Successional Patterns and Productivity Potentials of the Range Vegetation in the Warm, Arid Portions of the Southwestern United States

Carlton H. Herbel

ABSTRACT

Arid rangelands of the Southwest are fragile, easily damaged by abusive grazing, and subject to frequent droughts. The land resources in western Texas, southern and western New Mexico, and southern Arizona have plateaus, plains, basins, and many isolated mountain ranges. The growing season precipitation occurs during the summer, and the spring period is normally very dry and occasionally windy. The plant resources include the *Flourensia-Larrea* shrub savanna, the *Bouteloua-Hilaria* prairie, the *Bouteloua-Hilaria-Larrea* shrubsteppe, the *Larrea-Flourensia* association, the *Bouteloua-Hilaria* steppe, and the *Larrea-Franseria* association (Kuchler 1964). Pronghorn antelope and a number of rodents and rabbits occur throughout the area.

The three major arid ecosystems in the Southwest have a total of 89.5 million acres and currently have a stocking of 5,975,000 animal unit months. If the potential of these ecosystems could be realized, this area would support 450% of the animal unit months of stocking now present. The degree of management practiced depends on economic, political, and social factors, and the availability of technology, and these factors are dynamic.

Each ranch unit has different physical and biological characteristics and objectives, and must be managed accordingly. Undesirable plants have increased rapidly in the area. Woody plants, such as mesquite, creosotebush, and tarbush cannot be controlled by improved grazing practices alone. Various land use practices are discussed under control of unwanted plants, seeding, fire, rodent and rabbit control, fertilization, water spreading, game habitat, and riparian communities. A proper balance among climatic, soil, vegetation, and soil resources must be realized to properly manage rangelands.

Carlton H. Herbel is supervisory range scientist, Jornada Experimental Range, Agricultural Research Service, U.S. Department of Agriculture, Las Cruces, New Mexico 88003.

Developing Strategies for Rangeland Management, Natl. Research Counc, Natl. Acad Sciences, Westview Press Boulder, CO 1984

LAND, INCLUDING SOIL RESOURCES

The Western Range and Irrigated Region has plateaus, plains, basins, and many isolated mountain ranges. Land resource areas in western Texas, southern and western New Mexico, and southern Arizona considered in this paper are: 1) Southern Desertic Basins, Plains, and Mountains (Fig. 1, 42); 2) Southeastern Arizona Basin and Range (Fig. 1, 41); 3) Central Arizona Basin and Range (Fig. 1, 40); and 4) the lower elevation of the New Mexico and Arizona Plateaus and Mesas (Fig. 1, 36). Southern Desertic Basins, Plains, and Mountains (Fig. 1, 42) of western Texas and southern New Mexico, with a total of 40 million acres, are about 95% rangeland. About a third of the area is public land owned by the Federal Government. The mean annual precipitation ranges from 8 to 16 inches, the mean annual temperature from 50 to 79°F, and the frost-free period (consecutive days when the minimum temperature is above 32°F) from 200 to 240 days, over most of the area. The elevation ranges from 2,500 to 5,000 feet in basins and valleys and more than 8,200 feet in the mountains. Broad desert basins and valleys are bordered by slopes and terraces. Steep mountain ranges and many small mesas are common throughout the area. Red Desert and Lithosols are dominant in the area. Other soils are Calcisols in highly calcareous materials and Regosols in deep sands (Austin 1972).

Southeastern Arizona Basin and Range (Fig. 1, 41) totals about 11.5 million acres, of which 95% is rangeland. About 30% of the area is controlled by the Federal Government. The elevation ranges from 2,500 to 6,000 feet. There are some basins and dry lake beds in this nearly level broad plain. The mean annual precipitation ranges from 8 to 20 inches, the mean annual temperature from 55 to 70°F, and the frost-free period from 180 to 240 days. Principal soils are Red Desert, Brown, Reddish-Brown, and Calcisols. Alluvial soils are extensive on floodplains and on the lower younger alluvial fans (Austin 1972).

The Central Arizona Basin and Range (Fig. 1, 40) totals 12.3 million acres, 85% is used for range. About 50% of the land is owned by the Federal Government and 10% is Indian reservations. The mean annual precipitation is about 10 inches. The mean annual temperature ranges from 61 to 73°F, and the frost-free period from 225 to 300 days. The elevation ranges from 1,000 to 2,500 feet. The low basins are bordered by gently sloping alluvial fans separated by mountain ranges. The most extensive soils are Red Desert soils on the older alluvial fans and terraces, alluvial soils on floodplains and the younger alluvial fans, Calcisols in calcareous materials, and Lithosols on valley walls and mountain slopes (Austin 1972).

About 98% of the New Mexico and Arizona Plateaus and Mesas (Fig. 1, 36), which total 17 million acres, is rangeland. About 20% of the area is owned by the Federal Government and another 20% is Indian reservations. The mean annual precipitation ranges from 10 to 13 inches, the mean annual temperature is about 50°F and the average frost-free period ranges from 120 to 180 days. The elevation ranges from 5,000 to 6,900 feet. These plateaus and mesas generally have gentle slopes. Sierozems are extensive in the drier portions of the area. Regosols in deep sands and alluvial soils are important on floodplains throughout the area (Austin 1972).

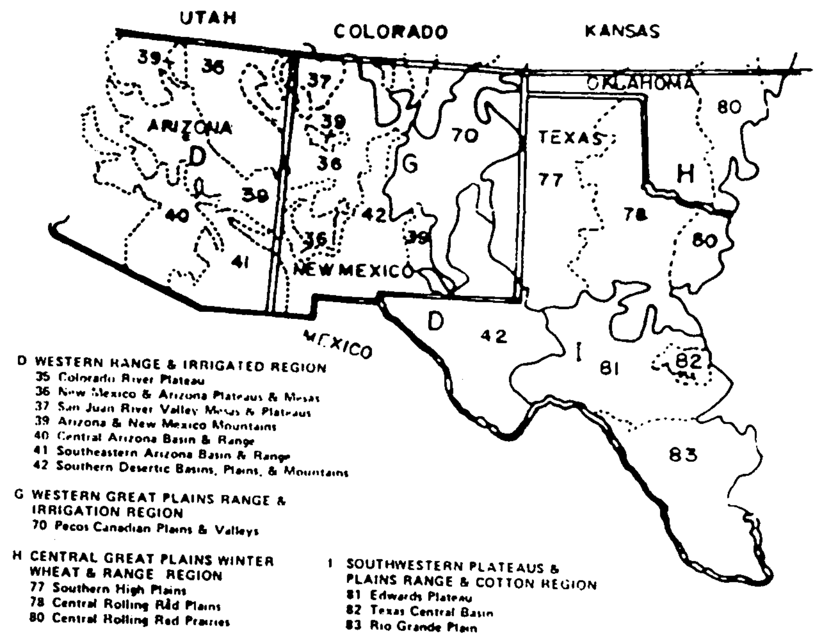

Figure 1. Land resources of the southwestern United States (from Austin 1972).

CLIMATE

Annual precipitation averages less than 10 inches in the lower elevations of New Mexico, Arizona, and western Texas to 18 inches in the southeastern part of the area near Del Rio, Texas (see Fig. 2 and Table 1). The precipitation not only varies greatly within and among seasons and years, but also among locations separated by short distances. In western Texas and New Mexico, and southern Arizona, the growing season precipitation occurs during the summer, and the spring period is normally very dry. The latter area has a slight increase in winter precipitation which has a significant impact on the vegetation. Spring-summer precipitation for the entire area is generally due to convective thunderstorms from moisture from the Gulf of Mexico. Winter precipitation is often due to broad fronts moving eastward from the Pacific Ocean. The entire region is frequently plagued by drought and during prolonged droughts it may resemble a desert. The region may also have high winds during some periods, that result in considerable erosion when they coincide with a reduction in protective vegetational cover. The mean annual evaporation is about 120 inches. The frost-free period averages 185 days at Las Cruces to 259 days/year at Tucson.

The major vegetational types of the region are determined primarily by precipitation. Arizona and the western third of New

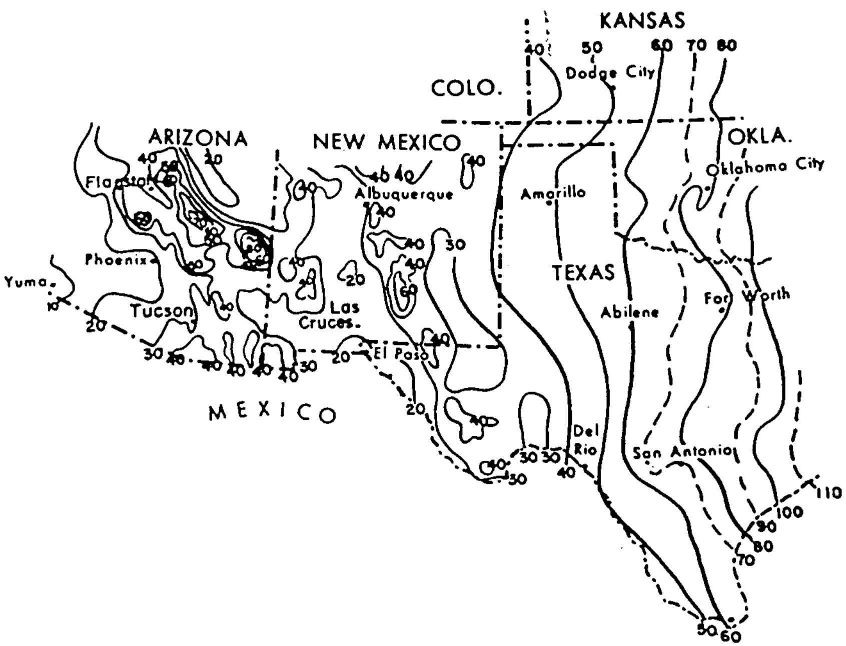

Figure 2. Average annual precipitation (cm) (1 inch = 2.54 cm) in the southwesten United States (from U.S. Department of Commerce 1975).

