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Chapter 5

UTILIZATION OF GRASS- AND SHRUBLANDS OF THE SOUTH-WESTERN UNITED STATES *

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INTRODUCTION

The rangelands of the south-western United States may seem limitless, but as a renewable source for livestock grazing, they are fragile, easily damaged by abuse, and subject to droughts. The original vegetation on large parts of these lands has been depleted by a combination of these factors, and a rapid increase of unwanted shrubs. Table 5.1 shows the area in rangeland and the livestock numbers in Table 5.1 are the totals for each state, the rangeland areas considered in this chapter are roughly the western half of Texas and Oklahoma, most of New Mexico, and all but the south-western quarter of Arizona.

CLIMATE

Annual precipitation ranges from less than 250 mm in the lower elevations of New Mexico, Arizona and western Texas to 750 mm in the eastern portions of the plains grasslands in central Texas and Oklahoma (see Fig. 5.1

TABLE 5.1

Rangelands in thousands of ha and livestock numbers in thousands in states of the south-western United States

	Texas	Oklahoma	New Mexico	Arizona
Rangeland [b]	47 355	9205	26 488	23 522
Cattle, beef [c]	16 552	6401	1855	1181
Sheep [d]	2688	89	575	510
Goats [d]	1150	[a]	[a]	[a]

[a] Small numbers, not estimated.
[b] Wooten et al. (1962).
[c] U.S. Department of Agriculture (1975a).
[d] U.S. Department of Agriculture (1975b).

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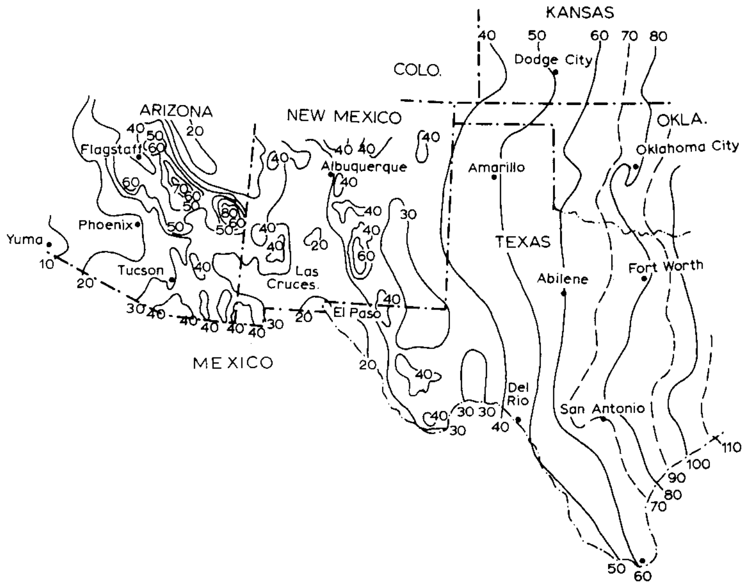

Fig. 5.1. Average annual precipitation (cm) in the south-western United States (from U.S. Department of Commerce, 1975).

and Table 5.2). The precipitation not only varies greatly within and among seasons and years, but also among locations separated by only short distances. About 70% of the mean annual precipitation occurs during the spring—summer period in the plains grasslands of Texas, Oklahoma and eastern New Mexico. In western New Mexico and southern Arizona, the growing season precipitation occurs during the summer, and the spring period is normally very dry. The latter areas have a slight increase in winter rainfall. Spring—summer precipitation for the entire area is generally due to convectional thunderstorms from the Gulf of Mexico, whereas the winter precipitation is due to broad fronts sweeping southward across the plains or moving westward from the Pacific. The entire region is frequently plagued by drought and during a prolonged drought may have a desert-like appearance. It may also have high winds during some periods, which result in considerable erosion when coinciding with a reduction in vegetational cover due to drought or over-grazing. The mean annual evaporation ranges from 2160 mm at Oklahoma City to 3050 mm at some of the lower elevations in south-western New Mexico and southern Arizona. The frost-free period (consecutive days when the minimum temperature is above 0°C) averages about 180 days in the north-eastern part of the region to 259 days at Tucson.

The major vegetational types of the region are determined primarily by precipitation. Arizona and the western third of New Mexico have been included by Trewartha (1961) in the Intermontane Precipitation Region (2a)

TABLE 5.2

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

	Jan.	Feb.	March	April	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Ann.
Amarillo, Texas													
Precipitation (mm)	17	16	21	34	86	73	59	66	48	45	17	20	500
Temperature (°C)	3	5	9	14	19	25	27	26	22	16	8	4	15
Del Rio, Texas													
Precipitation (mm)	23	22	21	35	69	58	33	39	66	50	16	21	453
Temperature (°C)	11	13	17	22	26	29	30	30	27	22	15	11	21
Oklahoma City, Oklahoma													
Precipitation (mm)	33	35	50	79	132	114	60	64	77	64	40	36	783
Temperature (°C)	3	5	9	16	20	26	28	28	23	17	9	5	16
Las Cruces, New Mexico													
Precipitation (mm)	12	13	8	4	8	13	33	43	31	19	8	12	203
Temperature (°C)	5	7	11	15	20	25	26	25	22	16	9	6	16
Tucson, Arizona													
Precipitation (mm)	21	21	13	7	3	7	52	73	25	16	16	23	279
Temperature (°C)	10	12	14	19	23	28	30	28	27	21	14	11	20
Flagstaff, Arizona													
Precipitation (mm)	46	45	37	30	13	18	58	72	40	39	25	42	465
Temperature (°C)	−3	−1	2	6	10	15	19	18	15	8	2	−1	8

(Fig. 5.2), bounded on the east by the Rocky Mountains and on the west by the Pacific Coast Ranges. A unique feature of this area is the existence of two rainy seasons, one maximum 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 mainly the result of the Pacific high pressure areas shifting southward, allowing lows to move inland, bringing with them masses of moist maritime air (Trewartha, 1961). The July—August rainfall is derived from air masses moving in from the Gulf of Mexico (Jurwitz, 1953). Most of these storms are local, convectional thunderstorms and do not result in the widespread activity characteristic of the winter period (Bryson, 1957).

The Great Plains has been termed the Interior Region by Trewartha (1961). It has a typical continental climate characterized by a predominance of warm season precipitation. Here, for the most part, winter is the season of lowest precipitation. Trewartha (1961) considers this a region of Type 3 precipitation. Sub-type 3a, primarily centering in New Mexico, receives its maximum moisture in July and August. The flow of maritime air into the region makes New Mexico a major centre of thunderstorm activity. No trace of a secondary winter maximum exists. Instead, the cold season is very dry due to the continental influence of the prevailing westerly winds.

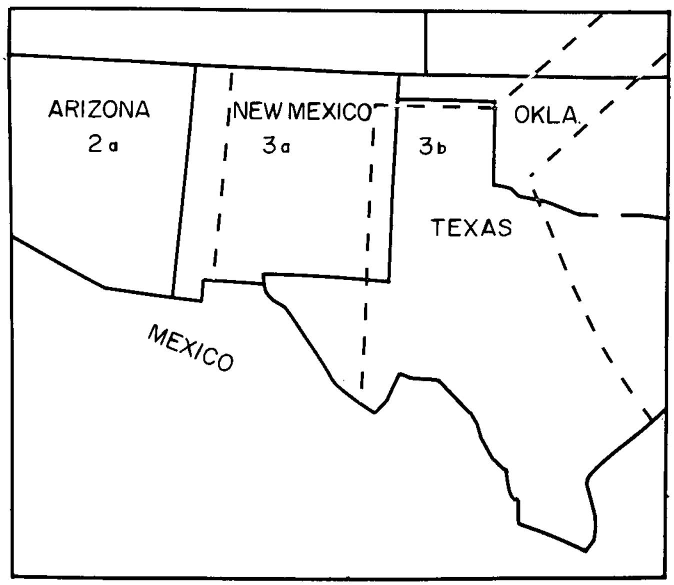

Fig. 5.2. Precipitation regions of the south-western United States (from Trewartha, 1961).

A unique precipitation pattern termed 3b by Trewartha (1961), exists in the southern part of the Great Plains, and includes major portions of Texas and Oklahoma. Here, little moisture is received from November through March. Instead, a double maximum of precipitation occurs in the warm season. One peak is reached in May, resulting from the flow of humid air from the Gulf of Mexico into the area where it is subsequently warmed by contact with the heated land surface. This is followed by a decrease in rainfall in late June, July and August which apparently results from a tongue of dry northerly air associated with a large low pressure cell positioned in the mid-troposphere over the southern Great Plains (Wexler and Namias, 1938). Movement of the cell in September results in a second maximum period of precipitation in late summer.

LAND, PLANT AND ANIMAL RESOURCES

Four land resource regions have been identified in the portions of Texas, Oklahoma, New Mexico and Arizona considered in this chapter (Austin, 1972) (Fig. 5.3). An outline of the land and plant resources discussed in the following pages is shown in Table 5.3.

South-Western Plateaus and Plains Range and Cotton Region (Fig. 5.3.I)

The land resource areas within this region are in southern Texas: Rio Grande Plain, Texas Central Basin and Edwards Plateau. The Rio Grande Plain (Fig. 5.3, 83), totalling 82 600 km^2, is about 80% rangeland. The mean annual precipitation within this area ranges from 500 to 870 mm. Mean annual temperature is 21°C and the average frost-free period ranges from 260 to 320 days. The elevation ranges from sea-level to 300 m. This plain is nearly level to gently undulating. Grumusols and reddish chestnut soils are extensive. Lithosols are confined to low, narrow ridges and low plateau-like areas. Sandy Regosols occur along the coast of the Gulf of Mexico, along the Rio Grande River and in the north-eastern part of the area. A clayey Regosol is found in the western part of the area. Calcisols are in sandy and silty old alluvium on stream terraces and deltas in the southern and western part of the area and in alluvial soils on narrow floodplains and deltas (Austin, 1972).

