

Overgrazing and Desertification in Northern Mexico: Highlights on Northeastern Region

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Abstract: Land degradation has recently been exacerbated in rangelands of Mexico by heavy grazing pressures. In the country, the grazing stock (cattle, goats, sheep and hogs) increased from 22 million in the early 1950's to approximately 50 million in the mid 1980's. Recorded local grazing pressures are surpassing from two to six times the recommended stocking rates of most rangelands of northern Mexico. Signals of deterioration of natural resources vary in time and space mainly because of ecosystem diversity, recurrent drought spells of different magnitudes, and economic and political issues. Estimates of carrying capacities and overgrazing rates are out of date, and very few quantitative parameters of desertification processes are available. However, there are qualitative and perceptual evidences of changes in soil and vegetation patterns, as well as socioeconomic issues, such as land tenure and forms of organization, that deserve to be discussed. Management practices, research, and social issues are addressed in this review from the desertification perspective, with the objective of highlighting the main causes of overgrazing and desertification. Needs for research and future tasks to achieve the sustainable management of rangelands of northern Mexico, with especial emphasis on those of the northeastern region, are also pointed out.

Keywords: Desertification, livestock, overgrazing, rangelands, land tenure, ejido, Tamaulipan thornscrub.

Mexico is truly a rangeland country. Around 55% of its total area is covered by forage vegetation, and currently 100% of the land with available forage is used for livestock grazing (INEGI 1998a,b; PEF, 1995). Spaniards first introduced livestock into the country early in the 16th century. Following mining, numerous herds of cattle were moved from southern and central areas of the country into the northern lands where abundant forage was only used by wild herbivores (Sánchez, 1969; Sluyter, 1998). Since then, northern Mexican lands had been used essentially for livestock production.

Land tenure changed in Mexico after the 1910's revolution. The Agrarian Reform, funded by the Constitution of 1917, provided large tracts of land to a community and formed the ejidos, -a communal land tenure system with legal, but partial rights on the land ownership. The ejidatario (landholder) held the land, but was not allowed to sell, rent, or mortgage it. Currently, ca 60% of the country land belongs to the ejido system of land tenure. Although some areas are used individually for cropland or intensive grazing, range is usually managed collectively. Pastoralism shifted from

nomadic pastoral systems during the times of the colony to a system in between the transhumant system and the heavily mechanized grazing domestic system.

The number of livestock has exponentially increased in time. Buller *et al.* (1960) reported approximately 22 million grazing animals (cattle, hogs, goats and sheep) in the 1950's, while in the early 1980's, the census from INEGI (1996) recorded 50 million grazing animals (cattle, hogs, goats and sheep) in the whole country. The livestock sector grew by 15% between 1970 and 1985, which was partially matched by land use changes at the expense of native tropical and temperate forests (PEF, 1995). Suitable climatic conditions, i.e., annual rainfall above longterm average from 1965 to 1980, in addition to economic and political incentives, contributed to this sharp increase in livestock densities. However, livestock was continuously and steadily reduced from the 1980's to the mid 1990's to 43 million (INEGI, 1998b). The number of hogs, goats and sheep were reduced by 27, 27 and 6%, respectively, while the number of cattle had no change since the 1980's. The drought spell that is currently hitting northern Mexico since the late 1980's may partially be responsible for reduction in the number of grazing animals, due to reduction in the carrying capacity of the range through degradation of plant communities and soil, and reduction of the whole ecosystem productivity.

Despite these oscillations in the numbers of domestic animals, which led to smaller stocks in later years, there is a quantitative, visual, and perceptual evidence that heavy grazing practices are degrading ecosystems

at an unprecedented rate in the country. Range condition and productivity is, in general, poor (Stoodart *et al.*, 1975). In addition to this, approximately 80% of the Mexican soils present erosion problems, caused mostly by overgrazing, resulting in losses of organic matter and fertility, reduced infiltration and increased runoff (PEF, 1995). Desertification is, therefore, an advancing process in northern Mexican rangelands. However, this is a phenomenon difficult to quantify because of the several factors involved, in addition to the several scales in time and space promoting its course. Thus, this paper focuses on reporting land degradation processes and consequences associated with heavy grazing regimes. Special emphasis is paid to vegetation changes by overgrazing and linked socio-economic issues at regional levels chiefly in the north-eastern region of the country, as well as research needs in topics where future attention is required.

For the sake of clarity, we consider in this paper that desertification is the process, through which a given piece of land is converted, not necessarily leading to a desert-like landscape, into a less productive system. Therefore, desertification may be a process of land deterioration with several stages, of which the earliest may be undetectable to an untrained eye. Following the terminology of the Society for Range Management, range or rangeland is considered as land with any vegetation type in the region with important use for livestock grazing due to the availability of forage, i.e., grasslands, shrublands/woodlands, or forests.

The Process of Desertification Due to Overgrazing

Overall implications

On the basis of conceptual models of rangeland degradation in many parts of the world, Milton *et al.* (1994) envisaged that grazing-induced desertification is a stepwise process that consists basically of four steps. In step zero (no grazing), the composition of the rangeland varies in response to climatic oscillations and stochastic, natural events. In the first step, domestic livestock cause a change in the age structure of plant populations; frequently defoliated species fail to set seed; toxic and distasteful plants, unaffected by grazing, set seed and increase in density. The second step involves a decrease in rangeland biodiversity, and productivity decreases in response to reduced rain use efficiency. The third step is the reduction of perennial plant cover, accelerated erosion and increasingly extreme temperature fluctuations on the soil surface. In some cases, the process of degradation may be stopped or minimized in the early stages when it is still possible to carry out some management strategies such as altering the grazing season, stocking intensity, or animal type (Westoby *et al.*, 1989). At late stages, reversal of degradation is unlikely to be effective, because it would involve removal of livestock from affected areas, as well as soil and vegetation manipulation (Gibbens *et al.*, 1992; Passera *et al.*, 1992).

Variations on plant composition, structure, and function: Grazing exerts an impact on density and biomass of individual species, reduction of species richness, and

changes in community organization (Novikoff, 1983; Zimmerman and Neueschwander, 1984; Archer, 1994). Overused plant species reduce the number of individuals because they produce fewer seeds and surviving seedlings. Then, there are not enough seedlings and young plants to replace senescent individuals (Milton *et al.*, 1994). Grazing also modifies the physical structure of plant communities in arid rangelands (Cooper, 1960). At the rangeland level, most plant communities are extremely patchy, and broad-scale climatic factors cannot account for the existence of these small-scale patterns (Belsky, 1986). Such patchy-patterns may become dominant and cause disruptions in the soil-plant processes, triggering diminishment of plant cover, increasing erosion, and a reduction in nutrients and water availability (Pieper, 1994). Thus, overgrazing and edaphic heterogeneity assume greater importance in determining both spatial and temporal community structure and function (Jurado and Reid, 1989; Archer and Smeins, 1991; Reid *et al.*, 1990).

Changes in soil nutrients and hydrological properties: Excessive grazing, over the long term, can potentially reduce nitrogen fixation, increase ammonia volatilization, lead to leaching and erosional losses, and cause a net directional transport of nutrients to localized portions of the landscape (Wilkinson and Lowery, 1973; Floate, 1981). Biomass ingested by grazing animals may not be returned via excreta and mortality to the range and may be lost from the system via harvesting of animal products, animal migration, or

transformation to labile or volatile forms (Parton and Risser, 1980). However, in the short term, atmospheric nutrient inputs and increased cycling rates may offset grazing induced losses from the system, besides the large nutrient pool within the organic component of the soil (Woodmansee, 1978).