Mexico have been included by Trewartha (1961) in the Intermountane Precipitation Region (2a) (Fig. 3), bounded on the east by the Rocky Mountains and on the west by the Pacific Coast Ranges. This region has two precipitation maximums, one occurring in winter and the other in summer, making it transitional between the winter maximum found on the Pacific Coast and the summer maximum typical of the Great Plains. In general, the winter maximum is strongest on the western edge of the region with the summer rains increasing in importance towards the east. Winter storms are primarily the result of the Pacific high pressure area shifting southward, allowing lows to move inland, bringing with them masses of maritime air (Trewartha 1961). The July-August rainfall is derived from air masses originating in the Gulf of Mexico (Jurwitz 1953). Most of these storms are local, convectional thunderstorms (Bryson 1957).

Precipitation sub-type 3a, occurring in New Mexico and western Texas, receives its maximum moisture in July and August (Trewartha 1961). The flow of maritime air from the Gulf of Mexico makes this region a center of thunderstorm activity. There is little evidence of a winter maximum. Instead, the winter-spring is quite dry due to the continental influence of the prevailing westerly winds.

TABLE 1.
Average climate features (U.S. Department of Commerce 1975)

	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Ann.
Del Rio, Texas													
Precipitation (inches)	0.9	0.9	0.8	1.4	2.7	2.3	1.3	1.5	2.6	2.0	0.6	0.8	17.8
Temperature (°F)	52	55	63	72	79	84	86	86	81	72	59	52	70
Las Cruces, New Mexico													
Precipitation (inches)	0.5	0.5	0.3	0.2	0.3	0.5	1.3	1.7	1.2	0.7	0.3	0.5	8.0
Temperature (°F)	41	45	52	59	68	77	79	77	72	61	48	43	61
Tucson, Arizona													
Precipitation (inches)	0.8	0.8	0.5	0.3	0.1	0.3	2.0	2.9	1.0	0.6	0.6	0.9	10.8
Temperature (°F)	50	54	57	66	73	82	86	82	81	70	57	52	68

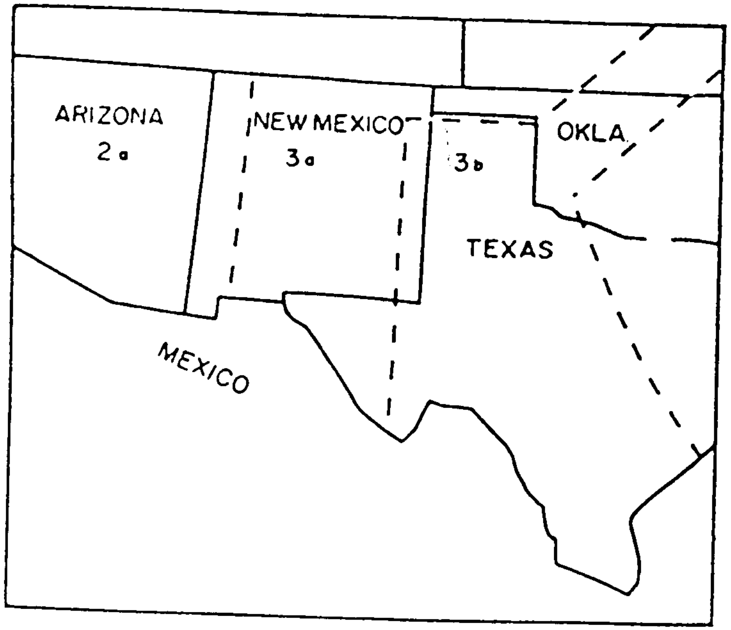

Figure 3. Precipitation regions of the southwestern United States (from Trewartha 1961).

VEGETATION RESOURCES

An outline of the land resources, and the plant resources discussed in this paper is shown in Table 2. The discussion of the vegetation follows the Potential Natural Vegetation by Kuchler (1964).

The major vegetation types of the Southern Desertic Basins, Plains, and Mountains are the Flourensia-Larrea shrub savanna, the Bouteloua-Hilaria prairie, and the Bouteloua-Hilaria-Larrea shrubsteppe. The dominant plants of the Flourensia-Larrea savanna are tarbush (Flourensia cernua)[1] and creosotebush (Larrea tridentata). Other major plant components are: whitethorn (Acacia constricta), poverty threeawn (Aristida divaricata), red threeawn (A. longiseta), cholla cactus (Opuntia imbricata), honey mesquite (Prosopis glandulosa), burrograss (Scleropogon brevifolius), and soaptree (Yucca elata). Dominants of the Bouteloua-Hilaria prairie are blue grama (Bouteloua gracilis) and tobosa (Hilaria mutica). Other major components of the vegetation are sideoats grama (Bouteloua curtipendula), black grama (B. eriopoda), cholla cactus, and broom snakeweed (Xanthocephalum sarothrae). The Bouteloua-Hilaria-Larrea shrubsteppe is dominated by black grama, tobosa, and creosotebush. Other major plants are whitethorn, poverty threeawn, red threeawn, sideoats grama, blue grama, cacti, honey mesquite,

TABLE 2.
Land and plant resources of the arid portions of the southwestern United States (refer to Figures 1 for the location of regions and areas) (Kuchler 1964; Austin 1972).

Western Range and Irrigated Region (Fig. 1, D).
A. Southern Desertic Basins, Plains and Mountains (Fig. 1, 42)
  (1) Flourensia-Larrea shrub savanna
  (2) Bouteloua-Hilaria prairie
  (3) Bouteloua-Hilaria-Larrea shrubsteppe
B. Southeastern Arizona Basin and Range (Fig. 1, 41)
  (1) Bouteloua-Hilaria-Larrea shrubsteppe
  (2) Larrea-Flourensia association
C. Central Arizona Basin and Range (Fig. 1, 40)
  (1) Larrea-Franseria association
D. New Mexico and Arizona Plateaus and Mesas (Fig. 1, 36)
  (1) Bouteloua-Hilaria steppe

alkali sacaton (Sporobolus airoides), sand dropseed (S. cryptandrus), and broom snakeweed (Kuchler 1964; Gould 1975).

Major vegetation types of the Southeastern Arizona Basin and Range are the Bouteloua-Hilaria-Larrea shrubsteppe and the Larrea-Flourensia association (Kuchler 1964). The Bouteloua-Hilaria-Larrea shrubsteppe association was previously described in the section on the Southern Desertic Basins, Plains, and Mountains. The dominants of the Larrea-Flourensia association are tarbush and creosotebush. Other major components of the vegetation are: whitethorn, catclaw (Acacia greggii), lecheguilla (Agave lecheguilla), gyp grama (Bouteloua breviseta), sotol (Dasyliron spp.), cacti, and honey mesquite (Kuchler 1964).

Vegetation of the Central Arizona Basin and Range is primarily of the Larrea-Franseria association. The dominants are white bursage (Franseria dumosa)[2] and creosotebush. The other major components of the vegetation are: catclaw, blue paloverde (Cercidium floridum)[2], feather plume (Dalea spinosa)[2], whitebrittlebush (Encelia farinosa)[2], triangle bursage (Franseria deltoidea)[2], biggalleta (Hilaria rigida)[2], strawtop pricklypear (Opuntia echinocarpa)[2], and velvet mesquite (Prosopis juliflora var. velutina)[2] (Kuchler 1964).

The major vegetation type of the lower elevations of the New Mexico and Arizona Plateaus and Mesas is the Bouteloua-Hilaria steppe. The dominant plants are blue grama and galleta (Hilaria jamesii). Other major plants are: locoweeds (Astragalus spp.), fourwing saltbush (Atriplex canescens), sideoats grama, green mormontea (Ephedra viridis), and small soapweed (Yucca glauca) (Kuchler 1964).

ANIMAL RESOURCES

Only a few species of animals occur through all the various resource areas in the Western Range and Irrigated Region. A generally distributed permeant is the pronghorn antelope

(Antilocapra americana). The bison (Bison bison) has never been prominent in this region. Mule deer (Odocoileus hemionus) and the black-tailed jack rabbit (Lepus californicus) occur throughout the region. The coyote (Canus latrans) and bobcat (Lynx rufus) help in reducing populations of rabbits and wood rats (Neotoma albigula). The badger (Taxidea taxus) is generally distributed throughout this area. The banner-tailed kangaroo rat (Dipodomys spectabilis) is one of the most characteristic rodents of the region. The antelope jack rabbit (Lepus alleni) and black-tailed jack rabbit are common influents in the Southern Desertic Basins, Plains, and Mountains and the Southeastern Arizona Basin and Range. The enemies of the jack rabbits include the golden eagle (Aquila chrysaetos), great horned owl (Bubo virginianus), red-tailed hawk (Buteo jamaicensis), and the ferruginous hawk (B. regalis). Other small mammals, besides those mentioned above, often encountered in these latter resource areas are: desert cottontail (Sylvilagus audubonii), grasshopper mouse (Onychomys spp.), Merriam's kangaroo rat (Dipodomys merriami), and the Bailey's pocket mouse (Perognathus baileyi) (Shelford 1963).

Small birds common to the area are: horned larks (Eremophila alpestris), black-throated sparrows (Amphispiza bilineata), lark sparrows (Chondestes grammacus), grasshopper sparrows (Ammodramus savannarum), loggerhead shrike (Lanius ludovicianus), and nighthawks (Chordeiles spp.). Some of the common reptiles are: earless lizards (Holbrookia maculata approximans and H. texana), Devil's River whiptail (Cnemidophorus perplexus), large kingsnake (Lampropeltus getulus splendida), rattlesnake (Crotalus spp.), and bullsnake (Pituophis catenifer). Some of the common insects are: locust (Ageneotettix deorum), squash bugs (Mecidea longula, Liorhyssus hyalinus, and Arhyssus lateralis), false chinch bug (Nysius ericiae), damsel bug (Nabis alternatus), stilt bug (Jalysus wickhami), lantern bug (Oliarus pima), leafhopper (Neokolla curcubita and Exitianus obscurinervis), leaf beetles (Promecosoma virida and Pachybrachis nigrofasciatus), snout beetles (Centrinaspis spp., Pantomorus albosignatus, and Mitostylus setosus), and ants (Pogonomyrmex barbatus, P. californicus, Dorymyrmex pyramicus, and Myrmecocystus melliger) (Shelford 1963).

