportunistic management for rangelands not at equilibrium. *Journal of Range Management* 42: 266-274.

Wilson, R.T. 1988. Small ruminant production systems in tropical Africa. *Small Ruminant Research* 1: 305-325.