Over grazing disturbs in the hydrology of soils by compaction mechanisms. The physical action of trampling by hooves reduces the size and number of the largest soil pores (Hillel, 1982; Rauzi and Hanson, 1966; Flory, 1936), increases the soil bulk density (Manzano and Návar, 2000; Tanner and Marmaril, 1959), reduces the number of soil aggregates (Warren *et al.*, 1986; Wood and Blackburn, 1984), reduces infiltration (Takar *et al.*, 1990; Rawls *et al.*, 1988; Thurow *et al.*, 1988; Wilcox and Wood, 1988; Gifford and Hawkins, 1978), increases surface runoff (Thurow, 1991; Novikoff, 1983; Hanson *et al.*, 1970; Rauzi and Hanson, 1966), and promotes soil erosion (Holechek *et al.*, 1989; Pluhar *et al.*, 1987; Weltz and Wood, 1986; Thurow *et al.*, 1986; Hanson *et al.*, 1970). The hydrological disturbance is highest under continuous heavy grazing conditions, although Savory (1983) speculated that in short rotations, in some places, overgrazing loosen the soil surface promoting the infiltration, reducing surface runoff and soil erosion. Nevertheless, this result may be short-lived, because the subsequent impact of falling raindrops may re-seal the soil surface (i.e., the unstable soil pores become plugged) after the first several minutes of an intense rainstorm (Blackburn, 1975). Moreover, studies aimed at determining the impacts of livestock trampling in the absence of concomitant removal of vegetation have generally shown

that trampling increases soil compaction (Zöbisch, 1993).

Effects on wildlife populations: While grazing has been an important selection pressure in many ecosystems, man has substantially changed its frequency, intensity, extent, and magnitude with the introduction of livestock (Archer and Smeins, 1991). Densities and abundance of indigenous animals tend to decrease in response to competition for food with domestic livestock and modification of habitat conditions such as food, cover, water, and space (Fogden, 1978). In many places in the middle Chihuahuan Desert (Mexico and USA) cattle intensively consumed over 78% of the plants that constituted the diet for different species of prairie dog (Lauenroth *et al.*, 1994). Rodents and hares, as well as granivorous and insectivorous birds may increase in response to vegetation changes caused by domestic livestock, but they decrease in severely degraded sites where vegetation is removed (Bucher, 1987; Kerley, 1992; Baker and Guthery, 1990). Livestock overgrazing has been the most important factor for the reduction of the desert mule deer population. Martínez (2000) reports lower mule deer population densities in areas with higher cattle grazing pressure, in comparison to areas without cattle grazing across the Chihuahuan Desert region in Mexico. In some cases, however, breeding birds and small mammals have showed increased richness and diversity on desertified rangelands in the northern portion of the same region (Whitford, 1997). In general, wild herbivores are often regarded as pests because they may compete with livestock by forage, consume seeds of desirable plants, impair restoration

efforts, or disperse seeds of undesirable weed and woody species. However, regarding these organisms as wholly detrimental over-simplifies their role. The condition of their populations is perhaps an indicator of the condition of the rangeland, and may therefore represent symptoms of deterioration rather than the cause (Milchunas *et al.*, 1988).

Microclimate shifts: The physical microclimate varies as grazing pressure diminishes plant cover and modifies plant community structure (Barry and Chorley, 1987; Jackson and Idso, 1975; Charney *et al.*, 1975; Idso and Deardorff, 1978; Otterman, 1974). This change occurs through: (i) the dependence of surface albedo on plant cover, and (ii) the elimination of organic soil. Ground covered by vegetation has an albedo in the range of 10 to 25%, whereas, in ground with no vegetation, it ranges from 35 to 45% in the case of dry, light sandy soils (Sellers, 1965). Thus, the reduction of plant cover by overgrazing is accompanied by a decrease in the net radiation balance in the system. Local and regional climatic effects of these changes in vegetation are possible. The soil environment becomes more xeric due to greater erosion and runoff causing soil climate changes, not due to any change in atmospheric conditions (Grover and Musik, 1990; Dregne, 1984).

Some misconceptions on grazing desertification indicators

Desertification is not always evident to the untrained eye, particularly in its initial stages. This implies that one of the main problems of desertification control is that it goes unnoticed until it is too late, both ecologically and economically, to stop it.

Hence, developing techniques to detect incipient desertification is of paramount importance in conserving the current biotic potential of rangeland ecosystems. Evaluation of the phenomenon is still a controversial issue in spite of the years of discussion on the topic. What attributes should be measured, how to measure and, most importantly, how these measures should be interpreted have been a matter of debate for decades (Friedel, 1991).

Most reports on the evaluation of desertification on grazing lands allude to overall vegetation cover as an indicator of the site condition, assuming that the lower the total percentage cover, the more desertified the area. It can be an erroneous assumption. For example, total vegetation cover has increased in overgrazed areas of north-eastern Mexico due to the presence of annual species on the understory, even though the number of woody palatable species has declined. Reductions on vegetation cover cannot be seen as synonym of desertification, as far as the soil preserves or improves its previous condition (e.g., bulk density, fertility, infiltration rates, microorganisms, electrical conductivity, etc.). Any attempt to define or assess desertification based on a single factor would be an oversimplification of the phenomena and is likely to lead to erroneous conclusions.

Certainly, most indicators of desertification developed, recently based on vegetation, include not only cover but also species composition. However, the criteria for assessing the site condition, based on its floristic composition, is rather subjective. Thus, some authors stressed that desertification can be assessed by the reduction of the productivity of "desirable"

plants (Dregne, 1983; Huss and Aguirre, 1978); or by the reduction, on the long term, of the productivity and diversity of "useful" plants and animals (Milton *et al.*, 1994). Such a criterion is not by itself a desertification parameter. The most desirable plants for a given ecosystem are the best-adapted ones, generally belonging to the native, original vegetation, which may confer a high degree of stability and resilience to the system, and not those that livestock prefer to consume. The use of species-based criteria in range management may lead to underestimation of the long-term ability of rangelands to sustain productivity when changes in species composition are minor and changes in soil fertility are negative and large; or may lead to overestimation of the impact of grazing when the opposite occurs (Milchunas and Lauenroth, 1993).

Ranks of range condition as "good" or "excellent" (e.g., that of an artificial pasture of an exotic grass) do not imply that rangeland is in a suitable status in terms of sustainability and conservation. Presence of cacti on overgrazed areas, for instance, may be an indicator of desertification process. However, they occur due to responses to competition factors or more appropriate conditions of light and soil temperature that promote their occurrence; but cacti are not an indicator just because they are "undesirable" for livestock. Floristic composition may, however, become important in terms of desertification considering that high densities of such a distasteful plant species within a community, with either a high or low diversity, may decrease organic matter inputs and soil fertility. This may occur due to the low quality (presence of

secondary plant metabolites, low nitrogen content, mature and lignified tissues, etc.) of the litter being incorporated into the soil, which in the long term (it is unknown how long) might diminish soil productivity (Bryant *et al.*, 1991).

The Regional Situation: Main Problems and Current Conditions

Desertification in Mexico, as in many other countries, is a multidimensional problem whose forms and levels vary depending on the prevailing natural, technical, and the socioeconomic and political situations. Overgrazing has been identified as the main cause of desertification in extensive areas of the country. Grazing lands occupy around 70 million hectares of the Mexican arid lands, mainly concentrated in the northern portion of the country. The north Mexican region included in the present study has four major grazing regions discussed by Buller *et al.* (1960) that considers mainly the Mexican States along the USA border (Table 1), of which Coahuila, Nuevo León, and Tamaulipas constitute the so-called north-east of Mexico.

