Structure and Function of Chihuahuan Desert Ecosystem
The Jornada Basin Long-Term Ecological Research Site
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Grazing Livestock Management in an Arid Ecosystem

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The history of livestock grazing in the Jornada Basin of southern New Mexico is a relatively recent story, but one of profound implications. For four centuries this region has supported a rangeland livestock industry—initially sheep (*Ovis aries*), goats (*Capra aegagrus hircus*), and cattle (*Bos taurus* and *Bos indicus*), but primarily beef cattle for the past 130 years. Throughout this brief history of a domesticated ruminant in an ecosystem without a significant presence of large hoofed mammals as part of its evolutionary development, the livestock industry has continually grappled with high degrees of temporal and spatial variation in forage production. Management of this consumptive use, whether during Spanish, Mexican, U.S. territorial, U.S. federal, or New Mexican governments, has constantly reaffirmed the need for grazing management to be flexible and responsive to the stress of droughts. The history of anecdotal experiences has been more recently augmented by scientific investigations first initiated in 1915. This chapter outlines the general history of livestock in this region, defining characteristics of herbivory in arid lands and principles of grazing management derived from nearly a century of studies on grazing by large domesticated herbivores.

General History

Seventeen ships carried 1,200 people and enough cattle, horses, sheep, and pigs to colonize northern Hispaniola during Columbus's second voyage in 1493. Livestock originating from the Andalusian Plain of southern Spain were loaded aboard ship at the southern port of Cádiz and the Canary Islands before making the 22-day voyage (Rouse 1977). It was not until 1521 that Gregorio Villalobos unloaded livestock in New Spain (Mexico) near Tampico; the actual number of cattle and their origin are disputed. Rouse (1977) claimed that 50 calves were transported to the mainland from either Cuba or Hispaniola, whereas Peplow (1958) and Wellman (1954) claimed 6 animals arrived from Hispaniola. Irrespective of the initial numbers, livestock were soon moved north from the Mexico City area during the early sixteenth century with both missionaries and resource extraction industries as retired military officers and Spanish nobility built a mining- and grazing-based economy throughout the region of present-day northern Mexico. By 1539 livestock had reached the present-day United States–Mexico border with the greatest concentrations being along the coasts and the central plateau. This northern expansion of a ranching frontier in North America was to development of Hispanic America what western expansion of farming across the continent in the nineteenth century was to Anglo America (Morrissey 1951). There were a million cattle in New Spain by 1600 with grazing associations formed under formal Spanish law (Bowling 1942). By 1609, the city of Santa Fe was a northern distribution point for livestock in the Americas.

Livestock were given to colonists by the Spanish government as an enticement for settlement (Bowling 1942). Scurlock (1998) reported estimates of livestock numbers in New Mexico from 1598 to 1830 (table 13-1).

Table 13-1. Livestock numbers in New Mexico, 1598-1830 (from Scurlock 1998).

Year	Sheep	Cattle	Goats	Horses	Mules	Totals
1598	4,000	1,000	1,000	150	–	6,150
1694	3,100	--	–	–	–	3,000
1697	4,000	650	170	–	–	4,820
1757	112,182[a]	16,157	[b]	7,356	–	135,695
1777	69,000	–	–	–	–	69,000
1820's	1,000,000	5,000	–	850	2,150	1,008,000

[a]Includes Hopi flocks.

[b]Included with sheep.

Sheep were the principal species in the New Mexico region of New Spain during this Spanish settlement period. Individual herds of 4,000–5,000 were common throughout the region (Hastings and Turner 1965). A transhumant grazing system was common, as flocks of sheep were annually driven from present-day northern New Mexico south through the Rio Grande Valley into Mexico to service livestock markets in Chihuahua and Durango (Scurlock 1998). The first reports of localized overgrazing by livestock appeared in the 1630s (Ford 1987). When Mexico gained independence from Spain in 1821, many of the Spanish settlements were abandoned, and livestock numbers declined. For example, there were fewer than 5,000 cattle in the Arizona territory during the mid-1800s.

