Mexican Grasslands and the Changing Aridlands of Mexico: An Overview and a Case Study in Northwestern Mexico

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ABSTRACT

Grasslands cover about 14% of Mexico. They comprise alpine and subalpine grasslands, tropical savannas, arid and semi-arid grasslands, and induced grasslands. Arid and semi-arid grasslands comprise most of the grass-dominated communities in Mexico. There is great concern about the transformation of these into thornscrub through the action of several interrelated factors, mainly: overgrazing and diminishing fire frequency. At the same time, the introduction and naturalization of African grasses is changing the structural and functional properties of native grasslands and are creating new grass-dominated communities at the expense of other types of vegetation. In some cases the conversion has been so successful that consequences are irreversible in the short-term. A case study in the Sonoran Desert is presented where African buffelgrass (*Pennisetum ciliare*) is being planted for the deliberate conversion of the desertscrub. It is now actively invading large tracts of central Sonora, Mexico. Its presence in desert communities introduce a grass/fire cycle in assemblages of species with little evolution with fire. The presence of buffelgrass is creating a new, highly xerophytic grassland in Sonora at the expense of the desertscrub. The conversion changes the structure and functioning of the community, lowering the standing crop biomass and overall diversity.

INTRODUCTION

Grasslands in Mexico are a diffuse, ecologically diverse, and poorly known biome. In his work on the *Vegetation of Mexico,* Rzedowski (1978) grouped as grasslands all communities that had grasses as major structural and floristic components. These included zacatonales, pastizales , high

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elevation grasslands (páramo), and savannas (sabana). Also he included segments of communities with shrubs and trees at various elevations, including transitional communities with a major component of grasses associated with pine forests, oak woodlands, mesquite forests (mezquitales), tropical deciduous forests, and thornscrub. However, given the botanical scope of his work, he dealt only superficially with the processes of land use. The processes of land conversion, modification, and disturbance are of paramount importance to arid grasslands and desertscrub not only ecologically, but also in economical terms because of the use of grasses as forage by livestock.

Grasses are well known for their resistance to harsh environmental conditions. In Mexico, as happens in many other regions, grasslands are usually found on marginal habitats where extreme heat, cold, aridity, flooding, or special soil structure and composition are limiting to most plants (Rzedowski 1978, Van Devender 1995). These features coupled with the presence of fire and grazing have created and maintained grass-dominated communities that follow poorly understood rules of persistence. Mexican grasslands encompass communities governed by climatic factors, recurrent fires, particular soil properties, presence of specific herbivores and granivores, disturbance by man and cattle, or a combination of these. Such factors create a mosaic of grassland associations that are present over most of the country (Rzedowski 1975, 1978, Brown 1982a, McClaran 1995). According to COTECOCA (National Commission for the Determination of Cattle Stocking Rates), grass-dominated communities cover almost 14% of Mexico (Jaramillo 1994a, b, c). These grasslands have been divided into three major categories by Rzedowski (1978): 1) Grasslands (pastizal), equivalent to short-grass prairie that include all grasslands growing on steppe climates, 2) Savanna (sabana , or pastizal de clima caliente), that are mainly tropical or subtropical grass-shrub associations usually growing on heavy, poorly drained soils that experience seasonal cycles of flooding and dryness, and 3) Alpine and subalpine grasslands and montane meadows (zacatonal y praderas alpinas) that occur in the tropical high mountains, mainly in central Mexico. Another major type of grassland present in Mexico is the induced grassland created by the transformation and conversion of other plant communities. These are usually established through the introduction of exotic grass species, and special cultural practices.

Other, less extensive grasslands have high habitat specificity caused mainly by special edaphic conditions, or disturbance of forests. Some extreme examples of these, are the tidal grasslands of *Distichlis palmeri* in the Colorado delta (Glenn *et al*. 1992), halophilous grasslands in some closed basins (bolsones), gypsophilous grasslands on karstic and sedimentary substrates, and high elevation grasslands derived from the destruction of the oak and pine forests, mainly along the Eje Neovolcanico in Central Mexico.