Some of the common mammals of the Central Arizona Basin and Range are: rock pocket mouse (Perognathus intermedius), Bailey's pocket mouse, rock squirrel (Citellus variegatus), hispid cotton rat (Sigmodon hispidus), spotted skunk (Spilogala gracilis), kit fox (Vulpes macrotis), desert cottontail, white-throated wood rat, peccary (Pecari tajacu), and white-tailed deer (Odocoileus virginianus). Some of the common birds are: Gila woodpecker (Centurus uropygialis), ash-throated fly-catcher (Myiarchus cinerascens), purple martin (Progne subis), roadrunner (Geococcyx californianus), Gambel's quail (Lophortyx gambelii), and the cactus wren (Camphylorhynchus brunneicapillum). Common reptiles are: tiger rattlesnake (Crotalus tigris), black-tailed rattlesnake (C. molossus), Mojave rattlesnake (C. scutulatus), bullsnake, Gila monster (Heloderma suspectum), collared lizard (Crotaphytus collaris), regal horned lizard (Phrynosoma solare), uta lizard (Uta spp.), whiptail lizard (Eumeces skiltonianus), desert spiny lizard (Sceloporus magister), zebra-tailed lizard (Callisaurus draconoides), and the desert tortoise (Gopherus agassizi). Some of the

Table 3.
Rangeland types, conditions, stocking rates, and production in the arid portions of the Southwest (from Renard et al. 1981; Sims et al. 1981).

Ecosystems[3]	Area NM	Area AZ	Area TX	Area Total	Condition (US)[1] Good	Condition (US)[1] Fair	Condition (US)[1] Poor	Condition (US)[1] Very Poor	Grazed (US)[1]	Stocking rate (US)[1]	Total stocking[2] Present	Total stocking[2] Potential
	----1,000 acre----				----%----				%	AUM/acre	--1,000 AUM's--	
Southwestern shrub-steppe	19,301	7,600	16,300	43,201	10.5	14.8	41.5	33.2	92	0.084	3,331	17,090
Desert shrub	299	22,499	27	22,825	17.4	36.4	31.5	14.7	70	0.041	653	2,264
Desert grassland	10,900	9,900	2,700	23,500	8.4	24.7	50.5	16.4	93	0.091	1,991	7,808
Total	30,500	39,999	19,027	89,526							5,975	27,162

[1] Condition, percentage grazed, and stocking rates are given for the specified ecosystem. The southwestern shrub-steppe only occurs in the three states, 28% of the desert shrub occurs in the three states, and 95% of the desert grasslands occur in NM, AZ, and TX.

[2] Present stocking = (total area) X (% grazed) X (stocking rate). Potential stocking was calculated by assuming that good, fair, poor, and very poor range conditions produced 80, 50, 30, and 10%, respectively, of the potential.

[3] The Southwestern Shrub-Steppe ecosystem includes the Bouteloua-Hilaria-Larrea shrubsteppe and the Flourensia-Larrea shrub savanna; the Desert Shrub ecosystem includes the Larrea-Franseria association, and in this table only, the Cercidium-Opuntia association; and the Desert Grasslands ecosystem includes the Bouteloua-Hilaria steppe and the Bouteloua-Hilaria prairie (Kuchler 1964).

common invertebrates are: crab spider (Misumenops celer), grasshopper (Trimerotropis pallidipennis and Platylactista azteca), bruchid (Acanthoscelides amicus), snout beetle (Apion ventriocosum), and the ants (Novomessor cockerelli and Pogonomyrmex barbatus nigrescens) (Shelford 1963).

PRODUCTION

Table 3 shows the area and present stocking of the major ecosystems in the arid portions of New Mexico, Arizona, and Texas. Also shown are the percentages of each ecosystem in various condition classes. From these data, we have calculated potential stocking based on reaching excellent condition (100%). Some land cannot support vegetation in excellent condition because the basic land resource will no longer sustain that level of production. However, other areas can exceed the production potential of native species on excellent range. Table 3 indicates that the three ecosystems in the three states could support about 450% of the animal unit months (AUM's) of stocking now present. To obtain this higher level would require intensive management. The degree of management practiced depends on economic, political, and social factors, and the availability of technology. If range production is increased, part of the addition could be allocated for uses other than livestock grazing.

Table 4 shows an estimate of the numbers of big game animals occurring in New Mexico, Arizona, and Texas. A portion of these animals occur in the more arid portions of these states.

PAST LAND USE

In 1600 the total population of pronghorn antelope was about 45 million in the arid and semiarid portions of the North American grasslands (Shelford 1963). The range cattle industry of the United States started in South Texas early in the nineteenth century (Fugate 1961). Most of the early cattle came from Spain by way of Mexico. From about 1840 to 1865, the cattle industry developed as stock farmers and others learned the new business and developed new techniques. The range cattle industry began to expand in 1866 after the Civil War. Destitute soldiers were returning from the war, hide hunters were killing the bison, the United States Army was pushing Indians onto reservations, and railroads were connecting the West with the more populous eastern United States. All these factors helped settle the West and created markets for cattle. Meanwhile, Texas ranges were stocked with multitudes of cattle, virtually worthless where they stood. During the period between 1866 and 1880, the cattle industry spread over most of the West. The trails going north from Texas were not single trails but merely a general direction of travel made up of numerous small trails converging at river fords and mountain passes (Herbel 1979).

Although sheep were among the animals first introduced from Europe into North America, they were relatively unimportant on the western rangelands before 1865 (Stoddart et al. 1975). Increases in range sheep production were minimal until there were railroads to carry the wool crop. After this development, sheepmen found much

Table 4.
Estimated numbers of big game in the Southwest (from the American Hunter 6(8):101-104, 1978).

	Number				Animal Units[a]			
	NM	AZ	TX	Total	NM	AZ	TX	Total
	1,000 head				1,000 AU's			
Bighorn sheep	0.8	3.0	<0.1	3.8	0.2	0.6	--	0.8
Mule deer	290.0	130.0	80.0(e)	500.0	72.5	32.5	20.0(e)	125.0
Javelina	1.2	30.0	--	31.2	--	--	--	--
Pronghorn antelope	26.0	7.5	14.7	48.2	4.4	1.3	2.5	8.2
Total	--	--	--	--	77.1	34.4	22.5	134.0

[a] 1 deer = 0.25 AU; 1 sheep = 0.20 AU; 1 pronghorn = 0.17 AU (from Heady 1975).

range that was well suited to their flocks and were attracted by the profits to be made from the grazing of free lands. From 1866 to 1901 there was a period of trail-herding in the sheep industry similar to that in the range cattle industry. Sheep were trailed from western rangelands to fattening and marketing points in the midwest. The pioneer sheepmen found they could increase their grazing land by seasonal migrations, sometimes covering vast areas. They grazed their animals yearlong, using the high, cool mountains during the summer months and the lower, warmer areas during the winter.

The range livestock industry boomed in the inflationary period after the Civil War, and except for a brief period of panic in 1873, phenomenal increases in numbers occurred until 1885 (Stoddart et al. 1975). The grass resource was considered to be limitless by many livestock owners, but the winter of 1885-1886, a winter of unprecedented severity, caused the livestock industry to collapse because there was no unused forage and no emergency feed. It has been estimated that this winter left 85% of the animals dead over wide areas on the range. As a consequence of this disaster, much of the speculative money supporting the boom was withdrawn. However, the remaining individuals had a long-term interest in raising livestock and were the real pioneers of the present range livestock industry.

In southern New Mexico, livestock numbers increased rapidly in the 1880's, especially near watering points. Many of the water wells were established between 1900 and 1910 so that the area was fully stocked by 1910 (Buffington and Herbel 1965). Wooton (1908) reported that the condition of New Mexico range was deteriorating and that it was not as productive as it was earlier. Cattle numbers also increased rapidly in Arizona in the 1880's. There were only 5,000 cattle in the Arizona Territory in 1870 (Martin 1975). Rapid movements of cattle from Texas and Mexico increased the number to 1,095,000 in 1890. Griffiths (1901) found the range in southern Arizona to be seriously depleted as a result of prolonged overstocking.

Land policies greatly affected the settlement and course of range management in the United States. At the time of its inception, the Federal Government had no land. However, shortly afterwards, several states turned over their unowned land to the Government and this became the first public domain. Most of the western lands were acquired for indirect considerations rather than for agricultural uses. For instance, the Southwest Territory was obtained from Mexico in 1846 to provide good harbors on the West Coast. Since no great value was attached to the land involved in these acquisitions, there was little concern for its judicious administration (Stoddart et al. 1975).

The land disposal measures enacted by the United States Government changed with time, as new circumstances arose, and as different economic segments were able to influence Congress. Zimmet (1966) identified five objectives of land-disposal policies: (1) sale of land to produce revenue for the Government; (2) facilitate the settlement and growth of new communities; (3) reward veterans of wars; (4) promote education and the construction of internal improvements, such as railroads, by grants of land; and (5) retention for reservations, national forests, and public domain.

One result of the Government's failure to regulate use of the public land was serious damage to range. During the period 1866 to 1934, when the Taylor Grazing Act was passed, little provision was made for administering grazing on public land. The result of this general lack of supervision was an intense competition among users to secure as much grazing as possible from the public lands. Such conditions resulted in extensive overgrazing on the range resource. Likewise, permitting land to be farmed in arid and semiarid areas led to much damage because it was unsuited for crop production. In most cases the farmers were from more humid climes and they discovered that the land was not sufficiently productive for cropping. During that time, the forage was destroyed and the land was subjected to erosion, which was sometimes so severe as to interfere seriously with revegetation after abandonment of farming practices (Stoddart et al. 1975).