The vegetation of the Rio Grande Plain is dominated by the *Prosopis—Acacia—Schizachyrium—Setaria* (Fig. 5.4) and the *Prosopis—Schizachyrium* associations. The dominant species of the former associations are: *Prosopis glandulosa* [1], *Acacia rigidula*, *Schizachyrium scoparium* var. *littoralis* and *Setaria macrostachya* (Fig. 5.4).

[1] Plant names follow Correll and Johnston, 1970.

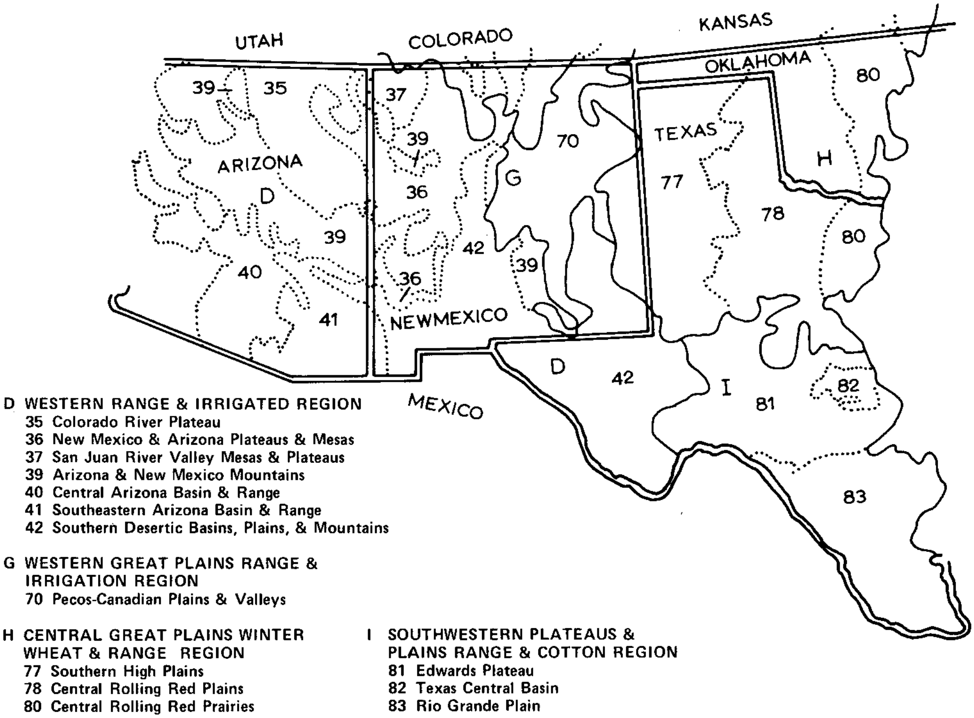

Fig. 5.3. Land resources of the south-western United States (from Austin, 1972).

Other major components of the association are: *Acacia berlandieri*, *A. farnesiana*, *Bothriochloa saccharoides*, *Cenchrus myosuroides*, *Chloris ciliata*, *C. verticillata*, *Opuntia leptocaulis*, *O. lindheimeri*, *Pappophorum bicolor* and *Trichloris pluriflora*. The dominants of the *Prosopis—Quercus—Schizachyrium* association are *Proposis glandulosa*, *Quercus virginiana* and *Schizachyrium scoparium* var. *littoralis*. Other major components are: *Brachiaria ciliatissima*, *Panicum virgatum*, *Paspalum hartwegianum*, *P. setaceum*, *Sorghastrum avenaceum* and *Trachypogon secundus* (Kuchler, 1964, Gould, 1975).

The Texas Central Basin (Fig. 5.3, 82), 7800 km^2, is about 90% rangeland, and is located in the eastern part of the Edwards Plateau. The mean annual precipitation within this area ranges from 625 to 750 mm. The mean annual temperature is 18°C and the frost-free period averages 240 days. The elevation ranges from 240 to 390 m. The rolling to hilly uplands are crossed by a few smooth valleys and many steep hills and ridges. Reddish Prairie soils occupy the smoother slopes of uplands and valleys, Lithosols occupy the steep hill slopes and rough stoney land occupies the steepest slopes, cliffs of limestone and granite ridges (Austin, 1972).

The vegetation of the Texas Central Basin is dominated by the *Prosopis*—

TABLE 5.3

Land and plant resources of the south-western United States (Kuchler, 1964; Austin, 1972)

I. South-western Plateaus and Plains Range and Cotton Region (Fig. 5.3, I)
  A. Rio Grande Plain (Fig. 5.3, 83)
    (1) *Prosopis—Acacia—Schizachyrium—Setaria* association (Fig. 5.4)
    (2) *Proposis—Quercus—Schizachyrium* association
  B. Texas Central Basin (Fig. 5.3, 82)
    (1) *Proposis—Quercus—Schizachyrium* savanna
  C. Edwards Plateau (Fig. 5.3, 81)
    (1) *Juniperus—Quercus—Schizachyrium* association (Fig. 5.5)
II. Central Great Plains Winter Wheat and Range Region (Fig. 5.3, H)
  A. Central Rolling Red Prairies (Fig. 5.3, 80)
    (1) *Schizachyrium—Stipa* association
    (2) *Quercus—Schizachyrium* cross timbers
  B. Central Rolling Red Plains (Fig. 5.3, 78)
    (1) *Proposis—Buchloe* association (Fig. 5.6)
  C. Southern High Plains (Fig. 5.3, 77)
    (1) *Bouteloua—Buchloe* association (Fig. 5.7)
    (2) *Quercus—Schizachyrium* association
III. Western Great Plains Range and Irrigated Region (Fig. 5.3, G)
  A. Pecos. Canadian Plains and Valleys (Fig. 5.3, 70)
    (1) *Bouteloua—Hilaria* steppe
    (2) *Bouteloua—Hilaria—Larrea* shrubsteppe
    (3) *Bouteloua—Buchloe* association
    (4) *Juniperus—Pinus* woodland
IV. Western Range and Irrigated Region (Fig. 5.3, D)
  A. Southern Desertic Basins, Plains and Mountains (Fig. 5.3, 42)
    (1) *Flourensia—Larrea* shrub savanna
    (2) *Bouteloua—Hilaria* prairie (Fig. 5.8)
    (3) *Bouteloua—Hilaria—Larrea* shrubsteppe
  B. Arizona and New Mexico Mountains (Fig. 5.3, 39)
    (1) *Juniperus—Pinus* woodland
    (2) Transition between *Quercus—Juniperus* woodland and *Cercocarpus—Quercus* association
    (3) *Pinus* forest (Fig. 5.9)
    (4) *Pinus—Pseudotsuga* forest
  C. South-eastern Arizona Basin and Range (Fig. 5.3, 41)
    (1) *Bouteloua—Hilaria—Larrea* shrubsteppe
    (2) *Larrea—Flourensia* association
  D. New Mexico and Arizona Plateaus and Mesas (Fig. 5.3, 36)
    (1) *Juniperus—Pinus* woodland
    (2) *Bouteloua—Hilaria* steppe
  E. Central Arizona Basin and Range (Fig. 5.3, 40)
    (1) *Larrea—Franseria* association
  F. San Juan River Valley Mesas and Plateaus (Fig. 5.3, 37)
    (1) *Atriplex—Sarcobatus* association
  G. Colorado River Plateau (Fig. 5.3, 35)
    (1) *Artemisia* association
    (2) *Juniperus—Pinus* woodland
    (3) *Bouteloua—Hilaria* steppe

Fig. 5.4. The *Prosopis—Acacia—Schizachyrium—Setaria* association in the Rio Grande Plain near Uvalde, Texas (photo: G.B. Donart).

Quercus—Schizachyrium savanna. The dominant species are *Prosopis glandulosa*, *Quercus* spp. and *Schizachyrium scoparium*. Other major components of the vegetation are: *Andropogon gerardi*, *Bothriochloa barbinodis*, *Bouteloua curtipendula*, *Buchloe dactyloides*, *Diospyros texana*, *Juniperus ashei*, *Quercus marilandica* and *Q. stellata* (Kuchler, 1964).

The Edwards Plateau (Fig. 5.3, 81) has about 85 700 km^2, and roughly 95% is in rangeland. The mean annual precipitation within this area ranges from 375 to 875 mm. The mean annual temperature ranges from 16 to 21°C, and the frost-free period averages 220 to 240 days. The elevation ranges from 300 to 1200 m. This broad dissected limestone plateau has gently undulating divides and broad valleys. Valley sides are steeply sloping to rolling or hilly. Shallow Lithosols, underlain by limestone, occupy the steeper slopes of the Edwards Plateau. Grumusols occur in valleys and on nearly level uplands: Calcisols occupy better drained level to gentle slopes where soil materials are less clayey, and alluvial soils occur on narrow flood plains (Austin, 1972).

