272121
1956
2

SHRUB INVASION OF A SOUTHERN NEW MEXICO

This thesis has been submitted in fulfillment of requirements for an advanced degree at the University of Arizona and is deposited in the library to be made available to borrowers under rules of the library. Brief quotations from this thesis are allowable without special permission, provided that adequate acknowledgment of source is made. Requests for permission for extended quotation from or reproduction of this manuscript in whole or in part may be granted by the head of the major department or the dean of the Graduate College when in their judgment the proposed use of the material is in the interests of scholarship. In all other instances, however, permission must be secured from the author.

A Thesis

submitted to the faculty of the

Department of Agronomy and Range Management

in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

in the Graduate College, University of Arizona

1956

Approved: R. R. Humphrey 8/21/56
Director of Thesis Date

E9791

1956

2

This thesis has been submitted in partial fulfillment of requirements for an advanced degree at the University of Arizona and is deposited in the Library to be made available to borrowers under rules of the Library. Brief quotations from this thesis are allowable without special permission, provided that accurate acknowledgment of source is made. Requests for permission for extended quotation from or reproduction of this manuscript in whole or in part may be granted by the head of the major department or the dean of the Graduate College when in their judgement the proposed use of the material is in the interests of scholarship. In all other instances, however, permission must be obtained from the author.

SIGNED:

Bruce L. Branscomb

CONTENTS

	Page
Introduction and Statement of the Problem	1
Description of Study Area	2
Description of Principal Invaders	4
Study Methods	8
Vegetation Changes on the Jornada and an Analysis of Contributing Factors	10
Climate as a Factor in Shrub Encroachment	16
Grazing Pressure as a Factor in Shrub Encroachment. . .	23
Fire as a Factor in Shrub Encroachment	28
Man as a Factor in Shrub Encroachment	34
The Desert Grassland as Climax	35
Bibliography	37

LIST OF TABLES

	Page
Table 1. - Percentage change in vegetation dominants on experimental range for the years 1915 to 1928; 1928 to 1946; and 1915 to 1946.....	9
Table 2. - Acreage and percent of total area occu- pied by vegetation dominants on Jornada Experimental Range by years 1915, 1928 and 1946.....	12

LIST OF FIGURES

	Page
Figure 1. - Vegetation dominants on Jornada	
Experimental Range in 1915	11
Figure 2. - Vegetation dominants on Jornada	
Experimental Range in 1928	13
Figure 3. - Vegetation dominants on Jornada	
Experimental Range in 1946	15
Figure 4. - Annual rainfall and accumulated	
deviations from long time means	
in southern New Mexico	17
Figure 5. - Vegetation changes along 1500 ft.	
belt transect by 500 ft. sectors	
on Jornada Experimental Range	22

ACKNOWLEDGEMENTS

I would like to express appreciation to Dr. Robert R. Humphrey for his guidance during the course of this study and for editing the manuscript; to Dr. Raymond M. Turner for his helpful suggestions and editing; and to Mr. David G. Wilson for his assistance and advice.

Appreciation is expressed also to the Jornada Experimental Range Unit, Agricultural Research Service, Las Cruces, New Mexico, and to the Rocky Mountain Forest and Range Experiment Station personnel for furnishing the basic data for this study. My thanks are extended also to Mr. Fred N. Ares for his help in securing the basic data, and to Mr. H. A. Paulsen, Jr. for suggesting the problem and for his aid in obtaining relative data.

SIGNED:

Bruce L. Branscomb

SHRUB INVASION OF A SOUTHERN NEW MEXICO DESERT GRASSLAND RANGE

INTRODUCTION

The Problem

Millions of acres of desert grassland in southwestern United States have been invaded by noxious shrubs. This has been pointed out repeatedly in reports of studies and scientific investigations carried on in the Southwest during the past 50 years. A comparison of historical records and present plant cover leads to the conclusion that vast acreages, once dominated by grass, have now been reduced to submarginal status by the encroachment and dominance of undesirable shrubs.

Much of the present desert grassland area is now at least lightly infested by shrubs; infestation does not have to be particularly heavy before the productivity of the range is seriously impaired. As shrub encroachment increases markedly, many of the valuable grasses are driven completely and permanently out (Valentine 1955).

One or more varieties of mesquite now occupy some seventy million acres in Texas, New Mexico, and Arizona (Parker and Martin 1952). Tarbush (Flourensia cernua (DC.) Prod.), creosote bush (Larrea tridentata (DC.) Coville), snakeweed (Gutierrezia sarothrae (Pursh) Britt.), and other woody species are invading the grasslands, or occur in pure stands across vast areas within those states where grasses once flourished.

The economic welfare of the Southwest depends, in a large measure, upon its grazing and soil resources; therefore, investigations to determine the extent of shrub invasion, rate of range deterioration and reasons underlying this retrogression in plant cover are of prime importance.