Northern Mexico, as a whole, is characterized by extensive grazing systems where overgrazing and trampling have been followed by soil compaction and the subsequent increased runoff and accelerated erosion. Soils of the steep slopes of the main northern range mountains (i.e., Sierra Madre Oriental and Sierra Madre Occidental), are more prone to soil erosion that result in huge losses of organic matter. Sandy soils of the altiplano and north-western regions are more susceptible to loosening rather than compaction, then being subject to great losses by wind and water

Table 1. Gross estimates of livestock number and recommended carrying capacities for each northern State and representative vegetation types

State	Number of animals			Carrying capacities for vegetation type (ha/A.U.*)		
	Cattle	Goats	Sheep	Grasslands	Shrublands	Forests
Chihuahua	1888647	217115	63617	15	33	20
Coahuila	758750	700882	77803	18	27	19
Durango	1057053	181574	57560	13	30	17
Nuevo Leon	682222	492602	95257	17	20	22
Sonora	196470	88380	42863	20	28	24
Tamaulipas	985175	236970	120134	16	21	**

* 1 A.U. = 1.025 cattle; 6.07 goats; 5.44 sheep (average values).

** All vegetation types different from grasslands were considered together.

Source: COTECOCA, 1973, 1978a, 1978b, 1978c, 1979a, 1979b.

erosion. Soils in the north-eastern region, on the other hand, are especially prone to compaction because of extreme climatic conditions (causing high dehydration), predominant texture (clayey soils with shrinking and swelling actions), and low contents of organic matter.

Grazing takes place on such diverse rangelands at different stocking loads, frequencies, and intensities. In general, ranges are overused at different rates. However, average carrying capacities and reported overgrazing rates do not reflect the real magnitude of the overgrazing problem. The average rangeland carrying capacity (or rangeland coefficient) for the whole country has been estimated at 16 hectares per animal unit (ha/AU) (an animal unit in Mexico is a 400 to 450 kg-pregnant cow, or its equivalent); for the northern region this is between 15 and 30 ha/AU for rangelands in regular to good condition, and even 50 ha/AU for specific sites in poor condition (Bassols, 1989). In the State of Sonora average overgrazing rate was reported to be 182% over the recommended

capacity; however, at the site scale, cases with overgrazing rates up to 1,500% have been observed (COTECOCA, 1978a). In the State of Tamaulipas overgrazing rates were reported at 203 and 479%, respectively (COTECOCA, 1978b). In addition, such rates are based on old estimates of biomass production (COTECOCA's evaluation of carrying capacities for all Mexican rangelands was done in the 1970's) that a given area can produce when being in a "good condition" (Table 1). It is thought that such a condition has changed since then, especially in the severely grazed areas. Thus, these reports do not represent the real condition and overuse of the range. These are, however, the only carrying capacity estimates available so far.

Livestock populations show a distribution pattern by animal type. Cattle seem to be the most preferred domestic animal in the States of the northern and north-western regions (Chihuahua, Durango, and Sonora). In most of these cases, extensive areas of natural, induced, and cultivated grasslands are used to freely

graze numerous herds of breed cattle. On the other hand, small ruminants are relatively more abundant in the north-eastern states (Coahuila, Nuevo León, and Tamaulipas). This is mainly due to cultural reasons. This is also favored by the availability of browse from the native shrubby thornscrub, which contributes for these states to have the highest carrying capacities within the shrublands (Table 1). Indeed goats are considered the most convenient domestic species to raise in the north-eastern region because they are predominantly browsers with a high preference for native shrubs and the drought resistant shrubs are the only available source of forage during the dry season (Ramírez-Lozano, 2000; Ramírez, 1999; López-Trujillo and García-Elizondo, 1995; Solanki, 1994; Mellado *et al.*, 1991). Over 26 shrub species have been identified as highly preferred by free ranging goats only in the State of Nuevo León (Téllez and Foroughbakhch, 1990; Foroughbakhch and Martínez, 1986). Most of the shrubs in the north-eastern region have a nutritive value for goats, other livestock and wild animals (Taylor *et al.*, 1997).

Goats are well adapted to extreme climatic conditions, and low productivity and scarped topography lands (Alanís, 1991). Considered as opportunistic, they convert low-quality resources to high-quality protein and, in the mean time, well-managed grazing systems may be useful to maintain and enhance the landscape (El Aich and Waterhouse, 1999). However, a number of technical and non-technical causes, such as overstocking of rangelands, and the lack of appropriate rotational grazing systems, coupled with land tenure issues and goat raising have been

found to be the most pervasive agent for vegetation and soil resources in the north-eastern region, as it is overgrazing by cattle and other livestock types in most northern Mexico.

Overgrazing and vegetation changes in rangeland

Vegetation changes in grasslands, as a consequence of livestock overgrazing, have resulted in a reduction of densities and productivity of grasses and herbaceous plants, and concomitant shrub invasion in overgrazed areas of arid and semi-arid lands of northern Mexico, as it has been seen in southern Texas, New Mexico, Arizona and other North American regions (Archer, 1994; González *et al.*, 1987; Chew, 1982; Huss and Aguirre, 1978; Bell, 1973; York and Dick-Peddie, 1969; Buffington and Herbel, 1965; Tapia and Hernández, 1957), as well as in South American grasslands (Schofield and Bucher, 1986; Semple, 1974). These changes are considered undesirable because they have reduced carrying capacities for livestock, contributed to soil erosion and reductions in stream flows, altered wildlife habitat, and threatened pastoralists or ecosystem sustainability (Archer *et al.*, 1999).

It has been believed that all the vegetation in the region was essentially grassland or grassland-savanna in the past, and it must be managed accordingly. Studies and historical records state that, at least 200 years ago, this area was dominated by extensive and open grasslands and had been shrub-invaded as a result of livestock overgrazing (Archer, 1989; Archer *et al.*, 1988; Herbel, 1986; Kuchler, 1964). From our perspective, however, such directional changes in vegetation through bush

encroachment, even when they certainly take place in arid grassland ecosystems, may have been broadly inferred to all grazing areas of northern Mexico, including ecosystems of a different nature from grasslands. This is the case of the vegetation of the north-eastern Coastal Plain (Rzedowsky, 1986). In northeastern Mexico the shrubby Tamaulipan thornscrub, which consists of an assemblage of tall, medium and dwarf shrubs form a highly diverse and extremely dense and closed plant community of about 80 shrub and tree-like species, over an understorey of around 30 annual and perennial species of grasses and herbs (Alanís, 1991; Reid *et al.*, 1990; Heiseke, 1986; Rojas-Mendoza, 1965). Historical records from pioneer botanists, report that woody species have been the dominant life form for centuries in the region and constitute the characteristic vegetation (del Hoyo, 1979; Rojas-Mendoza, 1965; Johnston, 1962). The Tamaulipan thornscrub occurs on both sides of the Rio Bravo/Rio Grande across the Mexico-USA border. It is estimated that 98% of this community in the American counterpart has been cleared since the early 1900's, and similar figures are for Mexico as well, to increase agriculture areas, seed artificial pastures, and expand urban developments (Collins, 1984). Adaptation of cattle to brush habitat possibly began with the first grazed herds brought by Spaniards to the region; cattle used shrubland for warmth and protection during winters and for calving in spring (Crosswhite, 1980). Little or no documentation is available on longterm perturbations to native flora associated with ranching in South Texas (Lonard, 1985), neither for north-eastern Mexico. Experimental evidence suggests that, under intense, frequent, and heavy grazing, this plant community seems to have

degradation pathways just in the opposite direction of those of grasslands, i.e., from woodies to grasses and herbs, mainly annuals (Manzano and Návar, 2000). Such changes tend to lead to a patched plant community, simpler, and more prone to disturbance; where decreasing plant and animal biodiversity and productivity, soil degradation, and detrimental microclimatic changes might be expected (Manzano and Návar, 2000; Petit *et al.*, 1995). Exclusions in this community may apparently lead to a shrubby community in its maximum peak of diversity and physiognomy, as has been observed after isolating an area from grazing and any human activity other than research for around 20 years in the south-eastern part of Nuevo León.