The vegetation of the Edwards Plateau is dominated by the *Juniperus—Quercus—Schizachyrium* association (Fig. 5.5). The plant dominants are: *Juniperus ashei*, *Quercus virginiana* and *Schizachyrium scoparium*. Other major components are: *Andropogon gerardi*, *Aristida glauca*, *A. purpurea*,

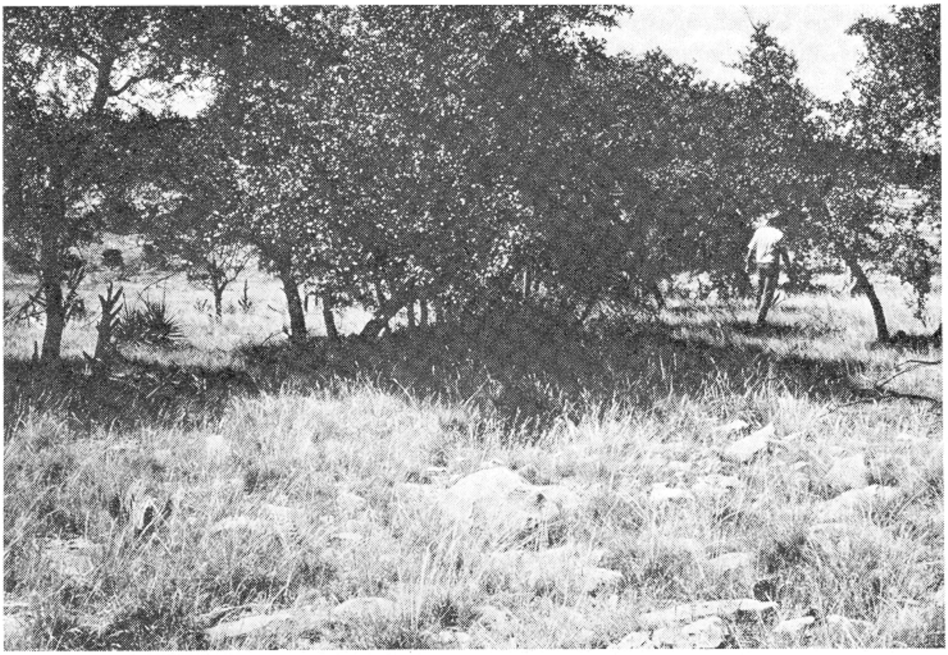

Fig. 5.5. The *Juniperus—Quercus—Schizachyrium* association in the Edwards Plateau near Sonora, Texas (photo: G.B. Donart).

Bouteloua curtipendula, *Buchloe dactyloides*, *Hilaria belangeri*, *Prosopis glandulosa* and *Sporobolus cryptandrus* (Kuchler, 1964; Gould, 1975).

The discussion of animal species found in the region follows Shelford (1963). This includes a treatment of presently dominant species and those that may have been important in the past. The following animals are common in the South-western Plateaus and Plains Range and Cotton Region; subspecies of the pygmy mouse (*Baiomys taylori*), harvest mouse (*Reithrodontomys fulvescens*), black-tailed jack rabbit (*Lepus californicus*), fox squirrel (*Sciurus niger*), badger (*Taxidea taxus*), spotted skunk (*Spilogala gracilis*), pocket gopher (*Geomys bursarius*), red wolf (*Canis niger*), coyote (*C. latrans*), white-tailed deer (*Odocoileus virginianus*), turkey (*Meleagris gallopavo*), scaled quail (*Callipepla squamata*) and mourning dove (*Lenaidura macroura*). Mammals that were dominant over the area in former times were the bison (*Bison bison*) and the pronghorn antelope (*Antilocapra americana*). Other birds characteristic of the area are the horned lark (*Eremophila alpestris*) and the boat-tailed grackle (*Cassadix mexicanus*). The common orthopterans are: *Melanoplus differentialis*, *Chortophaga viridifasciata*, *Ophulella palidna*, *O. speriosa*, *Orchelimum concinnum*, *Scudderia texensis*, *Spharagemon bolli* and *Psoloessa texana*. A hemnipteron present is the stink bug (*Mormidea lugens*). The chief coreid is *Mecidea longula*. The most common ant is *Crematogaster laeviuscula*. Two species of snails *Bulimulus alternatus* and *Helicina orbiculata*, occur in the trees and shrubs (Shelford, 1963).

Central Great Plains Winter Wheat and Range Region (Fig. 5.3, H)

The land resource areas within this region, mainly in Texas and Oklahoma, are: Central Rolling Red Prairies, Central Rolling Red Plains and Southern High Plains (Austin, 1972). The mean annual precipitation in the Central Rolling Red Prairies (Fig. 5.3, 80) ranges from 580 to 890 mm, and the mean annual temperature from 16 to 18°C, and the average frost-free period 200 to 240 days. The elevation ranges from 300 to 460 m. On this dissected plain, the divides are undulating to gently rolling, and the valley sides are steep. Reddish Prairie soils occupy the smoother upland slopes in most of this area, but Reddish Chestnut soils are most extensive on the slopes in the south-western part of the area. Lithosols are dominant on steep slopes and Regosols in deep sands. Alluvial soils are on floodplains and low terraces along the rivers. About half of the area is in rangeland and about half in cropland (Austin, 1972).

The vegetation of the Central Rolling Red Prairies is dominated by the *Schizachyrium—Stipa* association in the south and the *Quercus—Schizachyrium* cross timbers in the north (Kuchler, 1964). The dominant species in the *Schizachyrium—Stipa* association are *Schizachyrium scoparium* and *Stipa leucotricha*. Other major species are: *Andropogon gerardi, Bouteloua curtipendula, Panicum virgatum, Sorghastrum avenaceum* and *Sporobolus asper*. The dominants of the *Quercus—Schizachyrium* cross timbers are: *Schizachyrium scoparium, Quercus marilandica* and *Q. stellata*. Other major components are: *Andropogon gerardi, Bouteloua curtipendula, Sorghastrum avenaceum* and *Stipa leucotricha* (Kuchler, 1964).

The mean annual precipitation in the Central Rolling Red Plains (Fig. 5.3, 78) ranges from 500 to 750 mm (Austin, 1972), the mean annual temperature from 14 to 18°C, the mean frost-free period from 185 to 230 days. The elevation ranges from 450 to 900 m, increasing gradually from east to west. The broad divides are nearly level to gently sloping, and the valleys have short steep slopes on this dissected plain. Reddish Chestnut soils and Chestnut soils occupy most of the smoother uplands. In about half the area, consisting of more hilly lands, the soils are thin or have weakly expressed profiles — Regosols in deep sandy materials, Lithosols on slopes underlain by consolidated rocks, and Calcisols in areas with a strong horizon of calcium carbonate. About half of this area is rangeland and the other half is cropland (Austin, 1972).

The vegetation of the Central Rolling Red Plains is dominated by the *Prosopis—Buchloe* association (Kuchler, 1964). The dominant vegetation is *Buchloe dactyloides* and *Prosopis glandulosa* (Fig. 5.6). Other important

Fig. 5.6. The *Prosopis—Buchloe* association in the Central Rolling Red plains near Dickens, Texas.

plants are: *Bouteloua gracilis*, *Juniperus pinchotii*, *J. virginiana*, *Schedonnardus paniculatus* and *Yucca angustifolia* (Kuchler, 1964).

The Southern High Plains (Fig. 5.3, 77) has about 130 300 km^2, roughly 40% of which is in rangeland (Austin, 1972). The mean annual precipitation within this area ranges from 380 to 585 mm, the mean annual temperature from 13 to 16°C, and the frost-free period from 180 to 220 days. The elevation ranges from 760 to 1520 m. These smooth, high plains have gentle slopes except for the very steeply-sloping breaks along the major rivers. The deep sands in the south-western portion of this area have irregular dune topography. The principal soils of the uplands are Chestnut and Reddish Chestnut soils in loamy mantles. Calcisols are dominant on the more sloping parts and in shallow valleys, Lithosols on the steeper slopes and breaks, and Regosols and Reddish-Brown soils in the deep sands (Austin, 1972).

The vegetation of the Southern High Plains is generally dominated by the *Bouteloua—Buchloe* association, with the *Quercus—Schizachyrium* association dominating the more sandy sites. The dominant plants of the *Bouteloua—Buchloe* association (Fig. 5.7) are: *Bouteloua gracilis* and *Buchloe dactyloides*. Other major species are: *Bouteloua curtipendula*, *Machaeranthera pinnatifida*, *Opuntia polyacantha*, *Sporobolus cryptandrus* and *Yucca angustifolia*. The dominants of the *Quercus—Schizachyrium* associ-

Fig. 5.7. The *Bouteloua–Buchloe* association in the Southern High plains near Bronco, Texas.

ation are *Quercus mohriana* and *Schizachyrium scoparium*. Other major species are *Andropogon hallii*, *Artemisia filifolia*, *Bouteloua gracilis*, *Buchloe dactyloides*, *Eriogonum annuum*, *Juniperus pinchotii*, *Prosopis glandulosa*, *Quercus havardii*, *Sporobolus cryptandrus* and *Yucca angustifolia* (Kuchler, 1964).

The major animals in the Central Great Plains Winter Wheat and Range are: pronghorn antelope, black-tailed jack rabbit, desert cottontail (*Sylvilagus audubonii*), plains harvest mouse (*Reithrodontomys montanus*), grasshopper mouse (*Onychomys* spp.), deer mouse (*Peromyscus maniculatus*), prairie vole (*Microtus ochrogaster*), thirteen-lined ground squirrel (*Citellus tridecemlineatus*), spotted ground squirrel (*C. spilosoma*), short-tailed shrew (*Blarina brevicauda*), least shrew (*Cryptotis parva*), coyote, badger, Swainson's hawk (*Buteo swainsoni*), rough-legged hawk (*B. lagopus*), greater prairie chicken (*Tympanuchus cupido*), western meadowlark (*Sturnella neglecta*), horned lark, dickcissel (*Spiza americana*), McCown's longspur (*Rhynchophanes mccownii*), lark bunting (*Calamospiza melanocorys*), garter snake (*Thamnophis radix*), western diamondback rattlesnake (*Crotalus atrox*), bullsnake (*Pituophis catenifer*) and blue racer (*Coluber constrictor*). One of the abundant insect groups is the orthoptera. Some of the important ones are: *Encoptolophus sordidus costalis*, *Melanoplus keeleri luridus*, *Conocephalus saltans, Acrolophitus hirtipes, Amphitornus coloradus, Psoloessa delicatula, Aulocara elliotti* and *Metator pardalinus*. Other common insects are: the lygaeid (*Ligyrocarsis diffusus*), plant bug (*Lugus oblineatus*), predatory bug (*Orius insidiosis*), damsel bug (*Nabis ferus*), stink bug (*Euschistus variolarius*), chinch bug (*Blissus leucopterus*), leafhopper (*Agallia constriata*), twelve spotted cucumber beetle (*Diabrotica twelvepunctata*), scarab (*Aphodius distinctus*), lady beetle (*Hippodamia convergens*), robber fly (*Promachus* spp.) and the wheat stem sawfly (*Cephus cinctus*) (Shelford, 1963).