PRESENT CONDITIONS

The vegetation on some rangelands has improved since the 1930's. Moderate stocking is more common, and many ranchers have improved their ranges by seeding, controlling unwanted plants, or periodic resting of the vegetation from grazing (Herbel 1979). The portions of Texas discussed in this chapter have little land owned by the Federal Government. However, 34% of the land within New Mexico is controlled by an agency of the Federal Government, and 45% of Arizona is federally controlled (Stoddart et al. 1975). Most of this land is leased to ranchers for livestock grazing. These rangelands are no longer the almost exclusive domain of ranchers and public land administrators. Absentee owners, speculators, miners, sportsmen, and other recreationists have an increased interest in land practices. Public concern about aesthetics, habitat destruction, or the balance of nature has at times been great enough to halt range improvement projects.

Widespread concern about how public lands are managed has greatly increased planning costs of administration of public lands. To some extent, this concern also limits management options for private landholders (Martin 1975). As Byerly (1970) indicated, we must now solve the problems of agricultural production with methods that are socially and economically acceptable. Environmental impact statements must be prepared before major projects are initiated on public lands. Maximum sustained production of forage and livestock is no longer the only consideration in operations on public lands. However, with the increasing demand for food by the rapidly growing population of the world, increasing effort is placed on production of animal protein from lands not suited for cultivation. The challenge to the range manager is to bring a proper balance between the biological realities of the site and the demands of the consumer (Stoddart et al. 1975).

In general, ranges have relatively low biological productivity (Clawson 1972). They are sometimes termed economic residuals after more productive sites are converted to higher economic uses such as improved pastures or croplands (Paulsen 1975). While limited plant growth is typical of most ranges, rough topography, remoteness, shallow soil, low rainfall, and severe temperatures are also characteristic of some rangelands (Thomas and Ronningen 1965). In addition, socio-economic factors further complicate the manager's efforts.

Most of the ranges described here are grazed primarily by cattle. Efforts to improve productivity of rangeland must often be restricted because of economic considerations. Sometimes only relatively inexpensive means can be employed, and these must be amortized over long periods. In many cases, however, herbage and browse on rangeland could contribute far more feed for livestock and wildlife than it now provides (Paulsen 1975). One of the least expensive practices on rangeland is to manipulate grazing, but the results are inconclusive (Herbel 1971).

Original plant productivity has been reduced over large areas by past grazing abuses, brush invasion, droughts, and past attempts to cultivate non-arable land. In many areas, the degradation is so complete that seeding is required to restore at least a portion of the former productivity (Herbel 1973). In some situations seeding increases productivity above pristine levels.

Unwanted shrubs and weeds have increased markedly on large parts of the southwestern United States. There are 93 million acres of mesquite throughout the area (Platt 1959). Creosotebush and tarbush occupy about 50 million acres at lower elevations of the Western Range and Irrigated Region. Cactus and snakeweeds are a serious problem in parts of the Southwest.

The density of brush on rangelands of the southwestern United States has increased rapidly since 1900. A survey by the U.S. Soil Conservation Service found 90 million acres, or 82% of Texas grasslands were infested with one or more low-value woody plants (Smith and Rechenthin 1964). Smith and Rechenthin reported that 55 million acres were covered with dense stands of brush requiring control measures before any other range improvement could be made. Yet in spite of efforts to control brush by chemical and mechanical methods, its density is increasing. The survey showed that the area of mesquite alone has increased by 1.25 million acres during the period of 1938-1963.

Livestock grazing began about 1900 on the upland areas of southern New Mexico. Notes from the land survey in 1858 enabled Buffington and Herbel (1965) to reconstruct vegetation types from that time to 1963 on the Jornada Experimental Range near Las Cruces, New Mexico. Mesquite dominated only 5% of the area in 1858, but this had increased to 50% in 1963. Most of the stands of mesquite in 1858 were associated with Indian activities. The rapid increase in recent years is due to dispersal of mesquite seed by livestock. As mesquite begins to dominate a sandy site, low dunes form, and grass cover is greatly reduced.

Creosotebush dominated 0.4% of the study area on the Jornada Experimental Range in 1858 and 14.2% of the area in 1963 (Buffington and Herbel 1965). Tarbush dominated 0.4% of the study area in 1858 and 8.6% of the area in 1963. It originally grew on the slopes next to mountains, but it has moved down the slopes and is now most prevalent on heavier soils, where it competes with tobosa and burrograss. As mesquite and tarbush began to dominate the slopes next to mountains, the original grass stands became less dense. Eventually creosotebush moved onto those sites and gained dominance over the mesquite, tarbush, and the residual grass stand. Four to six inches of topsoil has been lost from slopes now dominated by creosotebush, leaving the larger pebbles and stones to form an erosion pavement. Creosotebush will also invade sites where the original grass stand has been depleted.

RECOMMENDED LAND USE PRACTICES

Each ranch unit has different characteristics and objectives, and must be managed accordingly. Ranches differ in the amount of improvements (fencing, water developments, equipment), the proportion of various soil and vegetation types, wildlife species, recreational opportunities, and livestock characteristics (kind, breed, and class). Often the degree of management is determined by economic conditions and the willingness of an operator to undertake practices involving some financial risk. Generally, the less costly practices will also reap less benefits. An example of low intensity management is to build fences, increase the watering points, and initiate a grazing system. The changes in productivity are very slow, and thus the return on investment is very slow (Herbel 1971). An example of a more intensive practice would be mechanical control of creosotebush combined with seeding of Boer lovegrass (Eragrostis chloromelas) and Lehmann lovegrass (E. lehmanniana) (Abernathy and Herbel 1973). This practice costs more and the risks are great, but the potential benefits are much higher (Herbel 1979).

Each land manager should assess the potential economic benefits to be obtained from each major vegetation and soil type. He must consider values obtained from livestock, wildlife, recreation, and water; then he can determine which treatment or combination of treatments to use. Possibilities include grazing systems, seeding, control of unwanted plants, burning, fertilization, water spreading, fencing, and increasing the watering points. After improvements have been completed, or at any point in the process, the land manager may modify his plans to maximize profits while maintaining the resource. Similarly, with changing technology or improving economic conditions, the manager may decide to intensify his improvement efforts (Herbel et al. 1974).

Control of Unwanted Plants

Undesirable plants can be controlled and ranges can be revegetated with forage species, but it takes judicious use of control methods and sound grazing practices. Woody plants such as mesquite, creosotebush, and tarbush cannot be eliminated by good grazing practices alone. The brush has to be controlled before the range can benefit from other practices such as grazing management, seeding, or water spreading. The most effective method for control of woody plants depends on the site, the species, and the degree of infestation. Any control of brush requires considerable attention to detail to obtain maximum benefits. Control of unwanted plants is generally less costly when invasion is just beginning and the plants are small and scattered. In this situation, a method is selected that will not destroy the residual forage plants. On sandy soils heavily infested with brush, a broadcast chemical method will control the undesirable plants and result in an increase of forage plants. Mechanical control methods are generally avoided on sandy soils because of the wind erosion hazard if a good plant cover is not maintained. Fortunately, natural revegetation is often quite rapid on sandy soils after chemical control of the brush. A mechanical method of control accompanied by seeding may be required on soils with a medium to heavy texture, a heavy infestation of brush, and a poor stand of desirable plants. Natural revegetation after brush control is often very slow on medium to heavy-textured soils (Herbel et al. 1974).

Controlling stands of mixed brush species with a single spray application is often difficult because species vary in degree and time of susceptibility to herbicides. To be effective, foliage applications of herbicides must be applied at the proper stage of growth. Treating mesquite even 1 week too early drastically reduces the effectiveness of spraying with 2,4,5-T (Valentine and Norris 1960). To achieve adequate initial control of many woody plants, two or more herbicidal applications are necessary. Two aerial spray applications of 0.5 lb/acre of 2,4,5-T, 1 to 3 years apart, killed 23-64% of the mesquite on sand dunes in southern New Mexico (Herbel and Gould 1970). Perennial grass yields on areas sprayed twice in 1958-1961 averaged 209 lb/acre during 1963-1968, compared to 35 lb/acre on an adjacent unsprayed area. The sand dunes have levelled and there has been less wind erosion on the sprayed areas.

Herbicides such as 2,4-D, 2,4,5-T, silvex, dicamba, and picloram control many plant species. Mixtures of picloram and 2,4,5-T or dicamba and 2,4,5-T are used to control mesquite in Texas, particularly where it is growing in association with other unwanted plants (Herbel 1979).

Individual plant treatments of dry herbicides are an effective and economic method of controlling sparse stands of brush. Monuron, picloram, dicamba, and other herbicides are applied as powder, granules, or pellets around the base of target plants (National Research Council 1968).

Bulldozing and mechanical grubbing, rootplowing, discing, and cabling or chaining are the major mechanical methods of brush control on rangeland. Bulldozing is effective on sparse stands of many species. Bulldozer blades or front-end loaders may be fitted with a stinger blade which is pushed under the crown of the plant to ensure uprooting of the bud zone. Experienced operators can lift and push over a shrub or small tree in one operation (National Research Council 1968). Grubbing with a stinger blade is used to control mesquite growing on medium-textured soils.

A rootplow is a horizontal blade attached to a track-type tractor. Rootplowing cuts off the shrub or small tree at depths of approximately 16 inches for mesquite or other resprouting species and 6 to 8 inches for non-sprouting species. Rootplowing kills 90% or more of all the vegetation growing on the area. The method is best adapted to dense brush areas having little or no residual grass and where seeding of desirable species is possible. It is used to control mesquite in Texas (Rechenthin et al. 1964), creosotebush and

tarbush in New Mexico (Abernathy and Herbel 1973), and chaparral in central Arizona (Cable 1975).

In discing, the brush is uprooted with a large disc plow or tandem disc. It is limited to small shallow rooted plants like tarbush and creosotebush. It also destroys grasses growing on the area, so, like rootplowing, it should only be used in areas where desirable plants can be established (National Research Council 1968).

Chaining and cabling involve the dragging of an anchor chain or heavy duty cable, 300 to 400 feet long, behind two track-type tractors (Fisher et al. 1959). The method is effective in controlling non-sprouting species. Cabling is used to control cholla cactus in New Mexico. It is useful in knocking down mesquite trees previously killed by aerial spraying, thereby reducing the cost of working livestock. Trees left standing prevent the operator from seeing his livestock.