In this paper, we will briefly describe the major types of grassland found in Mexico, and outline their distribution. Later, we will try to picture the two most extensive type of Mexican grasslands: desert grasslands, and induced desert grasslands. We will focus on their use, historical trends, threats and conflicts between pastoralists and conservationists. Finally, we will explore the development of a new type of grassland whose future as a permanent attribute of the aridlands is still uncertain, but likely to persist.

ECOLOGICAL DIMENSIONS

Alpine and Subalpine Grasslands

Alpine and subalpine grasslands cover about 3% of the country (*ca*. 18,250 ha, Jaramillo 1994a). Except for the alpine meadows and areas above the timberline, they are derived mainly from disturbances of coniferous forests. These grasslands occur on top of the major mountains of Mexico near the timberline (between 3500-4500 m; Rzedowski 1978). Only a few mountains in central Mexico have sufficient vertical development to provide this habitat, and thus are highly restricted in area. The climate is alpine (type ET), isothermal with average annual temperatures between 3-5°C, and annual rainfall between 600-800 mm. Beaman (1965) and Cruz (1969, in Rzedowski 1978) are among the few authors that have dealt with these communities, which according to Rzedowski (1978) are distinctly Mexican in term of species endemisms (70%). The maritime grasslands are more related at the specific level to South America than North America (18 vs 0% of total species), but at the generic level, holartic affinities predominate over neotropical (17 vs 12%). Typical grasses in these grasslands are: *Muhlenbergia quadridentata, Calamagrostis tolucencis, Festuca tolucencis, and F. livida* growing along with many Asteraceae and prostrate representatives of many other families.

On lower, but still high elevation sites in central Mexico, and along the major ranges some grasslands develop after the destruction of oak and pine forests and are kept in this seral stage by burning, cattle grazing, and use of their roots for broom manufacturing. These are similar to the alpine grasslands with the same tussock grasses plus many representatives of other genera with affinities to more arid communities, including *Andropogon, Aristida, Bouteloa, Hilaria, Stipa, and Trachypogon.* Such grasslands are much more extensive than their alpine counterparts, but still have small areal extent (*ca*. 515,000 ha, Jaramillo 1994a).

Tropical Savannas

Natural grasslands in tropical Mexico cover a rather small area (less than 1% of the country, Jaramillo 1994b). Most of the tropical grasslands have been classified as savanna (*ca*. 1,234,520 ha, Jaramillo 1994b). However, some very small patches can also be described as halophyte grass associations. Mexican savannas are tropical climate grass-shrubland associations that occur in periodically flooded lowlands. Proper savanna occur only in type A climates on heavy, argillaceous soils along the coast of the Gulf of Mexico, and in the Pacific basin from Sinaloa to Chiapas (Rzedowski 1978). The precipitation exceeds 1000 mm distributed in a well defined wet season during summer. In winter, most savannas experience a well defined seasonal drought.

There has been great debate over the origin and original distribution of tropical savannas. Some authors favor the idea that savannas are the final stages of evolution of tropical soils coupled with the periodic effects of fire (Miranda 1958, Rzedowski 1978), while others suggest that savannas are the product of disturbance by man, mainly by clearings for agriculture that have changed irreversibly the structure and drainage of the soil (Sarukhn 1968, Pennington and Sarukhn 1968).

Disregarding their origin and precolumbian distribution, tropical savannas owe their existence to the very same mechanisms proposed for the persistence of desert grasslands by McAuliffe (1995): the presence of an impermeable layer on the soil that permits little infiltration to deeper layers. In humid-seasonal climates, that layer causes flooding during the wet season, and xeric conditions during the dry months, limiting the development of trees and shrubs to isolated pockets of better drained terrain. Common woody species are: *Byrsonima crassifolia, Curatella americana, Crescentia alata, C. cujete, Quercus oleoides, Coccoloba* spp, and species of Melastomateaceae (Pennington and Sarukhn 1968, Rzedowski 1978). Grasses are mainly species of *Paspalum, Andropogon, Aristida, Imperata, Digitaria, Leptocoryphium,* and *Axonopus*, growing along with many Cyperaceae.