If it were assumed that original vegetation of the north-eastern Coastal Plain is better mirrored by the current shrubby vegetation than by a grassland situation, then the dominant Tamaulipan thorn scrub might be considered the most desirable condition of the vegetation, i.e., the climax (Clements, 1916), or a steady-state vegetation (Westoby *et al.*, 1989). In that case, application of ecological principles and range management strategies should be aimed to conserve and improve this plant community, instead of regarding it as worthless vegetation that has invaded and impaired the true grasslands and must be cleared from the landscape, as has been done for decades in large areas of the region (Maldonado, 1992; Collins, 1984). Native shrub species are well adapted to the extreme climatic fluctuations of the region, by virtue of their well developed root system (Návar *et al.*, 2000). They improve soil physical properties, and enhance nutrient uptake from

the lower depths (Návar and Bryan, 1990). Legumes, which are well known for promoting nitrogen fixation, represent around 30% of the shrubby component of the native vegetation (Reid *et al.*, 1990) and are the most important species in terms of diversity and canopy cover (González *et al.*, 1997).

Impact of grazing on shrublands of the north-eastern region is poorly documented due to the scarcity of data obtained under controlled stocking rate longterm experiments to allow for discrimination of the effects of climate and grazing regimes. While many authors (Maldonado, 1992; Heiseke and Foroughbakhch, 1985; Foroughbakhch and Peñaloza, 1988; Foroughbakhch *et al.*, 1987, among others) have reported soil erosion or degradation problems due to overgrazing in the Mexican north-eastern shrublands, there are very few publications providing specific field data on the issue. Manzano and Navar (2000), for instance, found significant increases in soil bulk density in only one year after a single overgrazing episode by goats, as well as detrimental changes in the community structure plant. During the period, soil bulk density increased 13% within treated plots, and 16% in untreated plots. Vertical structure of the plant community was modified through the reduction of leaf cover of shrubs up to 1.5 m along the plant profile and the increase in cover of annual grasses and herbs. Pando-Moreno (unpublished) has found two main degradation problems associated with grazing on rangelands in the region: an increase in compaction of the soil surface, and loss of fertility. These factors are well known to reduce infiltration rates, and

increase runoff and erosion. Practically, the effects of these factors are hardly separable, but their magnitude may vary independently from one to the other depending on the soil texture, vegetation cover, stocking rate and management. According to Pando-Moreno's results, compaction seems to be a more rapidly increasing problem in the area due to overgrazing, both for shrublands and for sown pastures. After analyzing sixteen sampling areas in rangelands in the north-east of Mexico, in 1996, 1997 and 1999, the same author reported an average increase in soil bulk density of 0.1574, which means an 11.92% increment.

Land tenure implications

Raising cattle for meat production is the most important rangeland use in the northern states of Mexico, usually under an extensive free grazing management system. This activity is mainly carried on by private landowners, who have developed traditional range management techniques originally adapted from north American ranchers, aimed at controlling shrub invasion in rangelands. These include, in most cases, the complete elimination of any woody individual from the grassland landscape. Indeed, large grazing areas in most of the region have been shrub-controlled through the use of fire, chemicals, and mechanical suppression. In many situations all the native shrub vegetation has been mechanically eliminated to either induce the growth of native grasses or to raise exotic grass species. Currently however, modern local range management techniques consider trees and shrubs as desirable, and allow their presence on grasslands, in low densities, as they are important components

of the range system that provide browse and shelter for grazing animals, and a more attractive habitat for hunting fauna. However, although such practices are currently employed, many private farm rangelands have continually been overused and shrub-cleared in the last few decades, especially during and after the green revolution (in the 1960's), when agriculture and sown pastures started to expand dramatically. In 1953-54, agricultural areas in the State of Tamaulipas covered 242,800 ha, and by 1980-81 they were expanded, at the expense of the Tamaulipan thornscrub, up to 1310,000 ha (USFWS, 1983). Only in the State of Nuevo León, over 150,000 ha were totally cleared during a five-year period in the early 1980's (at an average rate of 73 ha per day) under the State government's initiative (Maldonado, 1992), to expand agriculture lands and sow artificial pastures with exotic grasses, mainly in private ranches, increasing the fragmentation of the regional landscape.

Although the private grazing system has undoubtedly contributed to desertification of rangelands, the communal system is blamed for most of the severe overgrazing and the consequent land degradation. Since the Mexican revolution, ejidos replaced displaced private farms. Then a simultaneous and equally accelerated deterioration in the rangelands was evident (Escurra and Montaña, 1990; LaBaume and Dahl, 1986). There are two forms of property rights in the ejido: individual plots and common property lands, mainly in rangelands and forests. Land under individual jurisdiction is mainly allocated to crops, and the product of croplands is privately appropriated (McCarthy *et al.*, 1998). Meanwhile,

rangelands are collectively, freely, and heavily grazed without charges or regulations for the use of community resources.

A variety of domestic animals, such as goats, cattle, sheep, hogs, horses, and donkeys, usually forage communal rangelands. Since most of the communal land is not appropriate for agriculture due to the lack of water for irrigation, low fertility of soils, and generally scarped topography (Simon, 1998), landholders make use of increasingly hardy and more agile types of domestic livestock that feed on a wider spectrum of plant species (Milton *et al.*, 1994; Schofield and Bucher, 1986), in order to ensure a more complete use of the scarce rangeland resources, and to cope better with the harshness of the environment (the larger the herd, the more the survivors after a long dry season). Under this system, all users share the cost of using an additional unit of a resource, but the benefit of using this additional unit accrues to the individual user of that unit (LaBaume and Dahl, 1986). The wrong idea of "that belonging to everybody, does not belong to anybody", has caused in most cases indifference and lack of cooperation among landholders to develop appropriate management practices and conservation tasks on communal rangelands. However, as LaBaume and Dahl (1986) stated, it is possible that the real problem is not the communal land tenure regime, but the methods and forms of organization: some ejidatarios have relatively larger herds, each individual desires to be independent, possess his own herd, and be his own boss. Socio-economical models for communal land tenure have showed that, when cooperation among landholders in the management of communal rangelands fails

more land is allocated to crops and less land to range, but stocking rates on the other hand, increase dramatically.

Another important issue of concern is that livestock production practices are consuming the resources on which other natural resource-based enterprises also depend. Although new and improved technologies and practices that can potentially contribute to the creation of sustainable production systems are being developed, they are not reaching producers of all sizes, leaving small producers, such as ejidatarios, excluded from the implicit benefits because of their high costs. Furthermore, the individual holdings of ejidatarios are too small and their capacity to develop and implement efficient programs too limited to take advantage of opportunities that are available in the same region on larger enterprises (Consorcio Técnico *et al.*, 2000). The only way ejidatarios can obtain financial aid to have access to improved technologies is through governmental programs. They are highly dependent on such programs, which, apart from being not permanent, are budget-limited and subject to bureaucratic biases.