A grazing-based economy was reestablished following the 1848 Treaty of Guadalupe-Hidalgo and the conclusion of the American Civil War in 1865. By 1891, there were 1.5 million cattle in the Arizona and New Mexico territories, a region covering the current states of Arizona and New Mexico. This expansion in numbers was accompanied by an expansion onto rangelands not previously grazed by livestock (Hastings and Turner 1965). This regional exploitation was driven by speculation by Eastern and European investors capitalizing on new technologies for pumping water for livestock and fencing lands (McNaughton 1993). Aggressive programs to control predators and concurrent establishment of railroad networks that moved cattle to growing Eastern markets undoubtedly aided this expansion. Escalation of livestock numbers and their expansion into areas not previously grazed had serious ramifications (Buffington and Herbel 1965). By the early 1900s, reports on the widespread destruction of Southwestern rangelands by livestock overgrazing were common (Smith 1899; Wooton 1908). Historical details of the livestock industry's beginnings in the Jornada Basin are presented in chapter 1.

Cattle numbers in the Southwest peaked at over 1 million head in 1890, during World War I,and again in 1920 but by 1990 had declined to 900,000 head in Arizona and New Mexico (Fredrickson et al. 1998). Currently, forage demand in New Mexico and Arizona is approximately 10 million annual unit months, of which 37% are supplied from federally managed rangelands in these two states (Torell et al. 1992). The regional economy includes a grazing-based component that is predominately comprised of cattle. In New Mexico, 9,000+ ranching operations, totaling 600,000 head of beef cattle, generated approximately $800 million in cash receipts from livestock sales in 2001 (USDA 2001). The industry is an unconsolidated amalgamation of small businesses with highly variable economic viabilities (Fowler and Torell 1985). Most ranching enterprises have fewer than 250 cattle, employ fewer than 5 people, have been in operation for an average of 19 years, and annually spend $18,000 for community services and $19,000 on structural land improvements (Fowler 1993).

Herbivory

There are numerous general theories on the role of herbivores in shaping grassland and shrubland ecosystems. These theories include the autogenic hypotheses (Noy-Meir 1979/80), optimization theory (McNaughton 1979), evolutionary gradients of grazing history (Milchunas et al. 1988), plant traits adapted to large mammalian grazers (Mack and Thompson 1982), keystone guilds (Brown and Heske 1990), and plant chemical–mediated defoliation (Bryant et al. 1991). None of these theories easily accommodate the inclusion of an exotic large herbivore within an arid ecosystem such as the northern Chihuahuan Desert.

Though it is likely that domestication of cattle has altered some behaviors that were characteristic of their predecessors, the aurochs (*Bos primigenius*), particularly a lessening of their gregarious nature (Hemmer 1990), inherent foraging patterns of cattle are similar to other wild generalist ungulates. Diurnal behaviors are sensitive to environmental conditions such as day length and ambient temperatures (Arnold and Dudzinski 1978), vegetative conditions such as species composition and available biomass (Holloway et al. 1979), physiological states such as lactation (Wagner et al.

1986), and the history of prior grazing experiences (Burritt and Provenza 1989). Forage preferences can be extremely plastic, as diet selection is mediated by the central nervous system and mitigated by intrinsic feedbacks and external stimuli (Provenza et al. 1998).