Western Great Plains Range and Irrigated Region (Fig. 5.3, G)

West of the Southern High Plains is the Pecos-Canadian Plains and Valleys area in eastern New Mexico. This area totals 74 900 km^2 with more than three-quarters in rangeland. About 10% is controlled by various agencies of the Federal Government. The mean annual precipitation in this area varies from 300 to 400 mm, the mean annual temperature from 10 to 16°C, and the frost-free period from 160 to 200 days. The elevation ranges from 1200 to 1950 m. Most of the slopes of these dissected high plains are gentle to rolling, but bands of steep slopes and rough broken land border the stream valleys. Shallow soils and soils having weakly expressed profiles are widespread — Lithosols, rough broken land, and rockland on gentle to moderate slopes of uplands, and Regosols in deep sands. Reddish-Brown soils occur on the smoother uplands throughout most of the area, but Reddish Chestnut soils and Chestnut soils occur in the deeper materials in the northern part of the Pecos-Canadian Plains and Valleys (Austin, 1972).

The vegetation of the Pecos-Canadian Plains and Valleys is dominated by the *Bouteloua—Hilaria* steppe association, the *Bouteloua—Hilaria—Larrea* shrubsteppe association, the *Bouteloua—Buchloe* grass association and the *Juniperus—Pinus* woodland association. The vegetation of the *Bouteloua—Buchloe* association was previously described in the section on the Southern High Plains. The dominant plants of the *Bouteloua—Hilaria* association are *Bouteloua gracilis* and *Hilaria jamesii*. Other major species are: *Andropogon hallii, Artemisia tridentata, Bouleloua curtipendula, Schizachyrium scoparium* and *Yucca angustifolia*. The *Bouteloua—Hilaria—Larrea* shrubsteppe is dominated by *Bouteloua eriopoda, Hilaria mutica* and *Larrea tridentata*. Other major plants are *Acacia constricta, Aristida divaricata, A. longiseta, Bouteloua curtipendula, B. gracilis, Opuntia* spp., *Prosopis glandulosa, Sporobolus airoides, S. cryptandrus* and *Xanthocephalum sarothrae*. The dominant plants of the *Juniperus—Pinus* association are *Juniperus monosperma, J. osteosperma* [2], *Quercus emoryi, Q. undulata* and *Sporobolus cryptandrus* (Kuchler, 1964).

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[2] Plant names followed by [2] are from Kearney and Peebles (1969). All other nomenclature follows Correll and Johnston (1970).

The vertebrate influents and dominants of the Pecos-Canadian Plains and Valleys originally included the bison, pronghorn antelope and possibly deer. Less prominent animals, the conspicuous box turtle (*Terepene ornata*), kangaroo rat (*Dipodomys* spp.), bullsnake, garter snake, rattlesnake, lark bunting, scaled quail (*Callipepla squamata*), and the western meadowlark, were present. Grasshoppers of several species also exert considerable influence on the community. There are numerous burrowing insects present, including mutillids, digger wasps (*Ammophila procera*) and tiger beetles (*Cicindela* spp.). Coyotes and cottontails are also numerous (Shelford, 1963).

Western Range and Irrigated Region (Fig. 5.3, D)

This is a diverse region of plateaus, plains, basins and many isolated mountain ranges. The land resource areas in western Texas, southern and western New Mexico and all but the desertic portion of Arizona, are: Southern Desertic Basins, Plains and Mountains; Arizona and New Mexico Mountains; New Mexico and Arizona Plateaus and Mesas; South-eastern Arizona Basin and Range; Central Arizona Basin and Range; San Juan River Valley Mesas and Plateaus and Colorado River Plateau (Austin, 1972). The Southern Desertic Basins, Plains and Mountains of western Texas and southern New Mexico (Fig. 5.3, 42) with a total of 160 000 km^2, are about 95% rangeland. About a third of the land is under the jurisdiction of the Federal Government. The mean annual precipitation ranges from 200 to 400 mm, the mean annual temperature from 10 to 26°C, and the frost-free period from 200 to 240 days, over most of the area. The elevation ranges from 750 to 1500 m in basins and valleys and more than 2500 m in the mountains. Broad desert basins and valleys are bordered by gently to strongly sloping fans and terraces. Steep mountain ranges and many small mesas are common throughout the area. Red Desert soils and Lithosols are dominant in the area. Others are Calcisols in highly calcareous materials and Regosols in deep sands (Austin, 1972).

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 vegetation of the *Bouteloua—Hilaria—Larrea* shrubsteppe was previously described in the section describing the vegetation of the Pecos-Canadian Plains and Valleys. The dominant plants of the *Flourensia—Larrea* savanna are *Flourensia cernua* and *Larrea tridentata*. Other major plant components are: *Acacia constricta*, *Aristida divaricata*, *A. longiseta*, *Opuntia imbricata*, *Prosopis glandulosa*, *Scleropogon brevifolius* and *Yucca elata*. The dominants of the *Bouteloua—Hilaria* prairie are *Bouteloua gracilis* and *Hilaria mutica* (Fig. 5.8). Other major components of the vegetation are *Bouteloua curtipendula*, *B. eriopoda*, *Opuntia imbricata* and *Xanthocephalum sarothrae* (Kuchler, 1964; Gould, 1975).

Fig. 5.8. *Hilaria mutica* type in the *Bouteloua—Hilaria* Prairie association in the Southern Desertic Basins, Plains and Mountains near Las Cruces, New Mexico.

The Arizona and New Mexico Mountains (Fig. 5.3, 39) total 90 900 km^2. About 60% is controlled by the Federal Government, and an additional 10% is in Indian reservation; about 40% is rangeland. The elevation ranges from 1350 to 3000 m, with some mountain crests at 3750 m. Much of the area is so rough and steep that it has little economic use, but it includes some deeply dissected plateaus. The mean annual precipitation varies from 250 to 875 mm, increasing with elevation. The mean annual temperature ranges from 4°C at high elevations to 13°C at the lower elevations. Brown, Reddish-Brown and Reddish Chestnut are the principal soils in the foothills and valleys, but Lithosols, stony land and rock outcrops occupy large areas on both mountains and foothills (Austin, 1972).

The major vegetation types of the Arizona and New Mexico Mountains area are the *Juniperus—Pinus* woodland and a transition between the *Quercus—Juniperus* woodland and *Cercocarpus—Quercus* association; at higher elevations, the *Pinus* forest and the *Pinus—Pseudotsuga* forest. The vegetation of the *Juniperus—Pinus* woodland was previously described under the section on the Pecos-Canadian Plains and Valleys. The major plants of the *Quercus—Juniperus* woodland and the *Cercocarpus—Quercus* association are: *Juniperus deppeana*, *J. monosperma*, *Quercus emoryi*, *Q. gambelii*, *Q. grisea* and *Cercocarpus ledifolius* [2]. Some of the other species are: *Arcto-*

staphylos pungens, Bouteloua curtipendula, B. gracilis, Fallugia paradoxa, Nolina microcarpa, Pinus cembroides, Purshia tridentata, Quercus havardii, Q. turbinella, Q. undulata and *Rhus microphylla*. The dominant plant of the *Pinus* forest is *Pinus ponderosa* (Fig. 5.9). The other major components of the vegetation are: *Blepharoneuron tricholepis, Ceanothus fendleri, Festuca arizonica, Muhlenbergia montana, Pinus cembroides, Poa fendleriana, Pseudotsuga menziesii, Quercus gambelii* and *Stipa* spp. The dominant species of the *Pinus—Pseudotsuga* forest are *Pinus ponderosa* and *Pseudotsuga menziesii*. The other major plant species are: *Blepharoneuron tricholepis, Ceanothus fendleri, Festuca arizonica, Holodiscus discolor* and *Salix* spp. (Kuchler, 1964).

South-eastern Arizona Basin and Range (Fig. 5.3, 41) totals about 45 800 km^2, of which 95% is rangeland. About 30% of the area is controlled by the Federal Government. The elevation ranges from 750 to 1800 m. There are some basins and dry lake beds in this nearly level broad plain. The mean annual precipitation ranges from 200 to 500 mm, the mean annual temperature from 13 to 21°C, and the frost-free period from 180 to 240 days. The 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 major vegetation types of the South-eastern 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 Pecos-Canadian Plains and Valleys. The dominants of the *Larrea—Flourensia* association are *Flourensia cernua* and *Larrea tridentata*. Other major components of the vegetation are: *Acacia constricta, A. greggii, Agave lecheguilla, Bouteloua breviseta, Dasyliron* spp., *Opuntia* spp. and *Prosopis glandulosa* (Kuchler, 1964).

About 98% of the New Mexico and Arizona Plateaus and Mesas (Fig. 5.3, 36), which totals 67 900 km^2, is rangeland. About 20% of the area is controlled by the Federal Government and another 20% is Indian reservation. The mean annual precipitation ranges from 250 to 325 mm, the mean annual temperature is about 10°C and the average frost-free period ranges from 120 to 180 days. The elevation ranges from 1500 to 2100 m. 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).