There is some research on biological control of unwanted plants in the area, but results to date have not justified field-scale applications in the Southwest.

<u>Mesquite (Prosopis spp.)</u>. Mesquite invasion is considered detrimental throughout the semidesert range area. The first objection to mesquite is that it reduces the density and herbage yield of grasses. Mesquite foliage is used by livestock to some degree and the flowers and fruits are high-quality forage, but forage production by mesquite does not compensate for the decline in grass production as mesquite becomes thicker. McGinnies and Arnold (1939) found that mesquite requires three to four times as much water to produce a unit of dry matter as do native perennial grasses. Even moderate stands (as few as 25 trees/acres in Arizona, for example) may cut herbage production in half (Martin 1975). By reducing grass density, mesquite also induces or accelerates sheet and gully erosion. The lateral roots of mesquite remove moisture from the soil between the trees as well as beneath them. Wind tends to sweep litter and topsoil from the relatively bare areas between the trees and deposit it under the mesquite crowns. The net result is that growing conditions between trees become increasingly difficult and erosion accelerates.

Mesquite is also objectionable because it increases the cost and difficulty of handling range cattle. As the cost of range labor increases, this factor becomes increasingly important.

Several factors have contributed to mesquite increases on semidesert range. Range livestock have contributed both directly and indirectly. By consuming mesquite beans, many of which pass through the digestive tract of a cow, cattle have spread mesquite seeds throughout the grazed area. This is only one reason why mesquite stands usually are heaviest where cattle naturally congregate. Cattle have contributed indirectly to the spread of mesquite by past management and weakening the stands of perennial grasses. Vigorous perennial grasses compete strongly with mesquite seedlings. Experiments on the Santa Rita Experimental Range show that 16 times as many mesquite seedlings were established on bare areas as in vigorous stands of perennial grasses (Glendening and Paulsen 1955). Grazing also may have contributed to the spread of mesquite by reducing the amount of fuel for and the incidence of range fires. Honey mesquite occurs primarily in western Texas, southern New Mexico, and southeastern Arizona while velvet mesquite occurs primarily in southern Arizona. These species differ in some aspects.

Most mesquite-infested ranges can be restored to full productivity only if the mesquite is removed. Grass response following removal of moderate to dense stands of mesquite is excellent. A variety of mesquite control methods have been developed. Each method is peculiarly adapted to rather specific situations. Available methods include: (1) hand grubbing of mesquite seedlings, (2) individual tree treatment with diesel oil or with diesel oil containing herbicides, (3) application of granular herbicides to the soil around trees, (4) aerial spraying with herbicides, (5) individual tree dozing, (6) cabling or chaining, (7) roller chopping, (8) rootplowing, and (9) prescribed burning.

Hand grubbing, which is effective for plants up to 36 inches in canopy diameter is best for early invasion stands or colonies of small mesquites on relatively rock-free soils. Grubbing is a labor-intensive method. It will not pay immediate returns on the investment because the removal of small seedlings does not increase forage production perceptibly. Grubbing must be justified as preventive maintenance-insurance against future production decline (Herbel et al. 1958).

Diesel oil, like grubbing, requires so much labor that it is suitable mainly for small areas where mesquite control is especially needed. The method consists of spraying diesel oil against the trunk of the tree at groundline. Oil must saturate the bark on all sides of the stem. A quart of diesel oil will treat one to two trees. Mesquites that branch at or above groundline and have not more than five stems can be killed. Diesel oil fortified with 2,4,5-T is somewhat more effective than straight diesel oil, but the added cost is not usually justified. Diesel oil is not suitable for "dune" or "running" mesquite, nor is it suitable for use on flood plains where the bud zone has been buried beneath several inches of silt. Oil can be applied any time of year with kills up to 90%, but cool-season treatments give slightly higher kills, and labor is somewhat more efficient when the weather is not too hot. Diesel oil, if properly applied, will kill either trees or stumps (Martin 1975).

Individual mesquites can also be killed by applying granular herbicides to the soil around the base of the trees. Monuron, fenuron, and karbutilate are effective when properly used. The advantage these herbicides have over diesel oil is that they are effective against any growth form of mesquite. On sandy soils, Herbel and Gould (1970) found that 0.1 oz. (3 gm) active ingredient (a.i.) per 3 feet canopy diameter would give an average of 80% plant kill when fenuron or monuron were applied just before or in the early part of an expected rainy season.

For extensive control, application of herbicides by aircraft can be useful. Low-volatile esters of 2,4,5-T, when applied 2 years in succession and at the right time (Valentine and Norris 1960) provide effective control. Addition of picloram or other substances to

2,4,5-T has enhanced the kill in some experiments, but results have not been consistent.

Aerial applications of 2,4,5-T rarely kill more than 50 or 60% of the trees outright, but effective applications usually kill 90% or more of the top growth and markedly increase perennial grass production. Regrowth of mesquite after aerial spraying is relatively slow. On the Santa Rita Experimental Range, for example, mesquite control in 1954 and 1955 was still providing increased forage production in 1974. Greater increases in forage production could still be obtained by spraying a new area than by respraying the tract that was first sprayed 20 years before (Martin 1975).

Aerial spraying leaves the top wood standing. Although the standing dead trees are aesthetically displeasing, reduce visibility, and add to the difficulty of working cattle, they may provide some wildlife benefits.

Because the critical time for spraying mesquite with 2,4,5-T usually does not coincide with periods of active growth for other plants, the damage to species other than mesquite usually is negligible. Grasses are not visibly damaged, nor is there evidence to indicate that 2,4,5-T has been seriously detrimental directly to animals. The major impact on small animal populations probably results from changes in vegetation. Animals that do best in relatively sparse stands of grasses mixed with shrubs undoubtedly are affected adversely. Grassland species, on the other hand, should benefit. Since spraying does not result in 100% kill, sprouts from treated trees provide adequate mesquite foliage for browsing animals. On the other hand, spraying does stop production of flowers and fruits for several years. Recent studies on the Jornada Experimental Range, as yet unpublished, studied the effects of mesquite control on: productivity and phenology of plants; diets, habits, and performance of cattle; wind erosion of soils; insects, small mammals, birds, and soil micro-organisms; herbicide residuals; and alternate herbicides. It has already been determined that about 1.0 lb/acre a.i. of tebuthiuron will effectively control mesquite whereas 1.5 lb/acre may adversely affect the desirable herbaceous plants.

Individual tree dozing is a good method for removing scattered stands of mesquite. It is effective on all growth forms and at any time of year, except that small seedlings are likely to be overlooked. When carefully done, bulldozing kills a high percentage of the mesquite and has the advantage that the stumps are removed and the trees are knocked down. With little extra expense, the uprooted trees can sometimes be pushed into arroyos, leaving the bulk of the area free of obstructions. Increases in herbage production following bulldozing depend largely on the degree of release obtained and on the ability of the remnant grass to respond. Bulldozing is more acceptable than chemical control in some areas because it does not introduce herbicides into the environment.

Two tractors dragging a cable or anchor chain between them can be used to knock down either dead or live mesquite trees of almost any size. Cabling in both directions will uproot most trees that have large enough stems. The cable or chain will simply slide over smaller trees (up to about 2 inches in diameter) without damaging them seriously. Thus, a major disadvantage of cabling or chaining is that it usually results in rapid regrowth of sprouts from smaller trees.

Cabling knocks down not only the mesquite but other kinds of brush as well, and thereby provides an uninterrupted view. This has a real advantage from the standpoint of handling livestock. Cabling must always be followed by other control measures. Spraying individual sprouts with herbicides, aerial application of herbicides, and burning are possible maintenance measures.

Cabling is not effective on the low-growing, many-stemmed growth form of mesquite. On sandy soils where the many-stemmed mesquite forms dunes, cabling disturbs the soil too much and leads to excessive wind erosion. For mature dune-type mesquites, aerial spraying is preferable to mechanical control.

Huge roller choppers completely smash down all woody vegetation and provide a clear view, as does cabling or chaining. In fact, chopping may provide an even more uncluttered view because it does not leave the brush in piles as chaining or cabling sometimes does. Percent mesquite kill by chopping probably is no greater than with cabling, so followup measures are needed to maintain a brush-free aspect. Chopping and cabling do not destroy remnant stands of perennial grasses, although some plants are killed (Martin 1975).

Although rootplowing is the most destructive mechanical method of removing mesquite, it is also the most effective, because it uproots all plants in the area. Plants that survive are mainly those at the edge of a swath that are not completely severed by the blade. Small plants that are cut off but not flipped out also may survive, especially if the soil becomes wet soon after plowing. Rootplowing destroys or seriously disturbs all vegetation including the perennial grasses. Therefore, seeding at the time of plowing is usually essential for the prompt reestablishment of a forage stand (Herbel et al. 1973). However, Mathis et al. (1971) reported that herbage production 5 years after rootplowing was lower on seeded range than on range that was not seeded.

Prescribed burning can rarely be used to control moderate to dense mesquite stands because such stands seldom produce enough fuel to carry a fire. A hot fire in June may topkill almost all small mesquite plants (up to 0.4 inches in stem diameter at groundlines) and kill about 50% of them outright (Glendening and Paulsen 1955), but very few trees larger than 4 inches in basal stem diameter are killed. The only place for prescribed burning in mature mesquite stands, therefore, is following some other method that has seriously weakened or killed the original trees. Once the original stand has been controlled by mechanical or chemical methods and a stand of grasses has become reestablished, periodic burning may be useful for controlling reinvasion and regrowth. Burning at suitable intervals will kill small plants back to the groundline periodically, and keep most of them from maturing and producing seed.

Ecologically, burning is not necessarily inexpensive. Fires that will kill mesquite will also kill grasses. Burning studies on the Santa Rita Experimental Range show that some grasses are not seriously damaged by fire, while other grasses are damaged. The difference apparently results because some grasses are randomly disturbed, mostly in the openings between shrubs, whereas others grow mainly in shrub crowns where they are subjected to greater heat

as the shrubs burn. Unfortunately, many of our better long-lived grasses are severely damaged by fire and are very slow to recover. A June fire, for example, killed 90% of the black grama, compared to less than 50% of the mesquite (Cable 1965). Obviously, burning encourages species that can survive a fire or quickly reproduce themselves from seed. Our best forage species are deficient in these attributes. A fire that kills 90% of the grass but only from 10 to 50% of the mesquite may not be desirable.