Arid Grasslands

Arid grasslands, desert grasslands, semi-desert grasslands (including the Apacherian mixed shrub savanna of Burgess [1995]) form extensive areas with dominance or co-dominance by grasses. These have been described from northeastern Sonora, a long strip running on the eastern flank of the Sierra Madre Occidental from northwestern Chihuahua, to northeastern Jalisco on the Mexican Northern Plateau (Mesa del Norte), and a sizable area within the Mexican Central Plateau (Altiplano Central). These can be viewed as an extension of the large grasslands of the North

American mid-west (Shreve 1942, Rzedowski 1978, McClaran 1995). Such a broad distribution area include a multiplicity of climatic, soil and disturbance variants, producing grasslands with different structural, functional, and floristic features. The discussion by Burgess, and other authors in McClaran and Van Devender (see McClaran 1995) on the features of the desert grasslands is crucial in highlighting their inherent structural and functional instability, and their close relationships with other types of vegetation, mainly desertscrub, thornscrub and oak woodlands.

About 90% of the Mexican grasslands are concentrated in the arid and semi-arid regions (24,334,273 ha, Jaramillo 1994c). More than half of these (13,643,423 ha) can be grouped as short grass prairies, while the rest comprise different associations of tussock, bunch and halophyte grasses (Jaramillo 1994c). These extensive arid and semi-arid grasslands form a nearly continuous belt bordered by desertscrub and thornscrub at the lower elevations and woodlands and forests in the mountains and higher elevations. Most of these form a climatic climax according to Rzedowski (1978). However, more recent studies indicate that the role of soils and soil history play a major role in determining the presence of grasslands or other types of vegetation in a given area (McAuliffe 1995). This feature is particularly applicable to some of the western USA and Mexican grasslands that are present on bajadas and extensive alluvial fans along the flanks of the Sierra Madre Occidental, foothills of Basin and Range mountains, and the slopes and plains north of the Eje Neovolcanico.

Typically, Mexican grasslands develop on areas with steppe climate (type Bs). This feature is reflected on the close correlation between Bs climate and the distribution of grasslands (Gentry 1957, Rzedowski 1978, Schmutz *et al*. 1991, McClaran 1995). However, the most xeric grasslands can be found at the lower elevations in desert climates (type Bw), as happens near Moctezuma, Sonora; Delicias, Chihuahua, and Gomez-Palacio, Durango. Also, some grasslands in Mexico occur on exposed, southern slopes with shallow, argillaceous soils overlying a rocky impermeable layer. The latter occur in temperate mesothermal climates (Cw), as those encountered in intermediate elevations on both sides of the Sierra Madre Occidental. Even in Bs climates, where grasslands are more prevalent, other types of vegetation can be found. These are the extensive and highly structured thornscrub communities found on the western side of the Sierra Madre Occidental, and large tracts in the Bajío region that have a close affinity to tropical deciduous forests. These seem to replace grasslands in areas with warmer, more dependable weather (Rzedowski 1978, Burquez, Martinez and Felger in press).

Floristically, endemism at the species level is very important in Mexican grasslands. Two thirds of the grassland species in Durango, Mexico are endemic, and their phytogeographic affinities at the generic level are mainly tropical (Gentry 1957, Rzedowski 1975). This interpretation can be extended to most Mexican arid grasslands (Rzedowski 1978). Dominant grass species include many representatives of *Bouteloa, Aristida, Andropogon, Muhlenbergia, Setaria, Stipa* among others. Members of the Asteraceae are exceedingly common, along with herbs and shrubs prevalent on desertscrub and oak woodlands.

The New Desert Grasslands

Grasslands derived from other types of vegetation are common. Some have been already mentioned, as those derived from the destruction of pine and pine-oak forests in high elevation ecosystems. Others are the result of intentional conversion of one type of vegetation into grasslands. In most cases, once the pressure of the disturbance factor is released, the communities follow a trajectory that returns to conditions resembling those prior the disturbance. However, in some cases irreversible changes occur, leading to a new vegetation equilibrium. These sorts of phenomena are most evident in arid ecosystems where succession does not, even grossly, conform with the Clementsian paradigm. We will illustrate this issue with a case study: the conversion of large tracts of the Sonoran Desert into induced grasslands, and the seeming evolution of the community from desertscrub to a new grassland equilibrium.