Recent Federal government initiatives on land issues have led to the semi-privatization of the ejido. Nowadays, the ejidatarios have private property rights over their land and are allowed to trade it among them and with private producers, and/or to make associations with the latter ones, who would invest capital to improve production systems in the lands of the ejido. These reforms in the Mexican laws intend to transform the ejido into a more efficient and productive system. There may be two possible, and contrasting, future scenarios: (1) An

optimistic scenario, agreeable with the government's purposes, is a fair association ejidatario-private investor and among ejidatarios by means of which sustainable agriculture and animal production systems, and plausible economic inputs to ejidatarios, might be expected. A fair land trade would lead to improved rangelands through more judicious management techniques by the new owner. (2) The unfortunate scenario, which might be possible on the mid to long term, implies two things: socially, the reversal to the past socio-economic structure, when ejidatarios, by selling the land, become simple laborers on big haciendas; technically, it is feasible that under the bizarre association ejidatario-investor, focused mainly on the most fertile and profitable lands. Degraded rangelands might only be seen as available resource without any additive value and be abandoned from any management or improvement, as well as persistently overused because of the continued demand for livestock products from regional and foreign markets.

Alternatives for Improvement

The most frequent recommendation to lessen the grazing pressures on rangelands is to reduce the number of grazing animals and to allow severely grazed areas to rest for a given period of time, usually years. Nevertheless, a degraded range has a low value and generates little income for its owners to be able to afford to rest the land for a year or more (Milton *et al.*, 1994). As stated above, new forms of organizations are more important than land tenure to reduce these trends and increase output production. Then, solutions to reduce grazing pressures on communal rangelands have been aimed at better organization of the ejidatarios, without removing grazing animals from

range. The former Secretary of Agriculture and Livestock recommended the amalgamation of individual herds into a collective one of proper size, according to the range carrying capacity. This collective herd could belong to a grazing association. Members would hold shares of stock or some similar evidence of property rights, and the balance of unemployed labor could be used to create social capital, such as improvement of range infrastructure (LaBaume and Dahl, 1986). Hanselka *et al.* (1996) suggested the creation of cooperatives or associations for production and marketing to use the power of scale to better represent interests of individual ejidatarios. Although with some constraints, such as the willingness of ejidatarios to change individualism for common work within the communal land tenure system, proposals like these sound as advantageous and must be tested at local levels, starting with pilot ejidos and monitored regularly.

Making use of the natural potential of the land introducing alternative economic activities may convert the ejido's lands into a growing enterprise. Indeed the ejidos provide an existing opportunity for production and marketing enterprises for traditional rangeland products, but also for the non-traditional income potential that exists in the region, such as hunting, bird watching, nature-based tourism and other forms of recreation (Vázquez and González, 1999). In the last two decades, the combined production of livestock and wild animals increased dramatically in northern Mexico. Currently, more than 20 million hectares in diversified private ranches are utilized for sport hunting activities. These newly-fashioned enterprises are both ecologically

and economically more suitable than the livestock production, and can be a favourable option for ejidos to develop them within the new land tenure framework.

Agroforestry and silvopastoral systems could provide an alternative to improve pastoralism in the region, giving a greater buffer capacity and allowing for sustainable production even in critical years (Pando-Moreno and Villalón, 2000; González and Villarreal, 1989).

Since the last estimates of biomass production in rangelands were made 20 years ago, carrying capacity data for rangelands need to be updated. So far, COTECOCA's estimates are the only data source on which the stocking rates are based. In addition, biomass calculations must be made distinguishing all of the present biomass and the edible forage, and they should be specific for each domestic animal species, or groups of species, according to their diet and feeding habits. This certainly implies a huge amount of work and human and economical resources, and could take a long time, especially if we attempt to cover the entire territory with all its intrinsic heterogeneity. Then, it might be useful to develop an easy-to-follow standard technique that any interested producer or range manager would be able to practically determine the carrying capacity of a certain range.

It is certainly true that there are different trends on which characteristic rangeland vegetation of the region, i.e., grasslands and shrublands, may evolve when the system is under grazing stress. Origin of northern floras and vegetation is still uncertain, and controversial, and most of the available references are historical statements based

on empirical, personal observations subject to bias. However, it is hard to believe that rich and stable plant communities, such as the Tamaulipan thornscrub, are the result of grazing disturbance and be characterized as secondary vegetation in the region ecosystems. Then geological and fossil evidences, as well as additional ecological studies, such as those of Archer *et al.* (1999) and others, are definitely necessary at local/regional levels in order to truly identify the origin of the vegetation and infer any trend in the processes of vegetation degradation and recovery in north-eastern Mexican rangelands.

Conclusions

Range management, land tenure, and organization of producers arise as the main challenges regarding rangeland degradation in northern Mexico. Technically, improved grazing management may offer an opportunity for rangeland to recover diversity and productivity, although depends upon an understanding of processes regulating plant succession, stability, and resilience (May, 1997; Walker and Noy-Meir, 1981; Walker *et al.*, 1981). Therefore, studies aimed to improve the knowledge on the dynamics of the local vegetation and to identify definite thresholds and break points beyond which desertification processes accelerate are definitely necessary in the region's rangeland ecosystems. In practice, however, the achievement of sound range management is dependent on a number of natural, technical, and socio-economic and political factors described above. In view of the new changes on land tenure issues, the most convenient alternative to fairly counterbalance the concerns of all the involved parties, i.e., rangeland, ejidatarios, and private investors,

seems to be to take advantage of the situation and bring investment to the ejido through equitable alliances between ejidatarios and private investors for the diversification of production activities. Investment must be channeled to enhance rangeland through research and suitable range management as well. Thus, grazing management techniques can be appropriately prescribed, range resources conserved, and desertification processes lowered.

Acknowledgments

The authors wish to thank Aden Takar and Mark Juhasz for revising the manuscript and improving the language. The senior author wants to thank Consejo Nacional de Ciencia y Tecnologia, Mexico (CONACYT), and Dr. Rorke B. Bryan (University of Toronto) for the financial support and for the time allowed to prepare the present report.

References

- Alanís, F.G.J. 1991. *El matorral del Noreste de México como un recurso forrajero potencial para el ganado caprino. Reporte Científico. No. Especial 8.* Facultad de Ciencias Forestales. UANL. 23 p.
- Archer, S. 1989. Have southern savannas been converted to woodlands in recent history? *The American Naturalist* 134(4): 545-561.
- Archer, S. 1994. Woody plants encroachment into southwestern grasslands and savannas: Rates, patterns and proximate causes. In *Ecological Implications of Livestock Herbivory in the West* (Eds. M. Vavra, W.A. Laycock and R.D. Pieper). Denver. pp. 13-68. Society for Range Management.
- Archer, S., MacKay, W., Mott, J., Nicholson, S.E., Pando-Moreno, M., Rosenzweig, M.L., Seligman, N.G., West, N.E. and Williams, J. 1999. Arid and semi-arid land community dynamics in a management context. In *Arid Lands Management: Toward Ecological*