Creosotebush (Larrea tridentata). Creosotebush occupies vast areas of the more arid semidesert region. Gardner (1951) reported that creosotebush has occupied much former grassland in New Mexico since 1850. Its grazing value is nil, and herbage production in moderate to dense stands of creosotebush is negligible. Some ecologists believe that creosotebush even has the ability to replace mesquite on areas that formerly were grassland (Buffington and Herbel 1965). Since creosotebush occupies ranges with relatively low potential, the response of perennial grasses to removal of creosotebush often is not striking. Grass stands where creosotebush predominates usually are so sparse that the cost of high-risk seeding must be added to those of shrub control.

Because of the economics involved, less work has been done on control methods for creosotebush than for mesquite. Creosotebush is relatively resistant to aerial applications of phenoxy herbicides. It is a vigorous crown sprouter and its stems are too flexible for effective chaining or cabling. Rootplowing is effective, but is often too expensive to be justified. Abernathy and Herbel (1973) reported that shrub control, basin pitting, and seeding with a machine that does all three jobs at one pass can be used on selected creosotebush sites that have soils that support an adequate stand of forage plants. Individual creosotebush plants can also be killed by applying granular or pelleted herbicides to the soil around the base of the plants. On sandy loam soils, Herbel and Gould (1970) found that 0.07 oz. (2 gm) a.i. per 3 feet canopy diameter would give an average of 90% plant kill when fenuron-related herbicides were applied just before or in the early part of an expected rainy season. Recent unpublished research at the Jornada has determined that about 0.3 lb/acre a.i. of tebuthiuron pellets applied aerially will effectively control creosotebush.

Some work indicated that creosotebush (particularly young plants) is susceptible to fire (White 1968). Fire cannot be used in dense mature stands of creosotebush, however, because they rarely, if ever, provide enough herbaceous fuel to carry a fire. One possibility is to use fire following other treatments. Once the creosotebush has been removed and a stand of herbaceous vegetation established, fire might be used to prevent reinvasion. The prospects are only moderately good at best, however, because rainfall where creosotebush thrives does not often produce enough herbage to carry a fire.

Tarbush (Flourensia cernua). Tarbush occupies portions of the semidesert grassland, particularly medium to heavy textured soils. Platt (1959) indicated that it was a dominant plant on 13.3 million acres in the Southwest. It is a deciduous plant but it has some grazing value when it has leaves (Herbel and Nelson 1966). However, it readily replaces tobosa and burrograss, and severely hampers production of these desirable grasses. Treating single plants with dry herbicides is an effective method of controlling tarbush in stands up to about 160 plants/acre. Isocil, bromacil, fenuron-trichoroacetate, monuron-trichloroacetate, monuron, fenuron, and dicamba at 0.05 oz./3 feet canopy diameter a.i. killed in excess of 85% of the plants on clay loam soils. Best results were obtained when these materials were applied just prior to, or in the early part of, an expected rainy season (Herbel and Gould 1970).

Tarbush is most susceptible to herbicidal sprays after the plants have 2/3 of their full foliage but before they start to bloom. Spraying with 2 lb/acre dicamba in September has generally been the most effective (Herbel et al. 1974). Recently, we found that an aerial application of 0.25 lb/acre tebuthiuron was very effective in controlling tarbush.

Tarbush is relatively easy to kill by rootplowing, disking, or grubbing. Since tarbush becomes quite dry and brittle in the winter, chaining or railing at that time substantially reduces its cover. Chaining or railing does little damage to residual grasses, so a reduction in tarbush cover permits a substantial increase in production of any residual grasses (Herbel et al. 1974).

Cactus (Opuntia spp.). Various cacti species are a nuisance on substantial areas of semidesert range. Most widespread in southern Arizona are the cholla or tree cactus forms that predominate at the lower elevations and lower rainfall portions of the region. Cholla is a problem primarily because it occupies space and interferes with handling of cattle. It does not appear to compete seriously with perennial grasses. Due to the spines, however, grasses that grow under cholla are not available to cattle. Thus, cacti interfere more with the use of grasses than with their growth. Cholla stands in southern Arizona usually are not permanent. Stands tend to increase over a period of years, then die from natural causes. The cycle from invasion to die-off may run 40 to 50 years.

The chollas are fairly resistant to light applications of such herbicides as 2,4,5-T and 2,4-D. Each plant must be completely wetted. Chollas can easily be knocked down with a cable or chain. This method is quite effective in senescent stands. The number of rooted chollas per unit area may jump manyfold after cabling due to the rooting of joints on the ground, but most of these new plants die in about 3 years (Martin and Tschirley 1969).

Fires in June have killed about 50% of the cholla on the Santa Rita Experimental Range. Surviving plants usually were large individuals that were only partially burned. Periodic burning should be an effective tool for preventing cholla invasion (Martin 1975).

Pricklypear is a problem mainly where rainfall is somewhat higher than on areas occupied by cholla. Pricklypear apparently is less conspicuously cyclical than the cholla. It is equally hard to control with herbicides and about equally susceptible to fire.

Burroweed (Haplopappus tenuisectus). Burroweed is of concern primarily in southern Arizona and southwestern New Mexico. Although it is toxic, cattle are rarely poisoned. It germinates in the fall or winter on cool-season moisture. It competes less severely with the grasses than does mesquite because (1) it grows primarily in the

spring whereas grasses grow mainly in the summer, and (2) because its taproot system draws less heavily from soil moisture near the surface than is the case for perennial grasses. Burroweed stands tend to build up if cool-season moisture is above average, and decline when cool-season moisture is severely below average (Martin 1975).

Grubbing, mechanical treatments, and prescribed fire can all be used to control burroweed (Tschirley and Martin 1961). Grubbing generally is too expensive. Mowing in June or July is effective, but only on relatively level, rock-free terrain. Results with herbicides such as 2,4-D have been erratic. Burning in June with 500 lb/acre or more of herbage may kill up to 90% of the burroweed. Burning simply to control burroweed may not be feasible, however, not only because burroweed control does not greatly increase production of perennial grasses, but because many of the better perennial grasses are severely damaged by fires of the intensity needed to kill burroweed. Also, burroweed can quickly reoccupy the burned area if cool-season precipitation is high.

The fact that burroweed stands usually decline of their own accord after a few years also reduces urgency for burroweed control. Wooton (1916) reported an invasion of burroweed in 1903 near the southwest corner of the Santa Rita Experimental Range. By 1917 a considerable part of the burroweed was dead. Wooton attributed death of burroweed to crowding by grass. Whatever the cause, burroweed stands apparently were changing from year to year during the first two decades after the range was established. Two additional burroweed invasions have been recorded since. One reached its zenith around 1935, the other in 1968.

Another reason for caution about burroweed control is that most of the perennial grass plants on a range in poor condition are intermingled with burroweed or other shrubs. Removing the burroweed from such ranges would expose these remnant perennial grasses to increased grazing. Therefore, burroweed control on ranges where grazing is excessive may only accelerate the decline of perennial grasses (Martin 1975).

Snakeweed (Xanthocephalum spp.). Snakeweed, also a cool-season germinator, is more widespread than burroweed. Like burroweed, it is toxic although usually not fatal to cattle. More commonly, consumption of snakeweed by cattle results in abortion. Snakeweed can be controlled with ester formulations of 2,4-D. Aerial or ground sprays of 1 to 1 1/2 lb/acre (acid equivalent) in 10 gallons of water or oil-water emulsion are recommended. Spraying 2 years in succession is often necessary to control seedlings that emerge after the initial spraying. Time of spraying is critical. It should be done early in the spring when new growth is about 4 inches and while there is enough moisture in the soil to keep plants growing 2 or 3 more weeks (Martin 1975). A more recent finding is that low levels of picloram (1/8 - 1/4 lb/acre) may give excellent control of snakeweed and also have some residual effects to suppress new seedlings (Gerard unpublished data).

Snakeweed differs from burroweed in that it has a fibrous root system that occupies about the same soil levels as the roots of perennial grasses. Thus snakeweed may compete more directly with grasses than burroweed.

Seeding

Seeding arid rangelands is generally a difficult undertaking because of limiting climatic, soil, and/or topographic features. The good sites with a favorable climate are in cultivated crops. Therefore the task is to seed and grow range plants where even the hardiest crop plants are not productive and are difficult or impossible to establish.

Most range grasses should not be seeded deeper than 0.75 inch. Establishing seedlings is often difficult because of an adverse microenvironment (rapid drying, unfavorable temperatures, and crusting of the soil surface). Harsh environmenal conditions in the surface soil often prevent successful seedling establishment. Army and Hudspeth (1960) and Hudspeth and Taylor (1961) reported that sufficient moisture for seedling emergence could not be maintained on bare surface soil except under extremely favorably weather conditions in the Great Plains. Drier regions would have more intensive problems. The major objectives of preparing seedbeds for range seeding are: (1) to prepare a favorable microenvironment for seedling establishment; (2) remove or substantially reduce competing vegetation; and (3) if possible, leave litter on the surface of the soil to reduce erosion hazards and to improve the microclimate (Herbel 1972). Only a limited seeding success was obtained after pitting with a pitting disc and ripping (Thomas and Young 1956; Dortignac and Hickey 1963; Dudley and Hudspeth 1964). Ripping lines often seal-over in a relatively short time. Narrow pits can fill with soil rather rapidly on some sites.

The broad shallow pits made with the basin-forming machine developed by Frost and Hamilton (1965) made a good seedbed and lasted longer than conventional pits. Over a 4-year period, average production of seeded buffelgrass (Cenchrus ciliaris) was 690 lb/acre on broad pits and 253 lb/acre on conventional pits on a site in the Southeastern Arizona Basin and Range near Tucson (Slayback and Cable 1970). Pitting is generally most successful on medium to heavy-textured soils on flat or gently sloping sites.