The major vegetation types of the New Mexico and Arizona Plateaus and Mesas are the *Juniperus—Pinus* woodland and the *Bouteloua—Hilaria* steppe, both of which were previously described in the section on the Pecos-Canadian Plains and Valleys.

The Central Arizona Basin and Range (Fig. 5.3, 40) totals 49 200 km^2, 85% of which is used for range. About 50% of the land is controlled by the

Fig. 5.9. The *Pinus* forest in the Arizona and New Mexico Mountains north of Globe, Arizona.

Federal Government and 10% is Indian reservation. The mean annual precipitation is about 250 mm. The mean annual temperature ranges from 16 to 23°C, and the frost-free period from 225 to 300 days. The elevation ranges from 300 to 750 m. The low basins are bordered by gently sloping alluvial fans and are 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).

The vegetation of the Central Arizona Basin and Range is primarily of the *Larrea—Franseria* association. The dominants are *Franseria dumosa* [2] and *Larrea tridentata*. The other major components of the vegetation are: *Acacia greggii*, *Cercidium floridum* [2], *Dalea spinosa* [2], *Encelia farinosa* [2], *Franseria deltoidea* [2], *Hilaria rigida* [2], *Opuntia echinocarpa* [2] and *Prosopis juliflora* var. *velutina* [2] (Kuchler, 1964).

The San Juan River Valley Mesas and Plateaus (Fig. 5.3, 37) occupy 12 200 km^2 in north-western New Mexico. About 90% is rangeland, about 30% is controlled by the Federal Government and much of the remainder is in an Indian reservation. The mean annual precipitation ranges from 200 to 250 mm. The mean annual temperature is 10°C and the frost-free period is about 150 days. The elevation is 1500 to 1800 m. The gently sloping broad valleys and plains are bordered by deeply dissected bands of steep slopes and sharp local relief. The dominant soils are Sierozems and Desert soils. Alluvial soils occur on the narrow floodplains of major streams and Regosols in windblown soils in the same position. Lithosols are extensive and there are large areas of badlands in the dissected belts adjacent to the stream valleys (Austin, 1972).

The vegetation of the San Juan River Valley Mesas and Plateaus is dominated by the *Atriplex—Sarcobatus* association. The dominant species are *Atriplex confertifolia* and *Sarcobatus vermiculatus*. Other major components of the vegetation are: *Eurotia lanata*, *Grayia spinosa*, *Kochia americana* and *Suaeda torreyana* (Kuchler, 1964).

About two-thirds of the Colorado River Plateau (Fig. 5.3, 35) is either controlled by the Federal Government or in Indian reservations. The mean annual precipitation varies from 200 to 400 mm, the mean temperature from 7 to 13°C and the frost-free period from 150 to 220 days. The elevation ranges from 1500 to 2100 m. Gently sloping plateaus and mesas are deeply and abruptly cut by canyons. Sierozems and Calcisols occupy the plateau tops, older terraces and alluvial fans. Lithosols and badlands are also extensive (Austin, 1972).

The vegetation of the Colorado River Plateau is dominated by the *Artemisia* association, *Juniperus—Pinus* woodland and the *Bouteloua—Hilaria* steppe. The vegetation of the latter two associations was previous described in the section on the Pecos-Canadian Plains and Valleys. The *Artemisia* association is dominated by *Artemisia tridentata*. Other plant components are:

Agropyron smithii, Artemisia nova [2], *Atriplex confertifolia, Chrysothamnus* spp. and *Tetradymia canescens* [2] (Kuchler, 1964).

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. The bison has never been prominent in this region. Mule deer (*Odocoileus hemionus*) and the black-tailed jack rabbit occur throughout the region. The wolf (*Canis lupus*) has dens, mostly at the higher elevations. The coyote and bobcat (*Lynx rufus*) help in reducing populations of rabbits and wood rats (*Neotoma albigula*). The badger is generally distributed throughout. 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 South-eastern 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 rodents, besides those mentioned above, often encountered in these latter resource areas are: desert cottontail, grasshopper mouse, Merriam's kangaroo rat (*Dipodomys merriami*) and the Bailey's pocket mouse (*Perognathus baileyi*).

Small birds common to the area are: horned larks, 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 and bullsnake. 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, kit fox (*Vulpes macrotis*), desert cottontail, white-throated wood rat, peccary (*Pecari tajacu*) and white-tailed deer. Some of the common birds are: Gila woodpecker (*Centurus uropygialis*), ash-throated flycatcher (*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 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).

Common animals in the Colorado River Plateau and the Arizona and New Mexico Mountains are: mule deer, mountain lion (*Felis concolor*), coyote, black bear (*Euarctos americanus*), porcupine (*Erethizon dorsatum*), least chipmunk (*Eutamias minimus*), deer mouse (*Peromyscus maniculatus*) and bushy-tailed wood rat (*Neotoma cinerea*). The major arthropods are: Black Hills beetle (*Dendroctonus ponderosa*), bark beetle (*Ips integer*), shot borer (*Orthotomicus ornatus*) and carpenter ant (*Camponotus herculeanus modoc*). Some of the major birds are: pigmy nuthatch (*Sitta pygmaea*), white-breasted nuthatch (*S. carolinensis*), Mexican junco (*Junco phaeonotus*) and Steller's jay (*Cyanocitta stelleri*) (Shelford, 1963).

The most common animals in the San Juan River Valley Mesas and Plateaus are: Ord's kangaroo rat (*Dipodomys ordii*), sagebrush chipmunk (*Eutamias minimus*), little pocket mouse (*Perognathus longimembris*), Great Basin pocket mouse (*P. parvus*), black-tailed jack rabbit and the pronghorn antelope. The common birds are: horned lark, mourning dove, common nighthawk (*Chordeiles minor*), vesper sparrow (*Posocetes gramineus*), western kingbird (*Tyrannus verticalis*) and loggerhead shrike (*Lanius ludovicianus*). Common invertebrates are: spider (*Metepeira foxi*), leafhoppers (*Eutettix insanus* and *Aceratagallia cinerea*) and grasshoppers (*Trimerotropis pallidipennis* and *Melanoplus occidentalis*) (Shelford, 1963). The dominant mammals and birds given above generally occur at the same elevations throughout the region.

PAST LAND-USE

In 1600 there were probably 45 million bison occurring in all parts of the grassland of North America, except California. The size of herds in the Pecos-Canadian Plains and Valley area in eastern New Mexico was smaller than those in the Central Great Plains. In the latter region, extensive grazing by bison and prairie dogs (*Cynomys* spp.) tended to change the mid grasses dominated by *Schizachyrium scoparium* to short grasses of the *Bouteloua*—*Buchloe* association. The pronghorn antelope had a total population similar to that of the bison, but they tended to occupy drier portions of the grassland than did the bison (Shelford, 1963).

The range cattle industry of the United States started in the South-western Plateaus and Plains Region in South Texas early in the nineteenth century (Fugate, 1961). Most of the early cattle and cowboys 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.

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 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 mid-west. 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 eighteen-eighties, 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 eighteen-eighties. There were only 5000 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 over-stocking.

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. Though these original lands were the basis for the development of land policy, later acquisitions hold special interest to readers of this chapter. Most of the Western lands were acquired for indirect considerations rather than for agricultural uses. For instance, the South-west Territory was obtained from Mexico in 1846 to provide good harbours 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 influece 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 over-grazing on the range resource. Likewise, permitting land to be farmed in arid and semi-arid 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 nineteen-thirties. 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. The portions of Texas and Oklahoma 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 now 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 producer's efforts.

Most of the ranges described here are grazed primarily by cattle. However, in the Edwards Plateau and Texas Central Basin, sheep and/or goats are sometimes mixed with cattle to better utilize all classes of forage. Sheep graze many of the forbs and goats browse on the *Quercus* and other palatable shrubs (Merrill, 1954). Vegetation control exerted by sheep and goats is a fringe benefit besides the income from animal products. There is little evidence, however, that browsing by sheep or goats will reduce the growth and spread of *Prosopis*, *Juniperus*, *Acacia* or *Larrea* (Martin, 1975).

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, 1973b). In some situations seeding increases productivity above pristine levels.

Large parts of the south-western United States have been invaded by unwanted shrubs. There are 37 million ha of *Prosopis* spp. throughout the area (Platt, 1939). *Artemisia filifolia* and *Quercus havardii* are problems on sandy soils of the Central Great Plains Winter Wheat and Range Region. *Juniperus* spp. are dominant in the Edwards Plateau and parts of the Pecos-Canadian Plains and Valleys, and the mid-elevations in the Western Range and Irrigated Region. *Larrea tridentata* and *Flourensia cernua* occupy about 20 million ha at lower elevations of the Western Range and Irrigated Region. *Opuntia* spp. are a serious problem in parts of the South-western Plateaus and Plains Range and Cotton Region, the Pecos-Canadian Plains and Valleys and the Western Range and Irrigated Region.

The density of brush on rangelands of the south-western United States has increased rapidly since 1900. A survey by the U.S. Soil Conservation Service found 36 million ha, or 82% of Texas grasslands were infested with one or more low-value woody plants (Smith and Rechenthin, 1964). Smith and Rechenthin reported that 22 million ha 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 *Prosopis* alone has increased by half a million ha during the period of 1938—1963. The increase in brush in South Texas was primarily a local expansion and not a general expansion of the range of the species (Johnston, 1963). In most instances, species have moved from gulleys and watercourses onto upland sites.

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. *Prosopis* dominated only 5% of the area in 1858, but this had increased to 50% in 1963. Most of the stands of *Prosopis* in 1858 were associated with Indian activities. The rapid increase in recent years is due to dispersal of *Prosopis* seed by livestock. As *Prosopis* begins to dominate a sandy site, low dunes form, and grass cover is greatly reduced.