Modification and Conversion

Land used for human activities alter the land cover or vegetation. This alteration takes two major forms: modification and conversion. Modifications include the alteration of the quantity and quality of the land cover by subtle changes in use, while conversion is the replacement of one community type by another. Grazing is a common land modifier. The environment we see today in southwestern USA and northwestern Mexico is, in part, the consequence of land modified by the recent introduction of cattle. Historical documentation shows, for some areas like the San Pedro and San Rafael Valleys on the border between Arizona and Sonora, a lush, green valley laden with thick sacaton grasslands, and walnuts, ashes and willows in the canyons and wetlands. These have changed toward a more xeric condition (Bahre 1991). Now the vegetation cover and diversity have decreased, and many riparian habitats are impoverished. The process of land modification has been taken to its extreme, modifying, and in some cases, converting the former grasslands to thornscrub because of several interrelated factors that include changes in the periodicity of fire, and overgrazing by cattle as major elements (Fleishner 1994).

Although land cover modification effects are seldom considered in models of global change, their importance is beginning to permeate the current modeling of global biogeochemical cycles, by considering how they increase the greenhouse gases concentration, and lower the carbon storage, and biodiversity in natural communities. We will not elaborate more on this phenomenon, which has been treated exhaustively in the literature, but will only remark again that it is prevalent and widespread in the arid lands of Mexico and southwestern USA.

Conversion can occur by deliberate clearings and subsequent changes in the soils or by the natural invasion of new organisms into the land. The ecology of invasion has well documented examples. The prickly pears in Australia and the Klamath weed in America are examples of unexpectedly successful land conversion and later rehabilitation by appropriate biological control. Arid land conversion -the replacement of desertscrub by another vegetation- occurs by deliberate transformation of the land mainly by extirpating the desertscrub to transform it into agricultural land, and by the replacement of the desertscrub by induced grasslands to increase the stocking rate for cattle. This section deals with the present impact of the desert conversion and subsequent invasion by buffelgrass (*Pennisetum ciliare*) in Sonora and with how diversity is affected, and how, even the low desert carbon productivity, is being released into the atmosphere in ever increasing amounts.

Buffelgrass Ecology and the Sonoran Drylands

African buffelgrass has altered the landscape of large tracts of land in Australia and America. In central Australia and western North America it has established a strong foothold (Cox *et al*. 1988a, Cox 1991). It is the dominant herbaceous plant in large tracts of the southwestern USA and northern Mexico (8-10 million ha according to Cox 1991). In the Sonoran Desert it is actively invading natural desertscrub and thornscrub communities. Buffelgrass, 30 years after its introduction to NW Mexico, is altering the landscape at a fast pace(as happened to sizable areas of NW Australia, see Cox *et al*. 1988a, Ibarra *et al*. 1995). It is fully naturalized in Central Sonora and is establishing itself northwards with no recognition of national boundaries (Burgess *et al*. 1991, Yetman and Búrquez 1994).

Buffelgrass is native to the arid lands of eastern Africa. It has been successfully used as a forage in South Africa, where it has been encouraged by cultural practices and the introduction of more productive strains. In the 1940s the Soil Conservation Unit of USDA imported it to the Americas as an alien plant suitable for erosion control. By the sixties major efforts to release it into Mexican aridlands were made, resulting in its massive introduction to northern Mexico. There is an official estimate of 1.5 million ha already cleared purposely for buffel, and Sonora has now more than 600,000 ha officially planted with buffelgrass (Cox *et al.* 1988a. Johnson and Navarro 1992, Yetman and Burquez 1994). The government provides subsidies for desertscrub clearings for buffel, and permits are issued annually to increase their extent. Clearings are usually larger than officially granted, and many areas are converted illegally without government permits. These factors give a conservative estimate of about 1.2 million ha deliberately cleared in the state of Sonora. The prime habitat for conversion, as recommended by range managers of COTECOCA is central Sonora (Navarro 1988). These technicians have determined that about one third of the state (*ca.* 6,000,000 ha) was suitable for conversion into buffelgrass. Buffelgrass thrives in sites with precipitation between 150-600 mm, concentrated mainly during summertime. It prefers warm, frost-free weather, and flourishes in most soil types (Ibarra *et al.* 1995). The area proposed by government agencies cover most of the Sonoran Desert subdivision Plains of Sonora, and portions of the Foothills of Sonora, and tropical deciduous forests (Navarro 1988, Johnson and Navarro 1992).