Contour furrows form good seedbeds on medium to heavy-textured soils. It is desirable to use interrupted furrows to prevent a larger water loss if a furrow wall breaks and to preclude the necessity of furrowing exactly on the contour (Herbel 1972). Firming the soil beneath the seed while planting was more successful than firming the soil surface following seeding. Firming the soil after seeding has the following disadvantages: (1) it may push the seed deeper than desired, (2) it may restrict aeration in the seed zone, and (3) it enhances crusting on some soils (Herbel 1972).

A method of seeding arid and semiarid areas infested with brush has been discussed by Abernathy and Herbel (1973). The brush and competing vegetation are controlled by a rootplow. Basin pits are formed, and about 40% of the area is seeded with a press-wheel seeder. An attempt is made to concentrate the brush and water on the seeded area. Brush control, pitting, seeding, and brush placement are accomplished with one pass over the land.

Concentrating water, as with various land-forming procedures, does not always ensure seeding establishment. The surface soil still dries rapidly, particularly in hot, arid and semiarid areas. This rapid drying may lead to the formation of a heavy crust on medium- to heavy-textured soils. In those instances, if the surface could be shaded to reduce evaporation, seedling emergence and establishment would be greatly enhanced (Herbel 1972).

Plant species used for range seeding vary with climatic and site conditions, and management of a specific range unit. Improved ecotypes of many grass species have been selected for: superior seedling vigor; drought, disease and insect tolerance; forage and seed production; and the ability to reproduce vegetatively. Considerable use is made of seed harvests of native species. It is important to choose native ecotypes of local origin, generally within 200 miles north and 300 miles south of the area to be seeded. Some of the major native and introduced species used for seeding in the Southwest on light to medium-textured soils are: black grama, sideoats grama, Boer lovegrass, Lehmann lovegrass, yellow bluestem (Bothriochloa ischaemum), blue panicgrass (Panicum antidotale), and fourwing saltbush. Some of the species used on medium to heavy-textured soils are: alkali sacaton, sacaton (Sporobolus wrightii), vine mesquitegrass (Panicum obtusum), blue panicgrass, yellow bluestem, and fourwing saltbush.

Fire

Where prescribed burning is an applicable tool, many objectives can be achieved simultaneously. Increased herbage yields, increased utilization, increased availability of forage, improved wildlife habitat (more food with unburned patches for cover), control of undesirable shrubs, and control of various insects and diseases can all be achieved with one burn (Wright 1974). However, much of the area discussed in this chapter rarely has enough fuel for widespread fires.

Because of the variety of seasons and weather conditions, one must use care in interpreting the results of a burning study. If the data are from a wildfire, the fire probably occurred during a dry period. If the data are from a prescribed burn, the fire probably occurred when the weather and plant conditions were optimal. Fires during dry periods are harmful because they magnify drought stress on plants, whereas fires during wet periods are generally beneficial because moisture is not limiting and fires increase soil temperature and stimulate nitrification (Wright 1974). As an example, tobosa produced 2,813 lb/acre after burning during a wet year and only 625 lb/acre after burning during a dry year. The unburned controls produced 1,127 and 954 lb/acre, respectively (Wright 1972).

Except for black grama, most grasses in the Southern Desertic Basins, Plains, and Mountains recover from fire in 1 to 3 years. Black grama may take 3 to 8 years to recover because of periodic droughts (Wright 1980).

In the Southern Desertic Basins, Plains, and Mountains in southern New Mexico, Herbel and Nelson (1974) conducted a study to determine if tobosa could be grazed during the winter-spring when it is mostly dormant. The old growth on tobosa was burned for 3 years after the first storm. However, calf performance the following winter-spring was not improved by burning during the previous summer.

Prescribed burning can be recommended for controlling burroweed in southern Arizona (Tschirley and Martin 1961). However, Martin (1975) indicated that populations of burroweed tend to fluctuate without any control measures and therefore treatment could not be recommended. Martin further stated that prescribed burning cannot be generally recommended for the Central and Southeastern Arizona Basin and Range or the Southern Desertic Basins, Plains, and Mountains. Fires that kill shrubs usually kill grasses too, and fires that spare the grasses may not kill the shrubs. Burning in that area usually favors annual grasses and pioneering perennial grasses at the expense of the climax perennial grasses. When there is sufficient fuel, as sometimes occurs following one to two years of above-average summer precipitation, fire can be used to control cacti, broom snakeweed, creosotebush, and young mesquite plants (Wright 1980).

Management after a burn is essential (Wright 1974). Grazing animals will frequently concentrate on a burn because the feed is more palatable, nutritious, and available. Therefore, burning must be done on a manageable unit basis.

Rodent and Rabbit Control

Rodents and rabbits use vegetation that would otherwise be available for livestock and other animals. Rodents and rabbits can be more detrimental to range plants than cattle because they graze much closer and may even dig up the plants during dry periods. Because populations of jack rabbits and kangaroo rats tend to be highest on ranges in poor condition, their impact becomes more severe as productivity declines. Certain species (the Merriam kangaroo rat, for example) help establish shrubs by burying seeds in shallow surface caches at the optimum depth for germination (Martin 1975). However, some control may be desirable, particularly in drought years.

Direct methods of controlling rabbits and rodents by poisoning, trapping, shooting, rabbit drives, etc, usually provide only temporary relief and are rarely worth the cost. Most small mammals have survived man's most determined efforts to exterminate them. Vegetation management appears to offer a better approach to animal control. Improving the condition of a range from poor to good often eliminates the most evident rodent problems, but rodent control may be needed initially to start the upward trend. The availability of preferred food and cover as well as the balance between prey and predator species may be affected by the amount and kind of vegetation. And, while the causes and effects are not always clear, ranges in good to excellent condition have less serious rodent problems (Martin 1975).

Fertilization

Fertilizers have been applied to rangelands to increase forage production, to lengthen the green forage period, to improve the chances for successful establishment of seedlings, increase the rate of secondary succession, and have been suggested as a means of attracting animals to little-used parts of the range. Fertilizers

sometimes increase herbage production greatly, especially in seasons of above-average rainfall. These increases, though dramatic, may be of little practical use because ranges that are properly stocked always produce a surplus of forage in years of high rainfall. The extra forage produced by applying fertilizer in a wet year has little value for the rancher if he does not have enough animals to use it. Fertilizer applications would be much more helpful if they could be used to increase production in years of forage scarcity.

Fertilizers may have a place in the improvement of animal distribution and in utilizing relatively unpalatable species. Applications of fertilizer often result in closer utilization of the fertilized plots. In many cases the fertilized plots are grazed evenly with no apparent selectivity among species. This suggests that fertilizers can be used to enhance the palatability of forage in areas that animals often pass up. The economics of such applications have not been investigated.

Fertilizer may raise average levels of forage and livestock production above those that can be reached simply by improved grazing management, seeding, and shrub control. In some parts of the region, low amounts of available nitrogen (N) and phosphorus (P) in the soil limit plant growth. Fertilizing with N and P is economical only where there is adequate moisture and plant species that respond to the added nutrients (Herbel 1979).

On flood plains dominated by tobosa in the Southern Desertic Basins, Plains, and Mountains, it was concluded that fertilization with N and P was uneconomical in all but the best moisture conditions (Herbel 1963). In a year when favorable soil moisture conditions existed over a continuous 60-day growing period, 90 lb/acre N increased herbage yield from 2,791 lb/acre on the control to 6,955 lb/acre, but the benefits of annual treatment were small in two other years with above average rainfall. Some possibilities exist for using moderate rates of fertilizer to increase forage production on flood plains where this will permit longer growing season deferment of adjacent upland pastures.

On an area in the Southeastern Arizona Basin and Range dominated by Lehmann lovegrass and Santa Rita threeawn (*Aristida glabrata*), check plots yielded an average of 2,475 lb/acre (Holt and Wilson 1961). Fertilization with 25, 50, and 100 lb/acre N increased yields 66 to 158%. Cattle preferred the fertilized forage and exhibited no preferences for grass species. On unfertilized areas cattle showed marked species preferences. The fertilizer extended the green-feed period up to 6 weeks.

Water Spreading

Water spreading has two main functions: (1) increasing forage production by spreading of floodwater and the storage of water in the soil profile, and (2) reducing gully erosion and downstream flooding and sedimentation (Monson and Quesenberry 1958). Stream channels, dry most of the time, that flow for only short periods after heavy rain storms, generally provide the water supply for water spreading. The watershed area above the water spreading site should provide at least one flooding over the site per year for satisfactory forage production and additional floodings each year are advantageous (Miller et al. 1969).

Frequent and heavy deposits of sediment interfere with the effectiveness of the spreader system. Such deposits retard plant growth and often kill younger plants (Stokes et al. 1954). Hubbell and Gardner (1950) found that sediments carried by floodwater had an adverse effect on the yield of all grasses in the study area in the San Juan River Valley Mesas and Plains, except western wheatgrass (Agropyron smithii). Of the other grasses studied by them, alkali sacaton was only slightly affected by sedimentation, but galleta and blue grama were readily killed by sedimentation. The additional water provided by the water spreading substantially increased production of all the above grasses where sedimentation did not pose a problem to the particular species.

Game Habitat

Properly planned and executed game range improvement projects may increase game production through improved quantity and/or quality of the feed supply. Thus, most range improvement practices aid in increasing game animals. Range improvement also aids where game animals have increased in numbers to the point where the forage supply is being exhausted or the range is in a deteriorating condition. In the latter, an alternative would be to reduce the game herd to the carrying capacity indicated by the range condition (Lamb and Pieper 1971).

Hamilton (1976) increased gross income from hunting leases by 300% from 1965-1975 on the Chaparrosa Ranch in the Rio Grande Plain. He found that spraying mesquite in strip patterns maintained populations of deer while improving livestock production. Spraying an entire 1,430 acre pasture drastically reduced the deer herd in that pasture.