Larrea 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). *Flourensia* 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 *Hilaria mutica* and *Scleropogon brevifolius*. As *Prosopis* and *Flourensia* began to dominate the slopes next to mountains, the original grass stands became less dense. Eventually *Larrea* moved onto those sites and gained dominance over the *Prosopis*, *Flourensia* and the residual grass stand. 10 to 15 cm of topsoil has been lost from slopes now dominated by *Larrea*, leaving the larger pebbles and stones to form an erosion pavement. *Larrea* will also invade sites where the original grass stand has been depleted.

RECOMMENDED LAND-USE PRACTICES

Each ranch 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, 1973a). An example of a much more intensive system would be pastures seeded to *Eragrostis curvula* and grazed in conjunction with wheat and *Sorghum sudanense*. This system was described by McIlvain (1976) and discussed in detail later. The costs are much greater with this system, but the potential benefits are much higher.

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).

Grazing management

Merrill (1954) compared continuous year-long grazing at three intensities with deferred-rotation grazing at a moderate rate on the Edward Plateau near Sonora, Texas. There were three herds in the four-unit rotation system; each unit was grazed 12 months, then rested 4 months. Thus, during a 4-year cycle, each unit was deferred once during each of the 4-month periods. Stocking was with a combination of cattle, sheep and goats. The study was initiated in 1949. After 11 years the stocking rate of the units in the deferred-rotation system was increased 33% from 12.4 animal units km^{-2} to 16.6 animal units km^{-2} (Merrill, 1969). These units carried the increased grazing pressure and at the same time made greater range improvement than any of the units grazed continuously. Average annual net returns for 1959—1965 were \$ 1.78, \$ 2.91 and \$ 1.63 ha^{-1} with continuous stocking at the rate of 6.2, 12.4 and 18.6 animal units km^{-2}. The average net return for the same period on the rotation units was \$ 4.15 ha^{-1} (Merrill, 1969).

A two-unit, one-herd rotation; a four-unit, three-herd rotation; and year-long continuous grazing were compared on the Edwards Plateau near Barnhart, Texas (Huss and Allen, 1969). The four-unit rotation was the same as that described by Merrill (1954). In the two-unit rotation, the units were alternately grazed and deferred for 3- and 6-month periods (e.g. one unit was deferred 1 March to 1 June, grazed 1 June to 1 December, and deferred 1 December to 1 March). Thus, during a 2-year period, each unit was deferred 12 months with deferment during each season. All treatments were stocked with cattle and sheep at 10 animal units km^{-2}. During 1959—1965 the average annual net returns were \$ 3.06, \$ 3.90 and \$ 4.17 ha^{-1} for continuous, four-unit rotation, and two-unit rotation grazing, respectively (Huss and Allen, 1969). Huss and Allen found that combination use of cattle and sheep was more profitable than grazing either class alone. Merrill (1969) also found that combination grazing with cattle, sheep and goats was more profitable at Sonora than using sheep or cattle alone.

Fisher and Marion (1951) compared rotation and continuous grazing at a moderate rate on the Central Rolling Red Plains near Spur, Texas. The grazing season was about 1 May to 1 October. The rotation system consisted of grazing each of three units for 1 month and deferring it for 2 months for the 1942—1949 period. They concluded that: (1) rotational grazing did not improve the vegetational composition from 1942 to 1947; (2) rotational grazing increased differential use of the major grass species as the season progressed or during drought, and in some instances resulted in less moisture penetration on sites occupied by the more desirable species, and (3) gains of yearling steers grazing on the rotation units were slightly lower than those of yearling steers grazing on the continuous units.

Various grazing systems were compared at the Texas Experimental Ranch in the Central Rolling Red Prairies near Throckmorton during 1960—1968

(Kothmann et al., 1970). A moderate stocking rate with cows and supplemental feeding level of 0.7 kg day^{-1} of cottonseed cake during winter were used in comparing grazing systems. The three systems were year-long-continuous, a two-unit rotation similar to that studied at Barnhart, Texas, by Huss and Allen (1969), and a four-unit rotation similar to that studied at Barnhart by Huss and Allen and at Sonora, Texas, by Merrill (1954). Calf production per animal unit averaged 200, 208 and 221 kg for the moderate year-long continuous, two-unit rotation and four-unit rotation, respectively, for the 8 years.

Since 1969, 300 ranchers in Texas have initiated a high intensity—low frequency grazing system (Leithead, 1974). It provides for one herd of cattle to graze five to nine units for 15 to 40 days each, depending on the amount of forage available. When the forage in each unit is fully used, the herd is moved to another unit and is not returned to that unit for 4 to 12 months. Leithead (1974) found that the shorter grazing periods, 15 to 20 days, resulted in better livestock distribution and less selective grazing. In this system, units are not grazed during the same calendar period in successive years. Some conclusions by Roberts (1967) in studies of this system in South Africa are pertinent to this discussion. He indicated that livestock should not be moved at any set time nor should the units be stocked in a set sequence. At the time of year when plants are growing rapidly, the livestock should be moved frequently, perhaps as often as every 5 days, to prevent injury to plants. When the plants are dormant, livestock movements may be determined by nutrient requirements of livestock.

McIlvain and Shoop (1969) compared several grazing systems on native range in the Central Rolling Red Plains on the Southern Great Plains Field Station near Woodward, Oklahoma. They concluded that the following grazing systems have not proven superior to continuous year-long grazing at the same stocking rates: (1) summer and winter grazing; (2) alternate-year grazing; (3) three-unit rotations with rotations at 2-months, 1-month, 15-day and 10-day intervals, and (4) two-unit, 6-week, one-herd rotation. They cited some major reasons for the success of continuous year-long grazing in that area, as (1) forage production primarily depends on summer rainfall — and monthly forage production during the summer can vary from 25—700 kg ha^{-1}; (2) most species are grazed by cattle at one time or another; (3) many of the "increaser" species are excellent grazing plants and they may be very productive under certain conditions; (4) cattle use the forage before other losses occur; (5) young shoots and regrowth forage is more palatable and more nutritious than more mature forage; (6) grazed plants save moisture for later green growth, and (7) favourable growing seasons combined with proper management allow ranges to recover a desirable species composition. Some additional reasons for the success of year-long continuous grazing may be (1) use is light during the growing season under year-long continuous grazing, and (2) lighter stocking per unit area means less compaction of the soil by livestock when the soil is wet (Herbel, 1973a).

More recently McIlvain (1976) has compared native range with three complementary pasture systems: (1) native range plus *Eragrostis curvula*; (2) native range plus wheat—*Sorghum sudanense*, and (3) *E. curvula* plus wheat—*Sorghum.* The control treatment was continuous, moderate, year-long stocking of native range at 3.6 ha per steer. This latter system produced more beef at a lower cost while maintaining vigour and condition of the range, than in studies at Woodward (McIlvain and Shoop, 1965). In the native range plus *Eragrostis curvula* system, a total of 2.0 ha was required per steer; 90% of the total land was native range and 10% was *Eragrostis*. This proportion was used to avoid more intensive practices, such as hay-making, if a larger proportion of the land was seeded to *Eragrostis.* The approximate chronological order of grazing was:

Late October and November	— native range
December to March—April	— *Eragrostis* aftermath
March—April to early May	— native range
Early May to early September	— *Eragrostis*
Early September to early October	— native range

In the native range plus wheat—*Sorghum* system, a total of 1.8 ha was required per steer; 75% of the total land was native range, and 25% was double-cropped by planting wheat each October and *Sorghum sudanese* each June. The approximate chronological order of grazing was:

Late October to mid-March	— native range
Mid-March to early June	— wheat
Early June to early August	— native range
Early August to October	— *Sorghum*

The *Eragrostis* plus wheat—*Sorghum* system required 0.8 ha per steer; 50% of the total land was planted to *Eragrostis* and 50% was double-cropped with wheat and *Sorghum.* The approximate chronological order of grazing was:

Late October to mid-March	— *Eragrostis*
Mid-March to early June	— wheat
Early June to early August	— *Eragrostis*
Early August to October	— *Sorghum*

Some of the results from the various schemes are shown in Table 5.4. Beef production on these rangelands was doubled and quadrupled by using complementary pastures that required progressively higher levels of management and economic inputs per hectare. The major value of *Eragrostis curvula* as tame pasture is quantity. The essence of wheat—*Sorghum* as farmed forage for graze-out is quality. The native range provided stability and flexibility to complementary pasture systems. The philosophy of complementing low-producing rangelands with high-producing tame pastures or farmed forages, or both, makes it possible to: (1) use green forages in dry periods; (2) graze and rest each forage resource for its proper growth and development; (3) avoid grazing areas when and where poisonous plants are a problem; (4) use

TABLE 5.4

Generalized year-long beef production data, Central Rolling Red Plains, Wodward, Oklahoma (from McIlvain, 1976)

Grazing scheme	ha/Steer	Gain/Steer	Gain/ha
Native range (NR)	3.6	177	49
NR + *Eragrostis*	2.0 [a]	163	81
NR + wheat—*Sorghum*	1.8 [b]	191	104
Eragrostis + wheat-*Sorghum*	0.8 [c]	168	207

[a] 1.8 ha NR + 0.2 ha *Eragrostis.*
[b] 1.4 ha NR + 0.4 ha wheat—*Sorghum.*
[c] 0.4 ha *Eragrostis* + 0.4 wheat—*Sorghum.*

pastures for breeding cows; (5) use quality forages as green creeps for calves or steers needing a rapid gain and following them with cows or younger cattle to clean up the remaining forage; (6) improve the economics for practices such as brush control, insect control, fencing or fertilization, and (7) exploit the proven potential of higher milking dams, faster-growing calves, hybrid vigour and multiple births (McIlvain, 1976).