Norris (1951) has shown a loss of approximately 380 pounds of forage per acre when a light infestation of honey mesquite (Prosopis juliflora (Swartz) DC. var. glandulosa (Torr.) Cockerell) is allowed to develop and approaches a heavy stand. Other studies indicate that brush invasion on semi-arid grasslands is a problem of ever increasing importance (Paulsen 1955).

Studies by Brown (1950) and Mehrhoff (1955) have yielded valuable information pertaining to this problem as it applies to the desert grasslands of southern Arizona. Campbell (1929, 1931, 1934) and Gardner (1950, 1951) have contributed greatly to a solution of the problem in New Mexico. Other recent investigations have been carried out by Glendening (1952), Parker and Martin (1952), and Bogusch (1952).

In this study records of vegetational changes, environmental factors, and range utilization have been compiled, analyzed and evaluated in an attempt to determine the reasons for the encroachment of shrubs on a New Mexico semi-desert grassland range. The principal factors evaluated are grazing pressure, climate, fire, and the effect of man.

Description of Study Area

The Jornada Experimental Range, where data analyzed in this study were collected, lies in the Rio Grande Valley, Dona Ana County, in south-central New Mexico. It is bounded on the west by the Rio Grande

River and on the east by the San Andres Mountains. Headquarters are located twenty-three miles north of the city of Las Cruces. The experimental range encompasses approximately 145,000 acres of essentially flat mesa-land ranging in elevation from 3,900 to 4,700 feet. At the time of establishment as an experimental range under U. S. Forest Service management in 1915, the Jornada area included a portion of the San Andres Mountains. This mountain area of approximately 45,000 acres is known as the mountain pasture of the experimental range. The remaining 145,000 acres adjoining the mountain pasture on the west, composed of broad, flat, slightly undulating terrain, is known as the mesa. In this report only the latter is considered, and the terms mesa, and mesa portion, are used herein to delineate the area studied.

The area is typical of much of the semi-desert grassland of the southwest. Twenty-six million acres so classified in southern Arizona, New Mexico, and Texas are sufficiently similar in climate, soils, and vegetation that the results of studies carried out on the Jornada Experimental Range can be directly applied to these desert grassland areas (U.S.D.A. Forest Service Mimeo. 1951).

Much of the vegetation consists of species occurring in no other plant formation. Black grama (Bouteloua eriopoda Torr.) communities occur on the upland sites and tobosa grass (Hilaria mutica (Buckl.) Benth.) in the lowlands. Other grasses occurring in association with these two dominant species, but less abundant, are Aristida spp., Bouteloua spp., Hilaria spp., Muhlenbergia spp., and Sporobolus spp. Encroaching mesquite, tarbush, creosote-bush, and snakeweed associations

cover extensive areas. Noxious species other than the above include soapweed (Yucca elata Engelm.), Atriplex spp., Acacia spp., and Opuntia spp.

The soils are mostly quarternary alluvium with older sands and gravels (Darton 1922), often underlain at shallow depths with caliche. The topsoil over much of the range is sandy and subject to severe wind erosion; the dry lake beds and tobosa grass flats are of heavy, highly impervious clay soils.

The climate is arid; wind movement and evaporation rates are high, measuring approximately 35,000 miles and 100 inches per annum, respectively (Ares 1952). Rainfall, which may be extremely variable from year to year, averages nine inches per annum over the 90-year period of record. Precipitation has the winter-summer pattern typical of the Southwest, with summer storms characteristically local and violent. More than 50 percent of the total annual rainfall occurs during the summer months of July, August and September.

At the time of establishment as an experimental range in 1915, shrubby vegetation was well established in the area and was encroaching upon the grassland sites. Because of this, in part, studies were initiated to determine the most efficient systems of range management applicable to this and similar desert grassland sites.

Description of Principal Invaders

MESQUITE. Western honey mesquite, a member of the mimosa family, is a shrub growing in many-stemmed clumps 3 to 5 feet in diameter. The plants are normally 5 to 10 feet in height, but in some habitats may be only one or two feet high. They have extensive root systems,

the taproot often extending to a depth of 20 to 60 feet and the laterals reaching as far as 40 to 50 feet from the root-crown.

Honey mesquite inhabits dry, sandy, or gravelly plains, mesas, canyons, and hillsides at elevations between 2,500 and 5,000 feet. It is frequently characteristic of sand dunes, often dominating extensive areas in pure stands.

The species is exceptionally drought-enduring and aggressive. It is resistant to grazing and invades grasslands readily when the grass cover is broken. The plants have some value as browse, and serve as emergency feed for cattle during drought.