The major game species in the Arizona chaparral is deer. Deer populations are relatively low where the brush is dense and herbaceous understory is sparse (Cable 1975). Urness (1974) found that deer spent a quarter to half as much time on chaparral areas cleared by rootplowing as in untreated brush. However, he suggested that the deer probably received much more benefit per unit time on the cleared areas because of the relatively high volumes of high quality forage and because deer spent their time on these areas exclusively for feeding while resting and ruminating on untreated areas. Management plans for deer on chaparral must provide browse and cover.

The principal game species on the Southeastern Arizona Basin and Range and the Southern Desertic Basin, Plains, and Mountains are antelope, deer, quail, and doves. Habitats for these animals can often be improved without reducing, or even while increasing, the livestock capacity of a range (Herbel et al. 1974). Where a mixture of shrubs and grasses grow, an occasional fire seems to improve the browse. Antelope and game birds prefer mixed grass-forb vegetation to brush types. On areas infested with creosotebush, any treatment that increases herbaceous vegetation will help wildlife. Increasing the number of watering points where they are far apart will also benefit wildlife (Lamb and Pieper 1971).

The major objective for game-range improvement is to break-up homogeneous vegetation patterns into heterogeneous vegetation patterns. This gives the variety of feeding, nesting, and resting cover that is vital for wildlife. In some areas, heterogeneous vegetation patterns can be obtained by removing brush from the best sites and leaving the areas of poorest soils untreated. In general, good range management practices and good wildlife conditions are highly compatible, but some modifications in some range practices may improve conditions for game (Lamb and Pieper 1971).

RIPARIAN COMMUNITIES

Riparian may be defined as relating to or living on the bank of a natural watercourse. According to Brown et al. (1977), only a few southwestern drainages presently contain any extensive linear riparian forest development. Such forests were once extensive, but have decreased dramatically during the past century due to diversions and/or elimination of streamflows (McNatt 1979). Schmidly and Ditton (1979) listed several human impacts on riparian resources: 1) water diversion for irrigation purposes and stream channelization, 2) land flooding resulting from reservoir construction, 3) land clearing for conversion to croplands, 4) overgrazing by animals, 5) introduction of exotic plants and animals, 6) a rapid increase in recreation activity, and 7) increase of pesticides from drainage and erosion of nearby fields. For decades, the dominant use of riparian habitats in the Southwest has been water management, other values were not considered (Davis 1977). Controlling the cause of degradation of this important habitat will result in increases of the native cottonwoods (e.g., Fremont popular [Populus fremontii]) and willows (e.g., Goodding willow [Salix gooddingii]) (Brown et al. 1977). Using the principles given in the sections on control of unwanted plants and seeding, severely degradated sites can be readily reclaimed (Anderson et al. 1979). Some of the plants successfully revegetated were: blue paloverde, Goodding willow, cottonwoods, honey mesquite, fourwing saltbush, and big saltbush (Atriplex lentiformis).

NOTES

1. Plant names follow Correll and Johnston (1970).
2. Plant names followed by 2 are from Kearny and Peebles (1969). All other nomenclature follows Correll and Johnston (1970).

LITERATURE CITED

Abernathy, G. H., and C. H. Herbel. 1973. Brush eradicating, basin pitting, and seeding machine for arid to semi-arid rangeland. J. Range Manage. 26: 189-192.

Anderson, B. W., R. D. Ohmart, and J. Disano. 1979. Revegetating the riparian floodplain for wildlife. E. R. Johnson and J. F. McCormick, tech. coord., Strategies for Protection and Management of Floodplain Wetlands and Other Riparian Ecosystems. U.S.

Dep. Agric. Gen. Tech. Rep. WO-12, pp. 318-331, Washington, D.C.

Army, T. J., and E. B. Hudspeth, Jr. 1960. Alteration of the microclimate of the seed zone. Agron. J. 52:17-22.

Austin, M. E. 1972. Land resource regions and major land resource areas of the United States. U.S. Dep. Agric. Handb. 296.

Brown, D. E., C. H. Low, and J. F. Hausler. 1977. Southwestern riparian communities: Their biotic importance and management in Arizona. R. R. Johnson and D. A. Jones, tech. coord., Importance, Preservation and Management of Riparian Habitat: A Symposium. U.S. Dep. Agric. Gen. Tech. Rep. RM-43, pp. 201-211, Fort Collins, Colorado.

Bryson, R. A. 1957. The annual march of precipitation in Arizona, New Mexico and northwestern Mexico. Inst. Atmospheric Physics, Univ. Arizona, Tucson.

Buffington, L. C., and C. H. Herbel. 1965. Vegetational changes on semidesert grassland range from 1858 to 1963. Ecol. Monogr. 35:139-164.

Byerly, T. C. 1970. The environment and agriculture: Issues and answers. Agric. Sci. Rev. 8(1):1-8.

Cable, D. R. 1965. Damage to mesquite, Lehmann lovegrass, and black grama by a hot June fire. J. Range Manage. 18:326-329.

Cable, D. R. 1975. Influence of precipitation on perennial grass production in the semidesert Southwest. Ecology 56:91-96.

Clawson, M. 1972. Range management in the United States for the next one to three generations. J. Range Manage. 25:328-332.

Correll, D. S., and M. C. Johnston. 1970. Manual of the Vascular Plants of Texas. Renner, Texas: Texas Research Foundation.

Davis, G. A. 1977. Management alternatives for the riparian habitat in the Southwest. R. R. Johnson and D. A. Jones, tech. coord., Importance, Preservation and Management of Riparian Habitat: A Symposium. U.S. Dep. Agric. Gen. Tech. Rep. RM-43, pp. 59-67, Fort Collins, Colorado.

Dortignac, E. J., and W. C. Hickey, Jr. 1963. Surface runoff and erosion as affected by soil ripping. U.S. Dep. Agric., Forest Serv. (unserialized publication).

Dudley, R. F., and E. B. Hudspeth, Jr. 1964. Pitting and listing treatments on native shortgrass rangeland. Tex. Agric. Exp. Sta. Prog. Rep. 2313.

Fisher, C. E., C. H. Meadors, R. Behrens, E. D. Robison, P. T. Marion, and H. L. Morton. 1959. Control of mesquite on grazing lands. Tex. Agric. Exp. Sta. Bull. 935.

Frost, K. R., and L. Hamilton. 1965. Basin forming and reseeding of rangeland. Am. Soc. Agric. Engi. Trans. 8:202,203,207.

Fugate, F. L. 1961. Origins of the range era in South Texas. Agric. History 35: 155-158.

Gardner, J. L. 1951. Vegetation of the creosotebush area of the Rio Grande Valley in New Mexico. Ecol. Monogr. 21:379-403.

Glendening, G. E., and H. A. Paulsen, Jr. 1955. Reproduction and establishment of velvet mesquite as related to invasion of semidesert grasslands. U.S. Dep. Agric. Tech. Bull. 1127.

Gould, F. W. 1975. Texas plants, a checklist and ecological summary. Tex. Agric. Exp. Sta. Misc. Publ. 585.

Griffiths, D. 1901. Range improvements in Arizona. U.S. Dep. Agric., Bur. Plant Ind. Bull. 4.

Hamilton, W. 1976. The Chaparrosa--a study in resource integration. Proc. Symp. on Integration of Resources for Beef Cattle Production, Soc. Range Manage., pp. 71-75, Denver, Colorado.

Heady, H. F. 1975. Rangeland Management. New York: McGraw-Hill Co.

Herbel, C. H. 1963. Fertilizing tobosa on flood plains in the semidesert grassland. J. Range Manage. 16:133-138.

Herbel, C. H. 1971. A review of research related to development of grazing systems on native ranges of the western United States. U.S. Dep. Agric., Jornada Exp. Range Rep. 3, Las Cruces, New Mexico.

Herbel, C. H. 1972. Using mechanical equipment to modify the seedling environment. Wildland Shrubs--Their Biology and Utilization. U.S. Dep. Agric. Gen. Tech. Rep. INT-1, pp. 369-381, Ogden, Utah.

Herbel, C. H. 1973. Some developments related to seeding western rangelands. Range Research and Range Problems, Crop Sci. Soc. Am. Spec. Publ. 3, pp. 75-80, Madison, Wisconsin.

Herbel, C. H. 1979. Utilization of grass- and shrublands of the southwestern United States. B. H. Walker, ed., Management of Semi-Arid Ecosystems, Elsevier Publ. Co., pp. 161-203, Amsterdam, The Netherlands.

Herbel, C. H., G. H. Abernathy, C. C. Yarbrough, and D. K. Gardiner. 1973. Rootplowing and seeding arid rangelands in the Southwest. J. Range Manage. 26:193-197.

Herbel, C. H., F. Ares, and J. Bridges. 1958. Hand-grubbing mesquite in the semidesert grassland. J. Range Manage. 11:267-270.

Herbel, C. H., and W. L. Gould. 1970. Control of mesquite, creosote bush and tarbush on arid rangelands of the southwestern United States. Proc. 11th Intl. Grassl. Congr., pp. 38-44, Surfers Paradise, Queensland, Aust.

Herbel, C. H., and A. B. Nelson. 1966. Species preference of Hereford and Santa Gertrudis cattle on a southern New Mexico range. J. Range Manage. 19:173-176.

Herbel, C. H., and A. B. Nelson. 1974. Utilizing tobosa (Hilaria mutica [Buckl.] Benth.) during the winter and spring. Proc. 12th Intl. Grassl. Cong. III:184-190, Moscow, U.S.S.R.

Herbel, C. H., R. Steger, and W. L. Gould. 1974. Managing semidesert ranges of the Southwest. N. Mex. Agric. Ext. Circ. 456.

Holt, G. A., and D. G. Wilson. 1961. The effect of commercial fertilizers on forage production and utilization on a desert grassland site. J. Range Manage. 14:252-256.

Hubbell, D. S., and J. L. Gardner. 1950. Effects of diverting sediment-laden runoff from arroyos to range and crop lands. U.S. Dep. Agric. Tech. Bull. 1012.

Hudspeth, E. B., Jr., and H. M. Taylor. 1961. Factors affecting seedling emergence of Blackwell switchgrass. Agron. J. 53:331-335.