Native Herbivores

Desert grasslands have historically supported low chronic levels of herbivory by native vertebrates (chapter 12). In the Jornada Basin, native ungulate densities are low, and herbage consumption by small mammals has been estimated at < 5 $g/m^2/yr$ (Pieper et al. 1983). These intake levels are typically < 10% of aboveground net primary production (ANPP) (Pieper et al. 1983). In this environment of erratic and low productivity, herbivory by native species has been a historically chronic and minimal feature where most of the energy within this ecosystem is traditionally channeled through decomposers rather than herbivores. The black-tailed prairie dog (*Cynomys ludovicianus*) was an endemic species often found on heavy-textured playa soils common throughout the Jornada Basin (Oakes 2000). This species, possibly a keystone herbivore on these playa sites (Miller et al. 2000, and accompanying citations), was poisoned and eradicated prior to and during World War I to reduce forage competition with cattle. This action was justified by the performing federal agency as a means to increase meat production in support of the U.S. war effort. The prairie dog has remained extirpated from much of its former habitat in the Jornada Basin. Prior to extermination efforts, presence of this animal may have prevented woody plant dominance within more productive desert grassland sites receiving external surface and subsurface water flows (Weltzin et al. 1997). Other mammals, particularly kangaroo rats (*Dipodomys* spp.), are extremely important as both granivores and gramivores within this ecosystem (Heske et al. 1993; Kerley et al. 1997; see also chapter 12). Kangaroo rat presence or absence can be more influential on plant community dynamics than the presence or absence of livestock (Brown and Heske 1990). Kangaroo rats also were the targets of private and federal poisoning campaigns during the 1920s to improve forage conditions for livestock. These campaigns were quickly abandoned when the extent of the task was fully realized (Jornada Experimental Range Annual Reports 1925–26 unpublished) and likely resulted in large alterations in the demographics of native mammalian herbivores and their predators for short periods. As a consequence, grass–shrub interactions and other aspects of vegetarian dynamics were likely altered to some unknown degree as well. Competition for forage among cattle and native mammalian herbivores is relatively slight in desert environments. Dietary overlap is most pronounced between cattle and black-tailed jackrabbits (Wansi et al. 1992).

Though jackrabbits can influence numerous processes, their population densities are highly variable and independent of cattle presence. Although data on the amount of standing crop consumed and dietary overlap between herbivore species are useful, they do not account for degree of selectivity or the possible effects one herbivore may have on the diets of more selective herbivores. For example, although newly emergent plants and plant parts may constitute a relatively small percentage of the overall standing crop, their removal by selective herbivores, such as jackrabbits, may greatly alter vegetation dynamics. Removal of decadent plant material by generalist herbivores like livestock may facilitate greater selectivity for meristematic tissue by more selective native herbivores, ultimately affecting plant survival and native herbivore fecundity. In this case, the effect on vegetation dynamics of herbivores when viewed independently may not be as great as when the interactive effects of two or more herbivorous species are combined.

Livestock

For many arid and semiarid ecosystems, the amount of biomass supported per unit of primary production is about an order of magnitude greater under rangeland livestock production than under natural, nonagricultural systems (Oesterheld et al. 1992). This observation appears valid for the Jornada Basin. Biomass of native consumers present in upland grassland communities in the Jornada Basin is ~ 0.03 g/m^2 (Pieper et al. 1983). Under conservative stocking rates of nine animal units per 259 ha (640 acres or one section of land) during years of average forage production, the biomass of cattle supported on these grasslands would be about 1.7 g/m^2. Only under extremely low stocking rates or for grazing seasons of just a few months' duration per year would livestock biomass be lowered to levels equivalent to the native herbivore biomass supported by these grasslands.

Mature cattle consume 5–15 kg (dry matter basis; NRC 1996) of forage daily. A classic recommendation for stocking desert grassland is 1 cow/260 ha/25 mm precipitation/yr. This stocking level would result in a harvest rate of 7–21 g/m^2/yr from an area receiving 245 mm of precipitation. Reported values for forage consumption by cattle under conservative stocking of desert grasslands have been 8–14 g/m^2/yr (Pieper et al. 1983). Annual forage consumption during the widespread overstocked periods of the late nineteenth and early twentieth centuries may have ranged from 30 to 60 g/m^2.