TARBUSH. Tarbush, also known as blackbush, is a resinous, thick-leaved shrub of the composite family. It usually grows to a height of from 3 to 6 feet. Tarbush inhabits dry, sandy, or adobe plains, mesas and low foothills in the desert grassland at elevations from 3,500 to 5,000 feet. It often occupies large areas and forms a rather distinctive vegetation type. Tarbush will invade grassland sites when the sod is broken. The shrub is unpalatable to livestock, and serious losses of sheep have been reported when the animals graze the ripe fruits of this plant. No cattle losses have been reported. The fruit pods and leaves are sold as a drug in Mexico under the name of Hojase, and are used as a remedy for indigestion. (Dayton, 1931; Kearney and Peebles, 1952; Muenscher, 1951).

CREOSOTE BUSH. Creosote bush is a much-branched, evergreen shrub, 3 to 11 feet high, belonging to the caltrop family. It occurs rather indiscriminately within its range on plains and slopes from sea level to 4,000 feet elevation. The most common and widely distributed shrub

in the desert, creosote bush was found originally in the driest and hottest portions of North America, but has invaded the lower portions of the desert grassland in many areas of New Mexico and Arizona (Gardner, 1951). It forms pure stands over much of its range particularly on sandy or gravelly mesas.

The species has a capacity for withstanding excessive drought, and occurs in association with other xeric shrubs over thousands of acres in the lower Sonoran Desert. Creosote bush, although not a good soil builder, does stabilize and protect the soil on sites where it occurs. The plant is worthless as forage, and the growth of better forage plants is restricted where it is abundant (U.S.D.A. Forest Serv. Hdbk., 1937).

SLAKEWEED. Snakeweed is a woody perennial of the composite family. It has numerous erect stems 6 to 36 inches high, growing from a woody base. The seedling establishes a deep taproot during the first season, developing abundant lateral roots as it matures. Branches of the more mature plants often produce adventitious roots when partially covered by drift sand (Campbell and Bomberger, 1934). It occurs on plains and slopes in the upper creosote-bush desert at elevations from 4,000 to 8,000 feet.

Snakeweed is found on a wide range of soils but most commonly inhabits dry, well-drained, sandy, gravelly or clayey loams. It is a very aggressive plant which rapidly invades areas where the grass cover has been depleted.

This plant is poisonous to cattle when eaten in quantity, and its presence in dense stands is taken to be an indicator of overuse

of the more palatable forage. It does have some stabilizing effect on the soils in Prosopis sand-dune areas; however, surface runoff and soil loss are much greater on snakeweed infested grasslands than on those where the grass cover has not been broken by this encroachment (USDA. Forest Serv. Hdbk., 1937).

STUDY METHODS

Vegetation maps and field write-up sheets of the experimental range, derived from data compiled during range reconnaissance surveys in 1915 and 1928 were compared. Mosaics made from 1946 aerial photographs were also analyzed. Vegetation type lines were delineated on the mosaics and these types were ground-checked to determine vegetation dominants. Vegetation types shown on the maps were planimetered to determine acreage of each in 1915, 1928 and 1946. From these data the percentage of shrub cover on the experimental range at three different periods of time, separated by thirteen-year and eighteen-year intervals, was calculated and analyzed. As a further check on the rate of invasion, records from a permanent belt transect maintained since 1936 were compiled graphically and evaluated.

Records of management practices, operating procedures, stocking rates, and improvement practices were analyzed. Climatic data covering the past 90 years were obtained and analyzed in detail. Results of previous studies and conclusions drawn by other investigators concerning invasion of the desert grassland by noxious plants were thoroughly reviewed.

An extensive search of historical and scientific literature pertaining to the Southwest was made to determine the conditions that have existed throughout the desert grassland region since early Spanish explorations. Factors contributing to possible shrub encroachment were considered in the light of these records.

Table 1. Percent change in vegetation dominants on Jornada Experimental Range for the years 1915 to 1928; 1928 to 1946; and 1915 to 1946.

VEGETATION DOMINANTS	PERCENT CHANGE		
	1915 - 1928	1928 - 1946	1915 - 1946
GRASSLAND	-17	-14	-28
MESQUITE	74	20	107
TARBUSH-CREOSOTE	-8	0	-8
SNAKEWEED	-42	-25	-56

VEGETATION CHANGES ON THE JORNADA
AND AN ANALYSIS OF CONTRIBUTING FACTORS

Grassland

The grassland vegetation on the experimental range consists of two major associations; black grama on the upland sites and tobosa grass in the swales. The 1915 vegetation map (Fig. 1) shows 62,189 acres or 43 percent of the total mesa acreage classified as grassland dominant at that time (Table 2).

By 1928, 10,731 acres or 17 percent of the original grassland area was dominated by mesquite and snakeweed (Fig. 2, Table 1). Only 51,818 acres or 30 percent was still classed as grassland. By 1946 the grassland had been reduced an additional 7,152 acres; only 44,666 acres, or 31 percent of the mesa, remained as grassland dominant (Fig. 3). This represents a thirty-year shift from grass to brush of 17,523 acres. While this loss of grassland acreage is equal to only 12 percent of the total mesa area (Table 2), it represents a 28 percent loss of the acreage originally dominated by grass (Table 1).