- Sustainability* (Eds. T.W. Hoekstra and M. Shachak), pp. 48-74. University of Illinois Press.
- Archer, S., Scifres, C.J., Bassham, C.R. and Maggio, R. 1988. Autogenic succession in a subtropical savanna: conversion of grassland to thorn woodland. *Ecological Monographs* 58: 111-127.
- Archer, S. and Smeins, F.E. 1991. Ecosystem-level processes. In *Grazing Management: An Ecological Perspective* (Eds. R.K. Heitschmidt and J.W. Stuth), pp. 109-139. Timber Press, Portland, USA.
- Baker, D.L. and Guthery, F.S. 1990. Effect of continuous grazing on habitat and density of ground-foraging birds in South Texas. *Journal of Range Management* 43: 2-5.
- Barry, R.G. and Chorley, R.J. 1987. *Atmosphere, Weather, and Climate*. 5th Ed. Methuen & Co., New York.
- Bassols B.A. 1989. *Recursos Naturales de México: Teoría, Conocimiento y Uso*. Nuestro Tiempo, México.
- Bell, M.H. 1973. *Rangeland Management for Livestock Production*. University of Oklahoma Press, Oklahoma.
- Belsky, A.J. 1986. Does herbivory benefit plants? A review of the evidence. *American Naturalist* 127: 870-892.
- Blackburn, W.H. 1975. Factors influencing infiltration and sediment production of semiarid rangelands in Nevada. *Water Resources Research* 11: 929-937.
- Bryant, N.A., Provenza, F.D., Pastor, J., Reichardt, P.B., Clausen, P. and du Toit, J.T. 1991. Interactions between woody plants and browsing mammals mediated by secondary metabolites. *Annual Review Ecology System* 22: 431-446.
- Bucher, E.H. 1987. Herbivory in arid and semiarid regions of Argentina. *Rev. Chil. Hist. Nat.* 60: 265-273.
- Buffington, L.C. and Herbel, C.H. 1965. Vegetation changes on a semi-desert grassland range from 1858 to 1963. *Ecological Monographs* 35: 139-164.
- Buller, R.E., Hernández, X.E. and González, M.H. 1960. Grassland and livestock regions of Mexico. *Journal of Range Management* 13(1): 1-6.
- Charney, J., Stone, P.H. and Quirk, W.J. 1975. Drought in the Sahara: A biogeophysical feedback mechanism. *Science* 187: 434-435.
- Chew, R.M. 1982. Changes in herbaceous and suffrutescent perennials in grazed and ungrazed desertified grassland in southeastern Arizona 1958-1978. *American Midland Naturalist* 108: 159-169.
- Clements, F.E. 1916. *Plant succession: An Analysis of the Development of Vegetation*. Carnegie Inst., Washington, Pub. 242: 1-512.
- Collins, K. 1984. *Status and Management of Native South Texas Brushlands*. US Fish and Wildlife Service, Ecological Services. Corpus Christie TX.
- Consorcio Técnico del Noreste de México A.C., Center for Grazinglands and Ranch Management, and The Agriculture Program of the Texas A&M University System. 2000. *Proposal for improving integrated forage-based production systems and enhancing their influence on improvement of socio-economic conditions in northeast Mexico and South Texas*. Cd. Victoria, Tamaulipas, México. 27 p.
- Cooper, C.F. 1960. Changes in vegetation, structure, and growth of southwestern pine forests since white settlement. *Ecological Monographs* 30: 129-164.
- COTECOCA. 1973. *Coefficientes de agostadero de la República Mexicana. Estado de Nuevo León*. COTECOCA-SARH. México.
- COTECOCA. 1978a. *Coefficientes de agostadero de la República Mexicana. Estado de Sonora*. COTECOCA-SARH. México.
- COTECOCA. 1978b. *Coefficientes de agostadero de la República Mexicana. Estado de Tamaulipas*. COTECOCA-SARH. México.
- COTECOCA. 1978c. *Coefficientes de agostadero de la República Mexicana. Estado de Chihuahua*. COTECOCA-SARH. México.
- COTECOCA. 1979a. *Coefficientes de agostadero de la República Mexicana. Estado de Coahuila*. COTECOCA-SARH. México.
- COTECOCA. 1979b. *Coefficientes de agostadero de la República Mexicana. Estado de Durango*. COTECOCA-SARH. México.
- Crosswhite, F.S. 1980. Dry country plants of the south Texas plains. *Desert Plants* 2: 141-179.
- del Hoyo, E. 1979. *Historia del Nuevo Reino de León (1577-1723)*. 2nd Ed., Libros de México. México. 662 p.

- Dregne, H.E. 1983. *Desertification of Arid Lands*. Hardwood Academic Publishers.
- Dregne, H.E. 1984. North American deserts. In *Deserts and Arid Lands* (Ed. F. El-Baz), pp. 145-156. Martinus Nijhof Publishers. The Netherlands.
- El Aich, A. and Waterhouse, A. 1999. Small ruminants in environmental conservation. *Small Ruminant Research* 34: 271-287.
- Escurre, E. and Montaña, C. 1990. *Los recursos naturales renovables en el norte árido de México. Medio Ambiente y Desarrollo* Vol. 1 E. Leff (Coord.). Centro de Investigaciones Interdisciplinarias en Humanidades. UNAM. Porrúa. México.
- Floate, M.J.S. 1981. Effects of grazing by large herbivores on nitrogen cycling in agricultural ecosystems. *Terrestrial nitrogen cycles. Ecological Bulletin* 33: 585-601.
- Flory, E.L. 1936. Comparison of the environment and some physiological responses of prairie vegetation. *Ecology* 17: 67-103.
- Fogden, M.P.L. 1978. *The impact of lagomorphs and rodents on the cattle rangelands of northern Mexico. Report, 1973-1977*. Centre of Overseas Pest Research, College House, London.
- Foroughbakhch, P.R. and Martínez, A. 1986. *Estudio sobre diferentes tipos de agostaderos y la producción caprina en la región de Linares y Hualahuises, Nuevo León, México. Fundamentos ecológicos, usos actuales y potenciales de los bosques y matorrales en el noreste de México. Contribuciones de la Facultad de Silvicultura y Manejo de Recursos Naturales Renovables de Linares, Nuevo León, México*. pp. 159-183. *Schriften aus der Forstlichen Fakultät der Universität Göttingen. Unter der Niedersächsischen Forstlichen Versuchsanstalt*.
- Foroughbakhch, P.R. and Peñaloza, R. 1988. *Introducción de 10 especies forestales en el matorral del noreste de México. Reporte Científico No.8. Facultad de Ciencias Forestales, UANL. Linares, México*.
- Foroughbakhch, P.R., Peñaloza, R. and Stienen, H. 1987. Increasing productivity in the matorral of northeastern Mexico: domestication of ten native multipurpose tree species. In *Proceedings, Strategies for Classification and Management of Native Vegetation for Food Production in Arid Zones*, pp. 32-38. Tucson.
- Friedel, M.H. 1991. Range condition assessment and the concept of thresholds: A viewpoint. *Journal of Range Management* 44: 422-426.
- Gibbens, R.P., Beck, R.F., McNeely, R.P. and Herbel, C.H. 1992. Recent rates of mesquite establishment in the northern Chihuahuan Desert. *Journal of Range Management* 45: 585-588.
- Gifford, G.F. and Hawkins, R.H. 1978. Hydrologic impact of grazing on infiltration: A critical review. *Water Resources Research* 14: 305-313.
- González, E.M., Treviño, G.E.J. and Aguirre, O.A.C. 1997. Fisonomía y composición de la vegetación secundaria en un área de matorral del noreste de México. *Phytologia* 83(4): 257-269.
- González, C.E. and Villarreal, R. 1989. *Agrosilvicultura: Perspectivas en el tiempo y en el espacio. Simposio Agroforestal en México*. Linares, México. pp. 52-97.
- González, O.R.I., Javalera, M.R. and Ochoa, G.J.G. 1987. *Respuesta de la vegetación en áreas excluidas al pastoreo en el norte de Durango. Resultados de Investigación sobre ecología y manejo de pastizales en el norte de Durango 1978-1987*. CIFAP Durango. Publicación Especial No. 2. pp. 23-45.
- Grover, H.D. and Musik, B. 1990. Shrubland encroachment in southern New Mexico: An analysis of desertification processes in the American southwest. *Climatic Change* 17: 305-330.
- Hanselka, C.W., Thurow, A.P. and Hamilton, W.T. 1996. Rangeland resources and water issues in the lower Rio Grande River watershed: An economic and policy context for descriptive analysis. *Contract Report* (Ed. G.L. McBryde). Land tenure effects under NAFTA on a US-Mexico watershed. USDA, CSRS.
- Hanson, C.L., Kuhlman, A.R., Erickson, C.J. and Lewis, J.K. 1970. Grazing effects on runoff and vegetation of a western South Dakota rangeland. *Journal of Range Management* 23: 418-420.
- Heiseke, D. 1986. *Regeneración por rebrotes en dos tipos de matorral del Noreste de México. Schriften aus der Forst-lichen Fakultät der Universität Göttingen und der Niedersächsischen Forst-lichen Versuchsanstalt*. 84: 184-199.
- Heiseke, D. and Foroughbakhch, P.R. 1985. El matorral del noreste de México como recurso