In an unpublished report, Cassady and Valentine (1938) summarized results from one of the earliest studies of forage intake by cattle grazing black grama (*Bouteloua eriopoda*) grasslands. During the winter dormant seasons of 1936–38, mature cows (average body weight of 328 kg) consumed 6.9 kg (dry matter basis) per day of perennial grasses, of which 82% was black grama. This is an intake rate of 2.1% of body weight per day and a rate that nearly meets the nutritional requirements of a range beef cow in the last trimester of gestation. Available forage averaged 319 kg/ha (32 g/m^2), and the stocking rate during the study period resulted in a utilization of 54% (17.3 g/m^2) of the perennial grass forage.

Basal cover of perennial grasses on this study area in 1937–38 was estimated at 7%. Based on the forage intake results in this study, these authors estimated that the winter carrying capacity for this range would be 15.5 cows per section per year. This figure would have to be adjusted for the increased body weight (500 kg) of today's animal unit (AU) and a vastly increased milk production potential, resulting in a 52% greater daily forage intake. The general carrying capacity would be adjusted to 10.8 AU per section per year. This figure would also have to be adjusted for a utilization rate of 35% instead of 50%, reducing the general grazing capacity to 7.6 AU per section. Also, basal cover of black grama is highly variable across the Jornada Basin. Areas of desert grassland on the Jornada Experimental Range (JER) today average 3–5% basal cover, which would imply a general grazing capacity of 3.5 AU per section for dormant season use when forage intake would be about 2.1% (or less) of body weight. Thus, Cassady and Valentine's study in the 1930s helped define the relatively low grazing capacities that are inherent to the desert grasslands in the Jornada Basin.

Jornada desert grassland ANPP during a 3-year period of near average total annual precipitation and protected from cattle grazing ranged from 125–186 g/m^2 (Sims and Singh 1978). Production with conservative stocking was estimated at 58 (± 20) g/m^2 over a 15-year period, which included years of severe drought (Paulsen and Ares 1962). During some seasons, even conservative stocking can result in acute harvest rates within pastures or across ranches. Distribution of use is uneven due to physical, biological, and structural features of the environment (Holechek et al. 1999). Generally, a high proportion of tillers will be ungrazed, defoliated tillers will usually be grazed only once, and biomass removal from grazed tillers will be high; Senock et al. 1993). Sims and Singh (1978) reported maximum growth rates of warm season grasses at the Jornada were 1.5–3.4 g/m^2/day under nongrazing by livestock and 0.6–3.3 g/m^2/day[1] without livestock grazing conditions.

Long-Term Effects of Open-Range Cattle

There is an extensive body of literature on plant responses to herbivory (e.g., Detling 1988; Heitschmidt and Stuth 1991; Huntley 1991). Given that grassland ecosystems are governed by numerous direct and indirect biotic interactions (Lockwood and Lockwood 1993), of which grazing is an integral process (McNaughton 1991), the effects of herbivory cascade throughout these ecosystems. Its effects can be neutral, adverse, or beneficial (Sims and Singh 1978; Lacey and Van Poollen 1981), but interpretations are greatly influenced by dynamics of scale (Turner 1989).