Originally, buffelgrass was established by clearing the natural desertscrub by chain, and blade bulldozing, a process called desmonte (Hanselka and Johnson 1981). These started in the neighborhood of Carb in central Sonora in the 1970s. At the same time the CIPES (Centro de Investigaciones Pecuarias del Estado de Sonora) was created in Carb with the mission of developing new forms of exploitation of the range (CIPES 1989). Special emphasis was given to the conversion of the desert into managed induced grasslands. As a result, large areas can now be seen mostly devoid of arborescent desert, grossly on a circle 200 km in diameter centered around Hermosillo. Today, new desmontes are carried out under new government directives that encourage leaving about 20% of the original tree cover in the plains, and 100% along watercourses. However, given the invasive nature of buffelgrass, soon these ratios change towards a greater grass dominance.

Conversion has been beneficial to cattle growers because trials have shown that buffelgrass can increase the stocking rate of the land up to 3 times (CIPES 1989, Hanselka and Johnson 1991, Johnson and Navarro 1992). However, at the time of its introduction, several ecological considerations were not taken into account, mainly its ability to naturally spread into the desertscrub (See Cox *et al.* 1988a, Ibarra *et al.* 1995), particularly into heavily overgrazed desertscrub (Sonora averages 60% overstocking and in some areas up to 400%; Aguirre 1980, Johnson 1990). This capability created unexpected sequels difficult to assess at the time of introduction, but with far reaching consequences. Among these are the effect of supplanting key desert species, the weedy behavior creating problems mainly with the agriculture of perennials, and the overwhelming increase in the uncommon desert fires.

In addition to the clearings of desertscrub for buffel grasslands, large areas have been invaded by buffelgrass, mainly urban and suburban plots, and highway shoulders. A conservative estimate indicates that between 1,000-10,000 ha of pure stands of prime buffelgrass are distributed along the major Sonoran highways (Highways: 15, 16, 20, and 21). These highly disturbed communities are well watered by runoff from the tarmac, allowing almost a continuous production of seed throughout the year. Indeed, these are the main sources for commercial seed collection. However, only a small fraction of their seed output is gathered, and undoubtedly most of the seed crop disseminates along an ever increasing, vast, linear (more than 600 km along major roads), dispersal source to colonize the desertscrub. The response of buffelgrass to disturbance of the cryptobiotic crust of the desert is almost immediate germinating in the small depressions formed after breaking it. The process of natural colonization usually starts near roads or near deliberately induced grasslands. The grass progresses along watercourses - which are naturally disturbed during the rainy season, and which provide ample moisture- and finally radiates to the more fertile, slightly disturbed areas beneath tree crowns (MM and AB unpubl. data).

The presence of buffelgrass produces an increase of the fine-fuel, easily flammable fractions that start a fire cycle in a community with species with no adaptations to fire (D'Antonio and Vitousek 1992, McPherson 1995). Indeed, suburban fires in the Hermosillo area, virtually unknown before buffelgrass, increased in frequency to almost one every two days during the dry summer months prior to the rains (unpublished data assembled from recent reports at local newspapers, but see Bahre 1985, Humphrey 1987).