Working in the Southern Desertic Basins, Plains and Mountains, Herbel and Nelson (1969) developed the Best Pasture Grazing System. The system consists of establishing an objective for each range unit and stocking accordingly. The system is opportunistic, in that the use of forbs and short-lived grasses is maximized. They are of little value to the permanent range resource, but contribute much to livestock nutrition. No set stocking plan is established for a specific time period because of considerable variation in weather conditions that affect plant growth. In this system, the livestock are moved when the vegetation on another unit can be grazed to better advantage for both plants and animals than the unit being grazed. In the large range units in parts of the West, periodic opening and closing of watering places can be used to rotate grazing pressure to different areas within a range unit (Martin and Ward, 1970).

In range areas in the western United States, stocking must be adjusted to compensate for a highly variable forage crop. Flexible herd management has been suggested by several workers as the best method for maximizing livestock production without damaging the range resource during dry periods (Ares, 1952; Reynolds, 1954; Stubblefield, 1956; Paulsen and Ares, 1962; Boykin, 1967). Most of the severe damage to rangelands by grazing animals occurs during droughts. With flexible herd management, the herd is made up of not more than 55—60% breeding animals during average years. The remainder of the herd is composed of yearlings and replacement heifers. In years of low forage production, adjustments in the size and composition of the herd are planned to bring the herd within the carrying capacity of the range. Readily saleable animals such as weaners and yearlings are marketed. This is also a good time to cull the breeding herd of old animals and those with poor production. In the years of above-average precipitation, part or all of the natural increase from the breeding herd can be held over until the spring or fall, depending on conditions.

Hyder and Bement (1977) listed three requirements for a grazing system: (1) stocking the ranges to achieve not more than moderate use of the forage in the growing season every year, and to maintain a satisfactory botanical composition and productivity of herbage and livestock; (2) grazing should be deferred during the growing season once every few years to renew the vigour and productivity of preferred plants, and (3) include a period of heavy grazing in the dormant season once every few years to reduce unpalatable or ungrazed plants, equalize plant composition and promote more uniform grazing. There is no apparent justification for leaving a range unit ungrazed for an entire year. Some authors (e.g. Hormay and Talbot, 1961) justify rotation plans in terms of seed production, seed planting by trampling and seedling establishment. On most range ecosystems the climax species are long-lived perennials. Often these plants are poor seed producers and do not reproduce readily from seed. If the desirable species are depleted by drought or over-grazing, it is often difficult, if not impossible, to obtain recovery by manipulating the grazing. Therefore, it is extremely hazardous to deliberately over-stock an area during the growing season (Herbel, 1973a). The primary purpose of grazing management is to eliminate excessive grazing, especially in the growing season, in order to increase the vigour and productivity of existing plants (Hyder and Bement, 1977).

A grazing system must be highly flexible. Plant and animal requirements must be considered. For example, some of the range units in a ranch operation may be manipulated to furnish highly nutritious forage during the time of the year when livestock need a higher plane of nutrition. This may be done at a sacrifice of some of the "highly desirable" range species on these units. Further, it should be recognized that the critical growth stage of plants varies from year to year because of weather conditions. Because of grazing history and weather conditions, it may be more important to defer grazing in some years than others. Range units should be grazed when the key species are damaged least by grazing and when forage best meets the nutritional requirements of the livestock. This often means grazing on no pre-determined sequence (Herbel, 1973a).

Grazing systems should also be tailored to fit a variety of vegetation types, soil types and herd management plans. This means that there may be considerable variation in specific details from one ranch operation to the next. In some areas, continuous grazing may be the most profitable system. In some instances, it may be desirable to use an intensive system to attain a certain measure of improvement and then change to a different system for maximum net returns while maintaining the resource. The vagaries of weather, particularly drought, are common problems on rangelands and considerable flexibility must be built into any grazing plan, or for that matter, any activity on rangeland (Herbel, 1973a).

Seeding

Seeding semi-arid rangelands is generally a difficult undertaking because of limiting climatic, soil and/or topographic features. The good sites with a favourable 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 2 cm. Establishing seedlings is often difficult because of an adverse micro-environment (rapid drying, unfavourable temperatures and crusting of the soil surface). Harsh environmental 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 favourable weather conditions in the Central Great Plains Winter Wheat and Range Region. Drier regions would have more intensive problems. The major objectives of preparing seedbeds for range seeding are: (1) to prepare a favourable micro-environment 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 micro-climate (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 *Cenchrus ciliaris* was 773 kg ha^{-1} on broad pits and 283 kg ha^{-1} on conventional pits on a site in the South-eastern 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 semi-arid areas infested with brush has been discussed by Abernathy and Herbel (1973). The brush and competing vegetation are controlled by a root-plough. 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 (Fig. 5.10).

Concentrating water, as with various land-forming procedures, does not always ensure seedling establishment. The surface soil still dries rapidly, particularly in hot, arid and semi-arid 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 eco-types of many grass species have been selected for: superior seedling vigour; 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 eco-types of local origin, generally within 300 km north and 450 km south of the area to be seeded. Some of the major native and introduced species used for seeding in the South-west follow.

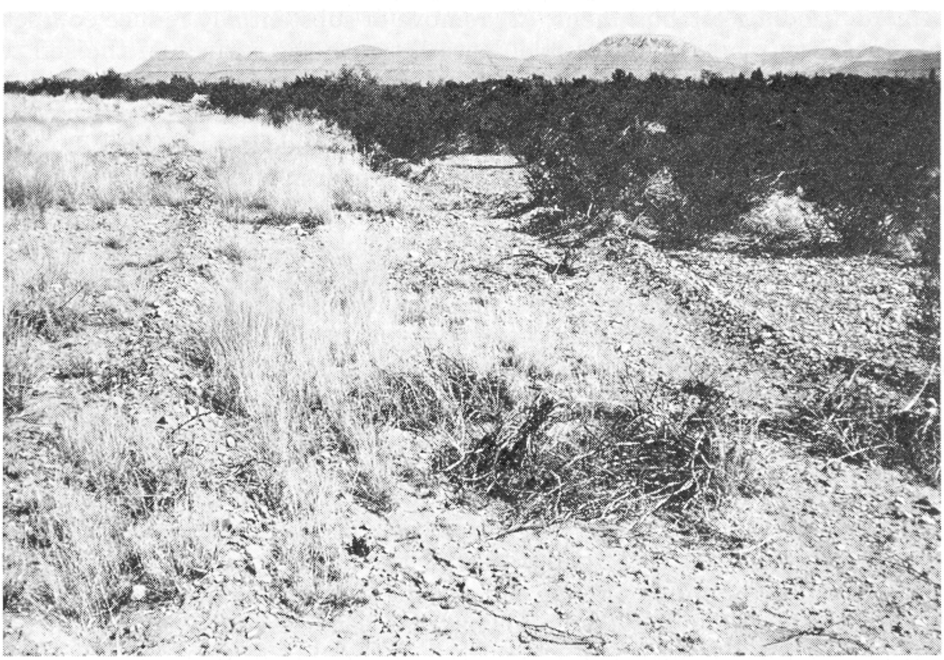

Fig. 5.10. An area dominated by *Larrea tridentata* (right) was root-ploughed and successfully seeded to *Eragrostis lehmanniana* and *Bouteloua eriopoda* (left).

South-western Plateaus and Plains Region: *Cenchrus ciliaris, Chloris gayana, Bothriochloa ischaemum, B. barbinodis, Bouteloua curtipendula, Schizachyrium scoparium, Panicum coloratum, P. antidotale, Leptochloa dubia* and *Stipa leucotricha.* Central Great Plains Winter Wheat and Range Region: *Andropogon gerardi, A. hallii, Schizachyrium scoparium, Bothriochloa caucasica, Buchloe dactyloides, Bouteloua gracilis, B. curtipendula, Eragrostis curvula, E. trichodes, Sporobolus airoides, Panicum obtusum, P. virgatum, Agropyron smithii* and *Stipa leucotricha.* Pecos-Canadian Plains and Valleys: *Agropyron smithii, Sporobolus airoides, Bouteloua gracilis, B. curtipendula, B. gracilis, Eragrostis chloromelas, E. lehmanniana, Agropyron desertorum, Atriplex canescens, Sporobolus airoides* and *Oryzopsis hymenoides.* Higher elevations of the Western Range and Irrigated Region, particularly following fires in the *Pinus* associations: *Poa ampla, Festuca arizonica, F. ovina* var. *duriuscula, Agropyron intermedium, Alopecurus pratensis, Bromus inermis, Dactylis glomerate, Lolium perenne* and *Phleum pratense.*

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 *Prosopis, Larrea, Flourensia, Quercus* and *Juniperus* 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 re-vegetation 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 re-vegetation 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 *Prosopis* 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 0.6 kg ha^{-1} of 2,4,5-T, 1 to 3 years apart killed 23—64% of the *Prosopis* on sand dunes in southern New Mexico (Herbel and Gould, 1970). Perennial grass yields on areas sprayed twice in 1958—1961 averaged 234 kg ha^{-1} during 1963—1968, compared to 39 kg ha^{-1} 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. The phenoxy herbicides are effectively used to control *Quercus* and *Artemisia* growing in the Central Great Plains Winter Wheat and Range Region. Mixtures of picloram and 2,4,5-T or dicamba and 2,4,5-T are sometimes used to control *Prosopis* in Texas, particularly where it is growing in association with other unwanted plants.

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, root-ploughing, 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). Bulldozing is used extensively to control *Juniperus* stands in the South-west. Grubbing with a stinger blade is used to control *Prosopis* growing on medium-textured soils in the Pecos-Canadian Plains and Valleys and the Southern High Plains.