Prior to the introduction of cattle, large (10^2–10^3 kg) native ungulates had been rare within the northern Chihuahuan Desert since the Pleistocene (McDonald 1981). Given this uneven history of megafauna presence, the Chihuahuan Desert hosts a range of plants with different degrees of adaptation to large herbivores. With the introduction of livestock, plants beter adapted to this presence of large herbivores flourished. A prominent example is honey mesquite (*Prosopis glandulosa)* with both chemical and morphological traits that deter herbivory, and with seed characteristics which encourage ingestion and exploit ungulate dispersal. Cattle directly and indirectly affect numerous ecological processes in similar fashion to native large herbivores and other types of disturbances (Pykala 2000). Their effects include alterations of NPP and plant–water relations, seed dispersal, species composition and life form, nutrient cycling and retention, energy flow efficiencies, food web interactions, and factors such as fire frequency (Sims and Singh 1978; Detling 1988; Archer and Smiens 1991; Hobbs et al. 1991). (Continue next paragraph..”The effects…”HERE.>>The effects of herbivory on ecosystems are best understood in regard to long-term dynamics (Huntley 1991). We view this perspective as particularly appropriate for subtropical grasslands for two primary reasons. First, this region is undergoing continual transitions between vegetation types, albeit in discontinuous fashions (Grover and Musick 1990). Ecotones (at several scales) are key study areas for elucidating dynamics of these systems (Gosz 1993; Neilson 1993). We know very little about the ecological dynamics of transitional states and their responses to disturbances such as defoliation. For example, competition for soil resources between perennial grasses and mesquite may be minimal early in the mesquite life cycle and at low mesquite density (Brown and Archer 1989). However, the dynamics of this competition are significantly altered under conditions of resource redistribution and increased mesquite density. Effects of herbivory, even examined at similar temporal and spatial scales, would be substantially different across this gradient of vegetation transition.

Second, we are dealing with a situation in which the primary large ungulate is an exotic domesticated ruminant whose density is directly regulated by humans. The fundamental question is not grazing as an optimization process within the ecosystem but of the sustainability and long term consequences of grazing by livestock. At its core, grazing is a behavioral process, and the key aspect of grazing behavior is the expressed forage preferences of livestock. The primary effects of livestock grazing in the Chihuahuan Desert are a function of diet selection. Pieper (1994) correctly stated that it could be extremely difficult to predict how livestock will affect rangeland resources because their effects will be highly dependent on the diversities and activities of the grazing animals. Different species and kinds of livestock have different forage preferences and those preferences are related to the array of choices, that is, available plant species. Studies of dietary selection by livestock in the Jornada Basin are summarized in table 13-2. <<COMP: Insert table 13-2 about here>>Basically, grazing is species specific (Hobbs and Huenneke 1992). For example, annual species are not typically found as major components in cattle diets. Kelt and Valone (1995) reported that only 2 of 79 annual species responded (increased) significantly following livestock removal. As with other deserts, understanding individual species responses to defoliation can serve as a good approximation to the understanding of many ecological phenomena in deserts (Noy-Meir 1979/80).

Table 13-2. Livestock dietary preferences by forage class in the Jornada basin.

		% of dietary composition			
Reference		Grasses	Forbs	Shrubs	Comments
Herbel & Nelson 1969	Hereford and Santa Gertrudis cows	58	30	12	5-7 species comprised 54-77% of diets; averaged across 4 seasons; 4 year study; upland and lowland sites; little difference between cattle breeds
Rosiere et al. 1975	Hereford steers	43	32	19	Between 2-8 species comprised 72% of diets across 4 seasons; unknown species comprised 6% of diets;
Anderson & Holechek 1983	Hereford x Angus heifers and steers	35	51	19	4 plant species comprised 55-60% of diets; summer grazing season; primarily a tobosa grass lowland; heifer and steer diets similar
Hakkila 1986	Hereford Brangus, and H x B steers	55	20	25	6 species comprised 83% of diets; averaged across 4 seasons; 1 species (mesa dropseed) used year round, and 2 other species (soapweed yucca and red threeawn) used > 80% of the time
Smith 1993	Hereford and H x Santa Gertrudis cows	65	29	6	2 grass species comprised 33-55% of cattle diets; one forb species comprised 41-66% of sheep diets; averaged across seasons and years; sheep diets relatively constant across seasons and years;
	Rambouillet ewes	8	87	5	

Grazing Management

The primary initial research objectives of the Jornada Range Reserve in 1915 were to quantify the carrying capacity of desert rangelands, establish a system of forage utilization consistent with plant growth requirements, and develop a range management plan to minimize stock loss during droughts (Havstad and Schlesinger 1996). A key problem for range management was the inaccurate judgment of carrying capacity