- forestal —evaluación de dos tipos de matorral en la región de Linares. *Reporte Científico No 1*. Facultad de Silvicultura y Manejo de Recursos Naturales Renovables, UANL. Linares, México.
- Herbel, C.H. 1986. Vegetation changes on arid rangelands of the southwestern United States. *Rangelands: A Resource Under Siege. Proceeding of the 2nd International Rangeland Congress* (Eds. P.J. Joss, P.W. Lynch and O.B. Williams), pp. 8-10. Cambridge Univ. Press.
- Hillel, D. 1982. *Introduction to Soil Physics*. Academic Press. San Diego. 364 p.
- Holechek, J.L., Pieper, R.D. and Herbel, C.H. 1989. *Range Management. Principles and Practices*. Prentice Hall. Englewood Cliffs, New Jersey.
- Huss, L.D. and Aguirre, V.E. 1978. *Fundamentos de manejo de pastizales*. ITESM. Monterrey, México.
- Idso, S.I. and Deardorff, J.W. 1978. Comments on the effect of variable surface albedo on atmospheric circulation in desert regions. *Journal of Applied Meteorology* 17: 560-565.
- INEGI 1996. *Anuario Estadístico de los Estados Unidos Mexicanos, 1996*. INEGI. México.
- INEGI 1998a. *Anuario Estadístico de los Estados Unidos Mexicanos, 1998*. INEGI. México.
- INEGI 1998b. *Estadísticas del medio ambiente, 1997*. INEGI-SEMARNAP. México.
- Jackson, R. D. and Idso, S.B. 1975. Surface albedo and desertification. *Science* 189: 1012-1013.
- Johnston, M.C. 1962. Past and present of grasslands of southern Texas and northern Mexico. *Ecology* 44: 456-466.
- Jurado, Y.E. and Reid, N. 1989. Influencia de factores edáficos, topográficos y perturbación sobre el matorral espinoso tamaulipeco en Linares, Nuevo León. *Reporte Científico No. 10*. Facultad de Ciencias Forestales. UANL. 29 p.
- Kerley, G.I.H. 1992. Ecological correlates of small mammal community structure in the semi-arid Karoo, South Africa. *Journal of Zoology* 227: 17-27.
- Kuchler, A.W. 1964. *The Potential Natural Vegetation of the Conterminous United States*. American Geographical Society, New York.
- LaBaume, J.T. and Dahl, B.E. 1986. Communal grazing: the case of the Mexican ejido. *Journal of Soil and Water Conservation*. Jan-Feb: 24-27.
- Lauenroth, W.K., Milchunas, D.G., Dodd, J.L., Hart, R.H., Heitschmidt, R.K. and Rittenhouse, L.R. 1994. Effects of grazing on ecosystems of the Great Plains. In *Ecological Implications of Livestock Herbivory in the West* (Eds. M. Vavra, W.A. Laycock and R.D. Pieper), pp. 69-100. Society for Range Management, Denver.
- Lonard, R.I. 1985. Natural communities of the south Texas plains. *Proceedings of the Texas Academy of Science, Conservation Committee on Natural Communities of Texas*. University of Texas, Dallas.
- López-Trujillo, R. and García-Elizondo, R. 1995. Botanical composition and diet quality of goats grazing natural and grass reseeded shrublands. *Small Ruminant Research* 16(1): 37-47.
- Maldonado, H.A. 1992. *Modelo para la evaluación cuantitativa de la desertificación. Tesis Profesional. Facultad de Ciencias Forestales, UANL. Linares, México*.
- Manzano, M.G. and Návar, J. 2000. Processes of desertification by goats overgrazing in the Tamaulipan thornscrub (matorral) in north-eastern Mexico. *Journal of Arid Environments* 44: 1-17.
- Martínez, A. 2000. *Estado de las poblaciones de venado bura del Desierto Chihuahuense en el noreste de México. Ciencia UANL* 3(4) In press.
- May, R.M. 1977. Thresholds and breakpoints in ecosystems with a multiplicity of stable states. *Nature* 269: 471-477.
- McCarthy, N., de Janvri, A. and Sadoulet, E. 1998. Land allocation under dual individual-collective use in Mexico. *Journal of Development Economics* 56: 239-264.
- Mellado, M., Foote, R.H., Rodríguez, A. and Zarate, P. 1991. Botanical composition and nutrient content of diets selected by goats grazing on desert grasslands in Northern Mexico. *Small Ruminant Research* 6(1-2): 141-150.
- Milchunas, D.G. and Lauenroth, W.K. 1993. Quantitative effects of grazing on vegetation and soils over a global range of environments. *Ecological Monographs* 63(4): 327-366.
- Milchunas D.G., Sala, O.E. and Lauenroth, W.K. 1988. A generalized model of the effects of grazing by large herbivores on grassland community structure. *American Naturalist* 132: 87-106.