Some common desert species, mainly brittlebush (*Encelia farinosa*) and cholla (*Opuntia fulgida*) recolonize buffel grasslands, but these are not palatable to cattle (Ibarra *et al.* 1985). The usual recommendation by range managers to maintain the grasslands has been prescribed burning (Cox *et al.* 1988b). However, cattlemen use it only as a last resort because burning is a sacrifice of valuable forage. Induced buffel grasslands are subjected to heavy grazing and ordinarily remain relatively open with a moderate accumulation of fine litter. Only after a good year of rains, or in stands not severely used, enough fuel accumulates increasing the chances of fire. No statistics are available, but most buffel grasslands in central Sonora have suffered at least one fire in the last 20 years, and many have been subjected to fires every few years. In more inaccessible areas, such as hillsides near highways or near buffel grasslands, the naturalized stands of buffelgrass are becoming dominant. As these are not so heavily grazed, there is enough litter accumulation as to start a natural fire cycle after a few years following colonization, and thus enlarging the affected area, and providing new seed sources.

Structure and Functioning of Buffel grasslands

It is well known that the fertility of the soil and the diversity of plant and animal life is much higher under the canopy of trees that outside their shade (Garca-Moya and McKell 1970, Burquez and Quintana 1994). Once trees are removed, a large guild of associated animals and plants disappear from the area. Paired sampling of neighboring plots with induced buffelgrass and desertscrub (with naturalized buffel) have shown that plant species richness decreases up to 4 times, and diversity goes down up to 10 times. Also, vertical heterogeneity of the vegetation changes from highly complex 2-3 strata to a single stratum (AB unpubl. data), suggesting corresponding effects on the fauna. Soils in converted desertscrub change dramatically. Buffelgrass exposes the soil to higher insolation, and changes soil features by increasing the organic matter content (Ibarra *et al.* 1995). Also, buffelgrass quickly deplete the soil nutrients, both by the net export of nutrients taken by cattle, and by the volatilization of nitrogen and secondarily of phosphorous and potassium after the recurrent fires.

Conversion from desertscrub to buffel grasslands changes the aboveground standing crop biomass by about 3-4 times (1-4 Mg/ha buffel vs 5-20 Mg/ha natural vegetation, AM and AB unpubl. data). That produces a release between 4-16 Mg/ha of carbon, mostly as carbon dioxide since nearly all the removed vegetation is burned after the clearings. Gross estimates indicate that about 5 million Mg have been already released into the atmosphere and, if the government goal is effected about 50 million Mg will be released. These figures are highly conservative because they only consider the land officially designated as buffel grasslands, and do not include the transformation that is occurring naturally, the numerous illegal clearings, and the contribution of below-ground biomass. For arid lands, these figures are staggering.

The Sonoran Savanna Revisited

Since Shreve (1951) described the vegetation of the Sonoran Desert, some changes have been made to the original boundaries. These include the segregation of the subdivision Foothills of Sonora into thornscrub (Brown and Lowe 1974, Felger and Lowe 1976, Brown 1982b, Turner and Brown 1982), the mention of the subtle boundary between some sections of the Arizona Upland, arid grasslands and thornscrub (Turner and Brown 1982), and the recognition that large sections of the Plains of Sonora subdivision were, and some still are, distinctly savannoid in appearance, dominance and composition (Shreve 1951, Brown 1982c, Van Devender *et al.* 1990). The successful introduction of buffelgrass into the Plains of Sonora seems to prove that a marginal advantage in water use, coupled with increased incidence of fire and disturbance by cattle, can shift dramatically the dominance from desert arborescent forms to desert grasslands in the deep alluvial soils of central Sonora..

HISTORICAL TRENDS AND CURRENT THREATS

Although a sizable portion of the land designated as Mexican arid grasslands might represent a climatic climax, most of their present area can be ascribed to cultural or biological factors (Rzedowski 1978). The instability of arid grasslands is best exemplified by the major changes that occur once recurrent disturbance agents come into play. Slight changes in the frequency and intensity of herbivory, granivory, and fire produce large changes in the structural and functional properties of the grassland, to the extreme of irreversibly (in the ecological sense) shifting the community into a new equilibrium state (Rzedowski 1978, Fleishner 1994, Burgess 1995, McPherson 1995, Jeltsch *et al.* 1996). There is a persistent idea that woody xerophytes have recently invaded the arid grasslands. However, the evidence comes mainly from anecdotal accounts gathered by ranchers and broad surveys by range managers that perceived the decreasing ratio of grasses to woody perennials as detrimental (as is to cattle, indeed, see Bahre 1991). The visually dramatic change from a community dominated by grasses to one with more vertical complexity might not represent an invasion of previously absent woody species, but the alteration of the dominance hierarchy of species already present in the area (Hastings and Turner 1965, Humphrey 1987). Several entangled factors are involved, perhaps fire suppression and overgrazing being the most relevant players (Bahre 1991).