(Wooton 1915). Jardine and Forsling (1922), Canfield (1939), and Paulsen and Ares (1962) established guidelines for carrying capacities of black grama rangelands. These classic studies used three different experimental designs to evaluate perennial grass responses to different livestock grazing strategies. Jardine and Forsling (1922) evaluated large-scale pasture responses on the Jornada Reserve and adjacent rangeland from 1915–19, a drought period. They measured basal cover responses of black grama to three coarsely applied management practices: (1) heavily grazed yearlong until 1918 and lightly grazed during the 1918 and 1919 growing seasons, (2) grazed yearlong 1915–19, and (3) reduced grazing during the growing season but fully utilized during the dormant seasons,1915–19. Basal cover responses of black grama, compared to an area protected from livestock grazing, clearly favored treatment 3, and the authors concluded that light grazing during the growing season was the appropriate grazing strategy for black grama dominated rangelands. Canfield (1939) conducted a small plot evaluation of black grama responses to different intensities and frequencies of clipping over an 11-year study. In evaluating black grama responses to clipping to either a 2.5 cm or 5 cm residue height at 2-, 4-, or 6-week intervals or once at the end of the growing season, by the end of the study all 1 m^2 plots clipped during the growing season were denuded. The obvious conclusion was that moderate or heavy use of black grama over an extended period was inappropriate. Paulsen and Ares (1962) summarized observations from small 1 m^2 plots arrayed across the JER where basal area of perennial grasses was recorded annually from 1916 to 1953. Plots were stratified to reflect nonuse and light, moderate, and heavy utilization by livestock. Results from this extensive long-term study clearly reflected the need to conservatively (< 40% of current year's growth removed) graze black grama and severely reduce or eliminate use during extensive drought periods. Subsequent research has reinforced the consistency of these guidelines, as Campbell and Crafts (1938), Paulsen and Ares (1962), and Holechek et al. (1994). These authors all concluded that proper utilization of black grama should be less than 40% of current year's growth.

The original philosophy was that proper utilization of the leaves and stems of the main forage plants was the basic principle of range management (Canfield 1939). General management guidelines published in the 1910s and 1920s are very similar to those promoted today. For example, nearly 80 years ago Jardine and Forsling (1922) recommended the following drought strategies: (1) limit breeding stock to carrying capacities during drought, (2) add surplus stock during good forage years depending on market conditions, (3) adjust range use seasonally depending on growth characteristics of key species, (4) establish permanent watering points no more than 5 miles apart, and (5) establish both herding and salting practices that achieve optimal stock distribution. Similar recommendations for drought conditions are outlined in one of the most current textbooks on range management (Holechek et al. 1998a). Interestingly, strategy #5 may have accelerated shrub expansion into areas formerly desert grasslands. Though livestock dispersal of mesquite seed was seen very early as a reason for mesquite encroachment (Campbell 1929), management practices were not employed to limit further dispersal. Enhancing livestock distribution with stock water and salt placements may have actually promoted mesquite seed dispersal.

Initial research on livestock production also emphasized strategies for drought. Most of the original efforts focused on supplemental feeding programs, especially those that used locally available foodstuffs, such as cottonseed products. For example, general recommendations were to feed 450–900 g per cow per day of supplemental protein to augment range forage for maintenance (Forsling 1924) with slightly higher quantities suggested for growth of stockers (Jardine and Hurtt 1917). These general recommendations have persisted over ensuing decades. Supplementation research has now typically narrowed its focus to mechanisms of and animal responses to protein and energy supplements to trigger specific physiological activities for specific animal production stages (Gambill et al. 1994).