- Milton, S.J., Dean, W.R.J., du Plessis, M.A. and Siegfried, W.R. 1994. A conceptual model of arid rangeland degradation. *Bioscience* 44(2): 70-76.
- Návar, J. and Bryan, R.B. 1990. Interception loss and rainfall redistribution by three semi-arid growing shrubs in northeastern Mexico. *Journal of Hydrology* 115: 51-63.
- Návar, J., Méndez, J., Bryan, R.B. and Kuhn, N.J. 2000. The contribution of shrinkage cracks to bypass flow during simulated rainfall experiments in northern Mexico. *Canadian Journal of Soil Science* (in press).
- Novikoff, G. 1983. Desertification by overgrazing. *Ambio* 12: 102-105.
- Otterman, J.E. 1974. Baring high-albedo soils by overgrazing: A hypothesized desertification mechanism. *Science* 186: 531-533.
- Pando-Moreno, M. and Villalón, H. 2000. Species with agroforestry potential from the Tamaulipan thornscrub in northeastern Mexico. *Agroforestry Today* (in press).
- Parton, W.J. and Risser, P.G. 1980. Impact of management practices on the tallgrass prairie. *Oecologia* 52: 370-375.
- Passera, C.B., Borsetto, O., Candia, R.J. and Stasi, C.R. 1992. Shrub control and seedling influences on grazing capacity in Argentina. *Journal of Range Management* 45: 480-482.
- PEF 1995. *Programa Forestal y de Suelo 1995-2000*. Poder Ejecutivo Federal-SEMARNAP. México.
- Pettit, N.E., Froend, R.H. and Ladd, P.G. 1995. Grazing in remnant woodland vegetation: changes in species composition and life form groups. *Journal of Vegetation Science* 6: 121-130.
- Pieper, R.D. 1994. Ecological implications of livestock grazing. In *Ecological Implications of Livestock Herbivory in the West* (Eds. M. Vavra, W.A. Laycock and R.D. Pieper), pp. 177-211. Society for Range Management, Denver.
- Pluhar, J.J., Knight, R.W. and Heitschmidt, R.K. 1987. Infiltration rates and sediments production as influenced by grazing systems in the Texas rolling plains. *Journal of Range Management* 40: 240-243.
- Ramírez-Lozano, R.G. 1999. Feed resources and feeding techniques of small ruminants under extensive management conditions. *Small Ruminant Research* 34(3): 215-230.
- Ramírez-Lozano, R.G. 2000. *Valor nutricional del forraje de árboles y arbustos*. Ciencia UANL. 3(3): 303-311.
- Rauzi, F.C. and Hanson, C.L. 1966. Water intake and runoff as affected by intensity of grazing. *Journal of Range Management* 19: 351-356.
- Rawls, W.J., Brakensiek, D.L., Simanton, J.R. and Hanson, C.L. 1988. Prediction of soil cover and soil rock for rangeland infiltration. *Journal of Range Management* 41(4): 307-308.
- Reid, N., Marroquin, J. and Beyer-Munzel, P. 1990. Utilization of shrubs and trees for browse, fuelwood and timber in the Tamaulipan thornscrub, northeastern Mexico. *Forest Ecology and Management* 36: 61-79.
- Rojas-Mendoza, P. 1965. *Generalidades sobre la vegetación del Estado de Nuevo León y datos acerca de su flora*. Thesis Doctoral. UNAM, Mexico.
- Rzedowsky, J. 1986. *Vegetación de México*. Limusa. México.
- Sánchez L.V.W. 1969. *Los recursos naturales de México*. IMRNR. México.
- Savory, A. 1983. The Savory grazing method or holistic resource management. *Rangelands* 5: 155-159.
- Schofield, C.J. and Bucher, E.H. 1986. Industrial contributions to desertification in South America. *Trends in Ecology and Evolution* 1: 78-80.
- Sellers, U.D. 1965. *Physical Climatology*. University of Chicago Press, Chicago.
- Semple, T.A. 1974. *Pasturas cultivadas y naturales*. Hemisferio Sur. Buenos Aires.
- Simon, J. 1998. *México en riesgo: un medio ambiente al borde del abismo*. Diana. México. 302 p.
- Sluyter, A. 1998. From archive to map to pastoral landscape: A spatial perspective on the livestock ecology of the sixteenth-century New Spain. *Environmental History* 3(4): 508-528.

- Solanki, G.S. 1994. Feeding habits and grazing behavior of goats in a semi-arid region of India. *Small Ruminant Research* 14(1): 39-43.
- Stoodart, E.H., Smith, A.D. and Box, T.W. 1975. *Range Management*. McGraw-Hill, New York.
- Takar, A.A., Dobrowski, J.P. and Thurow, T.L. 1990. Influence of grazing, vegetation life-form, and soil type on infiltration rates and interrill erosion on a Somalian rangeland. *Journal of Range Management* 43(6): 486-490.
- Tanner, C.B. and Marmaril, C.P. 1959. Pasture soil compaction by animal traffic. *Agronomy Journal* 51: 329-331.
- Tapia, J.C. and Hernández, X., E. 1957. *Producción forrajera y manejo de pastizales. Problemas de la industria agropecuaria en México*. IMRNR, México.
- Taylor, R.B., Rutledge, J. and Herrera, J.G. 1997. *A Field Guide to Common South Texas Shrubs*. Texas Parks and Wildlife. Austin. 106 p.
- Téllez, R. and Foroughbakhch, R. 1990. *Plantas aprovechadas por el ganado caprino en una zona de matorral mediano espinoso del noreste de México. Reporte Científico No. 21. Facultad de Ciencias Forestales, UANL. Linares, México*.
- Thurow, T.L., Blackburn, W.H. and Taylor Jr., C.A. 1986. Hydrologic characteristics of vegetation types as affected by livestock grazing systems, Edwards Plateau, Texas. *Journal of Range Management* 39: 505-508.
- Thurow, T.L., Blackburn, W.H. and Taylor Jr., C. A. 1988. Some vegetation responses to selected livestock grazing strategies, Edwards Plateau, Texas. *Journal of Range Management* 41: 108-114.
- Thurow, T.L. 1991. Hydrology and erosion. In *Grazing Management. An Ecological Perspective* (Eds. R.K. Heitschmidt and J.W. Stuth), pp. 141-159. Timber Press, Portland, USA.
- USFWS 1983. *Department of the Interior Land Protection Plan-Lower Rio Grande Valley National Wildlife Refuge in Cameron, Hidalgo, Starr, and Wallacy counties, Texas Region 2*. United States Fish and Wildlife Service. Albuquerque NM.
- Vázquez, M.A. and González, J.G.V. 1999. Range resource conservation for ecotourism. In *Proceedings of the 3rd Workshop on Conservation and Use of Natural Resources and Marketing of Beef Cattle*. pp. 196-200. Monterrey, Mexico.
- Walker, B.H., Ludwig, D., Holling, C.S. and Peterman, R.M. 1981. Stability of semi-arid savanna grazing systems. *Journal of Ecology* 69: 473-498.
- Walker, B.H. and Noy-Meir, I. 1981. Aspects of the stability and resilience of savanna ecosystems. In *Ecology of Tropical Savannas* (Eds. B.J. Huntley and B.H. Walker). Springer, Berlin.
- Warren, S.D., Thurow, T.L., Blackburn, W.H. and Garza, N.E. 1986. The influence of livestock trampling under intensive rotation grazing on soil hydrologic characteristics. *Journal of Range Management* 39: 491-495.
- Weltz, M. and Wood, M.K. 1986. Short duration grazing in central New Mexico: Effects on infiltration rates. *Journal of Range Management* 39: 365-368.
- Westoby, M., Walker, B. and Noy-Meir, I. 1989. Opportunistic management for rangelands not at equilibrium. *Journal of Range Management* 42: 266-274.
- Whitford, W.G. 1997. Desertification and animal biodiversity in the desert grasslands of North America. *Journal of Arid Environments* 37(4): 709-720.
- Wilcox, B.P. and Wood, M.K. 1988. Hydrologic impacts of sheep grazing on steep slopes in semiarid rangelands. *Journal of Range Management* 41(4): 303-306.
- Wilkinson, S.R. and Lowrey, R.W. 1973. Cycling in mineral nutrients in pasture ecosystems. In *Chemistry and Biochemistry of Herbage* (Eds. G.W. Butler and R.W. Bailey), Vol. 2, pp. 247-315. Academic Press, New York.
- Wood, M.K. and Blackburn, W.H. 1984. Vegetation and soil responses to cattle grazing systems in the Texas Rolling Plains. *Journal of Range Management* 37: 298-303.

- Woodmansee, R.G. 1978. Addition and losses of nitrogen in grassland ecosystem. *Bioscience* 28: 448-453.
- York, J.C. and Dick-Peddie, W.A. 1969. Vegetation changes in southern New Mexico during the past hundred years. In *Arid Lands in Perspective* (Eds. W.G. McGinnies and B.J. Goldman), pp. 157-166. Amer. Assoc. Adv. Sci., Washington, D.C. and the Univ. Ariz. Press, Tucson.
- Zimmerman, G.T. and Neueschwander, L.F. 1984. Livestock grazing influences on community structure, fire intensity, and fire frequency within the Douglas-fir/Ninebark habitat type. *Journal of Range Management* 37: 104-110.
- Zöbisch, M.A. 1993. Erosion susceptibility and soil loss on grazing lands in some semiarid and subhumid locations of Eastern Kenya. *Journal of Soil and Water Conservation* 48: 445-448.