A root-plough is a horizontal blade attached to a track-type tractor. Root-ploughing cuts off the shrub or small tree at depths of approximately 40 cm for *Prosopis* or other re-sprouting species and 15—20 cm for non-sprouting species. Root-ploughing 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 *Prosopis* in Texas (Rechenthin et al., 1964), *Larrea* and *Flourensia* in New Mexico (Abernathy and Herbel, 1973) and chaparral in central Arizona (Cable, 1975).

In discing, the brush is uprooted with a large disc plough or tandem disc. It is limited to small shallow-rooted plants like *Artemisia*, *Flourensia* and *Larrea*. It also destroys grasses growing on the area, so, like root-ploughing, 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, 90—120 m long, behind two track-type tractors (Fisher et al., 1959). The method is effective in controlling non-sprouting species like some *Juniperus* spp. Cabling is used to control *Opuntia imbricata* in New Mexico. It is useful in knocking down *Prosopis* 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 South-west.

Burning as a tool

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.

Box (1967) burned dense stands of *Hilaria mutica* in the Central Rolling Red Plains in the spring just when *Prosopis glandulosa* had begun growth. All the *Prosopis* were top-killed and about 10% were root-killed. Most of the trees re-sprouted from the base, but insects attacked the new sprouts and kept them eaten to the base. No insects were found on trees in the unburned plots. Similar results were obtained on *Condalia*. Box (1967) reported that a wildfire in the same area killed 26% of the *Bothriochloa saccharoides*, 84% of the *Aristida longiseta*, 32% of the *Buchloe dactyloides*, 48% of the *Panicum obtusum*, 40% of the *Setaria leucopila* and 72% of the *Sporobolus cryptandrus*. Although all plants were damaged, those high in the successional scale, *Buchloe* and *Bothriochloa*, were harmed least. 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, *Hilaria mutica* produced 3151 kg ha^{-1} after burning during a wet year and only 700 kg ha^{-1} after burning during a dry year. The unburned controls produced 1263 and 1068 kg ha^{-1}, respectively (Wright, 1972).

In the Southern Desertic Basins, Plains and Mountains in southern New Mexico, Herbel and Nelson (1974) conducted a study to determine if *Hilaria mutica* could be grazed during the winter—spring when it is mostly dormant.

The old growth on *Hilaria* was burned in the summer after the first storm for 3 years. However, calf performance the following winter—spring was not improved by burning the previous summer.

Prescribed burning can be recommended for controlling *Aplopappus tenuisectus* in southern Arizona (Tschirley and Martin, 1961). However, Martin (1975) indicated that populations of *Aplopappus* 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 South-eastern 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 favours annual grasses and pioneering perennial grasses at the expense of the climax perennial grasses.

Burning must be combined with other methods to control *Quercus* spp. in order to improve forage production in the chaparral portions of the Arizona Mountains (Cable, 1975). Five successive annual burnings were required to reduce the number of shrub *Quercus* sprouts below pre-burn numbers (Pond and Cable, 1960). Burning a former chaparral area in winter, 7 years after root-ploughing and seeding, effectively top-killed shrub sprouts but did not harm the grass (Pase, 1971). This type of burning, repeated periodically, might offer a method of suppressing shrub growth on areas where the chaparral has been controlled.

Burning of live, non-sprouting *Juniperus* trees is an effective, economical method of control in Arizona and New Mexico (Arnold et al., 1964). Where *Juniperus* is invading grasslands, trees up to 1 m high are easily killed and the herbaceous understory will carry a fire. Burning is also used after chaining, bulldozing or piling to get rid of unwanted slash and to kill missed plants. *Juniperus* trees in open stands can be individually ignited and burned by the use of propane or oil burners (Vallentine, 1971). The canopy is enveloped in flame by igniting the trees at the base. All the non-sprouting *Juniperus* trees were killed by scorching 60% of the crown.

The benefits of ground fires in the *Pinus* forests, dominated by *Pinus ponderosa*, in the Arizona and New Mexico Mountains are: (1) increased water production; (2) increased forage production; (3) providing space for hunting and camping; (4) preventing or reducing destruction of the harvest by wildfire, and (5) improving the aesthetic values (Vallentine, 1971). Humphrey (1962) concluded that the moderately open savanna stands of *Pinus*, essentially free of understory trees and shrubs, and supporting a good stand of grasses and forbs, has been maintained by lightning-caused fires. These recurrent natural fires prevented dense thickets of young *Pinus* and understory brush and kept fires from developing in the tree crowns by preventing large accumulations of fuel.

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.

Fertilization

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.

In the Central Rolling Red Plains, forage yields of *Eragrostis curvula* increased about 50% with 34 kg N ha^{-1} (McIlvain and Shoop, 1970). A single application in April increased gains of yearling steers by 10%, carrying capacity by 25%, beef production per unit area by 31%, and profit per ha by 36%. *Eragrostis* fertilized with N was more palatable, stayed green longer at the beginning of droughts, made more rapid regrowth after grazing and produced more seed.

On rangeland dominated by *Bouteloua gracilis* in the Pecos-Canadian Plains and Valleys, 45 kg N ha^{-1} increased herbage production from 974 kg ha^{-1} on the control to 1487 kg ha^{-1} and 67 kg N ha^{-1} increased production from 974 to 1801 kg ha^{-1}. This same range fertilized with 45 kg N ha^{-1} produced steer gains of 54 kg ha^{-1}, whereas unfertilized range produced gains of only 26 kg ha^{-1} (Dwyer, 1971). The increase was due mainly to the greater number of yearling steers that could be grazed on the fertilized range.

On the Rio Grande Plain, P fertilization increased herbage yields and provided needed P to the grazing livestock (Vallentine, 1971). Calving was increased from 69 to 98% and the weight of calf produced per ha was approximately doubled.

On flood plains dominated by *Hilaria mutica* 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 favourable soil moisture conditions existed over a continuous 60-day growing period, 101 kg N ha^{-1} increased herbage yield from 3126 kg ha^{-1} on the control to 7790 kg ha^{-1}, 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 South-eastern Arizona Basin and Range dominated by *Eragrostis lehmanniana* and *Aristida glabrata*, check plots yielded an average of 2772 kg ha^{-1} (Holt and Wilson, 1961). Fertilization with 28, 56 and 112 kg N ha^{-1} 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 *Agropyron smithii.* Of the other grasses studied by them, *Sporobolus airoides* was only slightly affected by sedimentation, but *Hilaria jamesii* and *Bouteloua gracilis* 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 aids 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 conditon. 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 *Prosopis* in strip patterns maintained populations of deer while improving livestock production. Spraying an entire 1600 ha pasture drastically reduced the deer herd in that pasture.

The mixed conifer forest in the Arizona and New Mexico Mountains is used by elk (*Cervus canadensis*), deer (*Odocoileus hemionus*), turkey (*Meleagris gallopavo*), grouse (*Dendrogapus obscurus fuliginosus*), bighorn sheep (*Ovis canadensis*) and beaver (*Castor canadensis*) (Lamb and Pieper, 1971). Forage yields are highest in forest openings and these are preferred by the grazing animals (Reynolds, 1962). Intensive livestock grazing can cause deer and elk to avoid an area. The presence of some slash remaining from harvesting timber may tend to favour deer over cattle and therefore reduce direct competition (Reynolds, 1966). Light-to-moderate grazing by livestock apparently has little effect on big-game animals (Clary, 1975). Reductions of the timber overstory, whether to improve yields of water or timber, will virtually always increase herbage. Big-game numbers usually increase with the improved forage supply. Seeding after wildfire improves the habitat for both deer and elk (Kruse, 1972).

The *Pinus—Juniperus* zone is of critical importance to deer and is used to some extent by turkeys and elk (Lamb and Pieper, 1971). Range improvement work has included cabling, chaining, bulldozing, broadcast burning, single tree cutting, tree crushing and various combinations of these treatments. Any of these methods will improve a game range if properly designed. Cleared areas should be kept narrow so that deer using the openings are always close to cover. Ideally, the openings should not be over 400 m wide. The steep slopes and the rocky ridges with shallow soil should be left untreated. Thinning *Juniperus* trees where there are more than 370 ha^{-1} also improves game habitat. The control method chosen to improve forage for livestock should cause minimal damage to browse plants for wildlife (Paulsen, 1975).

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 root-ploughing 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 South-eastern 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 *Larrea*, 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).

Some examples of optimizing ranch production follow. In the Rio Grande Plain, *Prosopis* would be sprayed in strips and *Cenchrus ciliaris* seeded on the more productive soils. In the Edwards Plateau and the Texas Central Basin, the stands of *Juniperus* would be thinned by chaining, *Bouteloua curtipendula* would be seeded on selected sites and a grazing system would be initiated. On the Central Rolling Red Plains, practices would include spraying *Artemisia filifolia* and seeding about 10% of the ranch unit with *Eragrostis curvula*. On the Southern High Plains, *Prosopis* would be sprayed and *Hilaria mutica* would be burned. The *Juniperus* would be controlled on selected sites on the Pecos-Canadian Plains and Valleys, the Arizona and New Mexico Mountains, the New Mexico and Arizona Plateaus and Mesas and Colorado River Plateau and some areas would be seeded with *Agropyron smithii*, *Bouteloua gracilis* and *B. curtipendula*. Some of the practices in the Southeastern Arizona Basin and Range, and the Southern Desertic Basins, Plains and Mountains would include spraying the *Prosopis* and root-ploughing the *Larrea* and seeding with *Eragrostis lehmanniana* and *E. chloromelas*. The land manager should select those practices that increase productivity of the land while considering the total environment.

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