More novel research has emphasized specialized practices for emergency feed conditions and management of poisonous plants. Soapweed (*Yucca elata*) was found to be a palatable emergency feed when fed chopped and fresh (Forsling 1919). Ensiling was not determined to be necessary. Other plant species were either deemed not suitable as emergency feeds (i.e., *Dasylirion wheeleri* and *Yucca macrocarpa*) or required spine removal (*Opuntia* spp.). Interestingly, burning spines from prickly pear cactus (in 1924 Forsling estimated that one person could prepare cactus feed for 200–400 had of cattle in a day) was employed during the 1994–95 drought in the Southwestern United States, though not in the Jornada Basin. However, even in the 1910s and 1920s the use of emergency feed practices was not viewed as responsible management.

As in other Western rangeland regions, studies of poisonous plants provided both initial guidelines for livestock management and insight into the difficulties of plant control in a desert environment. For southern New Mexico, drymaria (*Drymaria pachyphylla*) became a problem in response to overgrazing in the late 1800s and early 1900s (Little 1937). Drymaria is highly toxic and causes death within hours of consumption of a lethal dose. Though generally unpalatable, losses can occur for all classes of livestock especially in summer months if other forage is unavailable. For clay soils, drymaria was viewed as an early several species with infestations characteristic of degraded areas (Campbell 1931). Avoidance of grazing in drymaria-infested areas was the recommended management strategy. Various measures of control (fencing, burning, spraying, and revegetation) were determined to be either too expensive or ineffective. The recommended control practice was hoeing, but eradication was not viewed as a viable possibility. These general characteristics relative to management and control recommendations for poisonous plants persist today (James et al. 1993).

Though most complex grazing systems have not been shown to improve rangeland conditions in the desert Southwest (Martin 1975), specialized grazing systems have demonstrated some merit. In Arizona, rotation grazing did not improve ranges that were in good condition, but a rotational seasonal rest and grazing system may accelerate recovery of ranges in poor condition (Martin and Severson 1988). The benefits of more intensive grazing systems, such as short-duration grazing, are generally negative (Bryant et al. 1989). A few examples of good rangeland conditions under intensive grazing management in the arid zone exist, but these examples are undocumented in the scientific literature. The success of these specific situations is probably due to a unique combination of progressive management and a thorough understanding by the ranchers of the ecological characteristics of their specific rangeland. In the Jornada Basin, Beck and McNeely (1997) reported results of a long-term study comparing continuous, year-long grazing with seasonal use by cattle. Herbage production varied 100-fold over the course of this study, irrespective of the two grazing strategies. Forage quantity and quality in this environment limited the average calf production to 0.32 g/m^2. These data illustrate the overriding restricting effect of annual variation in primary production on the options for creative and intensive management in this environment. Other studies comparing continuous use to a rotational or seasonal use system in tobosa-dominated (*Pleuraphis mutica*) grasslands have demonstrated some differences in grazing effects (Senock et al. 1993) but no differences in animal performance (Tadingar 1982).

The grazing system developed at the Jornada in recognition of the dynamic nature of forage production in this region was the “best pasture” (Herbel and Nelson 1969). This pasture-scale system is highly flexible in terms of grazing season, and it exploits ephemeral growth of forage. The best pasture system does not involve rotation of livestock at a predetermined calendar date. The only use of a grazing capacity concept is the estimation of an average stocking rate (animal units per section) for each pasture. However, this capacity is recognized to be quite variable depending on actual forage production. The best pasture grazing system requires flexible herd management where livestock numbers and class are adjusted to forage production and location. The latter is an extremely important consideration in this environment because ANPP can be spatially highly variable. In an unpublished study, livestock production from 1940 to 1951 under flexible herd management was compared to the period of 1927–34 under constant stocking. Though more cattle were stocked from 1927–34, the annual production per cow under flexible management was 31% higher. The best pasture system is not routinely discussed as a specific method for grazing management in the Southwestern United States. However, the general principles of flexible herd management and adjustment of stocking in response to variation in forage production are widely used in many range livestock operations.