Livestock was bred in Mexico before its introduction in the present USA. Major herbivores were brought to central Mexico right from the start of the conquest of Mexico by the Spaniards, and horses represented a major technological advantage over the native Mexicans (Daz del Castillo 1984). Cattle was reared during the colonial times providing meat and animal traction mainly for the mining industries (Ezcurra and Montana 1988). The pristine American landscape seen by the conquistadores regained some of the megafauna lost during the Holocene (see Martin and Klein 1984), and some localized areas near major population centers and mines were impacted by increasing deforestation and overgrazing. Twenty years after the arrival of Spaniards into central Mexico, a large herd of livestock was carried along with the Coronado expedition marking the start of the cattle industry in the aridlands of northern Mexico (Wagoner 1952). Our perception of pristine is rather romantic, as large tracts of land were already altered by agriculture, urban and engineering developments, and large-scale use of forests and drylands to provide fuel (see for example Ezcurra [1992] for an account of the deforestation caused by the construction of the Teotihuacan pyramids). However, it was not until the development of the haciendas , during the nineteen century, that large-scale cattle production started, leading to extensive overgrazing. A respite from the large-scale overgrazing occurred during the Mexican revolution in 1910, when herds were heavily culled (Wagoner 1952). This episode caused a marked, but short-lived, reduction of the cattle herds, allowing some recovery of the arid grasslands. By the 1930s the Mexican government started a process of land distribution that lasted almost sixty years and allocated most of the federal land in Mexico, either to private individual holders, or to communal holders, mainly in the form of ejidos . The process of redistribution to private land holders allowed a maximum property size based on an estimate of the sustainable stocking rate (enough land to sustain 500 head of cattle). As in any legislation, many legal loopholes were and are exploited to increase the land controlled by investors, increasing their share of the land at the expense of ejidatarios who did not have, until the very recent modifications to the constitution, access to credit. Grassland resilience has been abused by overstocking, creating a less productive system. In the near future little can be done to ameliorate the pressure imposed upon these tenuously-balanced communities. The search for new forms of use of the range has now focused on the desertscrub and one avenue has been its conversion into a new form of grassland disregarding the ecological and economical imbalances that are produced by the introduction of highly aggressive alien species.

COMMON GROUND BETWEEN ECOLOGISTS AND PASTORALISTS

Grasslands are extremely important to mankind because of their use by domestic livestock, mainly cattle. At least one third of the Mexican cattle industry take advantage of the forage present in drylands, of these, a large proportion are localized in arid grasslands (Ezcurra and Montaa 1988). Most grasslands in Mexico have been used intensively and extensively for cattle, both by private and communal exploitation (Wagoner 1952, Ruiz 1988). Factors such as land tenure, better roads, increasing local population pressures, shifts from subsistence to market economy, and new cultural practices are likely to result in ecological change of grasslands than does climate (see Humphrey 1987, Fleishner 1994). The former are all interrelated. The opening of new and better roads, coupled with better transportation facilities has opened tracts of grassland previously unavailable for intensive local and export exploitation. The development of new techniques to provide water to cattle, the transference of large tracts of land from small-scale farmers to cattle barons, have all shifted the balance from a subsistence economy into a market economy (see contributions in Camou 1991, Prez 1992, 1993). The owners of most of the large cattle herds live in large cities mostly detached from the rural environment, and the small holders and ejidatarios are constrained by economic pressures with the need to share their range with many comrades. Both strategies overexploit the scant drylands resources because the land management has been aimed to a single resource: cattle raising. From a previous state of local ranching, subsistence farming and gathering, pastoralists have shifted to a single commodity. This scheme points to an ever increasing impoverishment of the drylands at the expense of a rich ecological heritage of multiple use of resources.

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