There have been a few long-term studies of the effects on arid rangelands of extended rest periods with no grazing by livestock. In southeastern Arizona, Bock and Bock (1993) reported that exclusion of livestock for 22 years increased the total cover of perennial grasses on a site with an average annual precipitation of 430 mm. In the drier Jornada Basin, Atwood (1987) examined four exclosures in black grama–dominated grasslands after 17, 22, 32, and 48 years of rest. Basal cover of black grama was greater in the 32- and 48-year exclosures compared to adjacent grazed areas. However, no differences between grazed and rested areas were noted after 17 years of rest, and basal cover of black grama was actually greater in the grazed area compared to the exclosure receiving 22 years of rest. Obviously, black grama is slow to respond to protection, and responses can be highly variable depending on ecological conditions at the time of rest initiation.

Various techniques (such as esophageal fistulation) for animal nutrition research allow investigations of the interactions between plants and livestock. Cattle genotypes with relatively modest performance traits, such as milk production, might be more successful in this nutrient-sparse environment. It is possible that some desired characteristics would mirror those inherent in the original cattle breeds introduced to North America in the sixteenth century.

Research on plant–animal interactions now reflects the widespread diversity of shrubs in the Chihuahuan Desert. Foraging behaviors are strongly mediated by secondary plant chemistry (Estell et al. 1994), and chronic ingestion may have postingestive consequences that further shape preferences (Fredrickson et al. 1994). The use of livestock as biocontrol agents for remediation will require detailed knowledge of this chemically mediated interaction to be an effective technology.

Conclusions

In summarizing 45 years of grazing research in the arid region of south-central New Mexico, Paulsen and Ares (1961) wrote: “Sustained grazing capacity does not exist on the semi-desert ranges . . . stocking may be high in some periods (meaning that primary production is high and high livestock numbers would be appropriate) and in others there is virtually no capacity.”

Our knowledge of various effects of livestock grazing in arid environments has been well synthesized (Pieper 1994). We have a general understanding of the importance of controlling timing, intensity, and frequency of grazing (Holechek et al. 1998b). It is also well recognized that livestock grazing under poor management or excessive use can have various negative effects, some of which are severe and long-lasting. Proper utilization of forage species has long been recognized as a key component of livestock grazing management (Canfield 1939). Jardine and Forsling (1922) established early guidelines for carrying capacities of desert grasslands. These authors and others have repeatedly concluded that proper utilization of arid grasslands should be less than 40% of current year's growth (Campbell and Crafts 1938; Paulsen and Ares 1962; Holechek et al. 1994, 1999).

The primary problems related to management of livestock grazing in arid and semiarid rangelands are those faced by producers since the seventeenth century: (1) coping with temporal variations in forage production, (2) manipulating an animal behavioral process (grazing) that is plant species–specific, (3) managing grazing across landscapes with limited (if any) ability to monitor or assess impacts, and (4) controlling dispersal of seeds. The most persistent problems are the annual and seasonal deficits in available forage due to the natural recurrent disturbance of drought in this environment. Forage production on upland desert rangelands can average between 150 and 250 g/m^2 (see chapter 11) during years of normal precipitation but may be < 100 g/m^2 during drought years (Herbel and Gibbens 1996; see table 11-2 in chapter 11). Almost any grazing during severe drought years would exceed proper utilization. Conservative stocking at 10–30% below capacity has also been recommended as both a strategy to cope with drought and as a means to improve vegetation conditions on some ranges (Holechek et al. 1999). Though Paulsen and Ares (1961) concluded that grazing could not be viewed as sustainable, to some extent this depends on the spatial scale of livestock management. Conservative stocking is probably the most important practice to improve conditions and approach sustained livestock use of New Mexico's arid rangelands. Based on our knowledge of the role of native consumers in this system, this recommendation reflects intent to minimize the affects of livestock on energy flows and appropriately manage their effects on ecosystem processes.