Mesquite

In 1915 mesquite was dominant on 27,545 acres, 19 percent of the total mesa area (Table 2). By 1928 this shrub had become dominant on 47,754 acres, or 33 percent of the mesa, an encroachment upon 20,209 acres of grassland and lower growing brush types. This represented a 74 percent increase in the acreage originally classed as mesquite dominant (Table 1). The invaded area extended across the northern portion and surrounded the mesquite-dominated portion in the western half of the experimental range (Fig. 2).

VEGETATION DOMINANTS ON
JORNADA EXPERIMENTAL RANGE
IN 1915

U.S. DEPARTMENT OF AGRICULTURE
FOREST SERVICE

THE JORNADA RANGE RESERVE
DONA ANA COUNTY
NEW MEXICO

YEAR	VEGETATION DOMINANTS					
	Mesquite	Tarbush- creosote	Snakeweed	All Shrubs	Grass spp.	TOTALS
	<u>acres</u> <u>%</u>	<u>acres</u> <u>%</u>	<u>acres</u> <u>%</u>	<u>acres</u> <u>%</u>	<u>acres</u> <u>%</u>	<u>acres</u> <u>%</u>
1915	27545 19	40108 27	15488 11	83141 57	62189 43	145330 100
1928	47754 33	36730 25	9028 6	93512 64	51818 36	145330 100
1946	57133 39	36774 25	6757 5	100664 69	44666 31	145330 100
<u>Net Change</u>	29588 20 gain	3334 2 loss	8731 6 loss	17523 12 gain	17523 12 loss	0

Table 2. ACREAGE AND PERCENT OF TOTAL AREA OCCUPIED BY VEGETATION DOMINANTS ON JORNADA EXPERIMENTAL RANGE by years 1915, 1928, and 1946.

FIGURE 2

VEGETATION DOMINANTS ON
JORNADA EXPERIMENTAL RANGE
IN 1928

U.S. DEPARTMENT OF AGRICULTURE
FOREST SERVICE

THE JORNADA RANGE RESERVE
DONA ANA COUNTY
NEW MEXICO

A total of 57,133 acres or 39 percent of the mesa was classed as mesquite dominant in 1946; this was a 20 percent gain since 1928 in total mesa acreage dominated (Table 2). The encroachment took place mainly at the expense of the lower-growing shrubs; however, extensive areas that were formerly grassland had also been invaded (Fig. 3).

The area dominated by mesquite in 1946 represented an increase of 107 percent in the acreage dominated by this shrub in 1915 (Table 1).

Tarbush-creosote

Approximately 40,100 acres, or 27 percent of the mesa, was dominated by tarbush-creosote vegetation in 1915 (Table 2). The type predominated in the southeastern fourth of the mesa (Fig. 1). During the thirteen-year period between 1915 and 1926 the tarbush-creosote acreage was reduced by 8 percent (Table 1). This 3,378-acre reduction was accounted for mainly by mesquite sand-dune encroachment in the east-central portion of the mesa (Fig. 2). During the next eighteen years there was no significant change, and in 1946 the area dominated by this association was essentially the same as in 1928 (Fig. 3).

Snakeweed

Snakeweed was dominant on 15,488 acres or 11 percent of the mesa in 1915 (Table 2). The snakeweed areas were mainly in the west-central and northwest portions of the experimental range between the grassland and mesquite types (Fig. 1). By 1928 only 9,028 acres of the mesa were classified as snakeweed dominant. This represented a 42 percent reduction of snakeweed acreage in thirteen years (Table 1),

VEGETATION DOMINANTS ON
JORNADA EXPERIMENTAL RANGE
IN 1946

U.S. DEPARTMENT OF AGRICULTURE
FOREST SERVICE

JORNADA EXPERIMENTAL RANGE
DONA ANA COUNTY
NEW MEXICO

a change due mostly to encroaching mesquite. At the same time, however, snakeweed also invaded a large area previously classed as grassland (Fig. 2). A further reduction in snakeweed dominated area, amounting to 5 percent of the mesa acreage, took place during the next eighteen-year interval. This was an overall loss of 8,731 acres since 1915 (Table 2), which is a 56 percent reduction in the original snakeweed-type acreage (Table 1).

Climate as a Factor in Shrub Encroachment

Records of precipitation in southern New Mexico have been kept since 1853. These data were recorded by frontier army posts until the State College climatic stations were established in 1892. The 102-year span of record is broken by missing or incomplete data for thirteen years, leaving only 89 years of record. However, this 89-year span does seem to indicate the presence of a definite cyclic pattern of precipitation. This pattern can be seen in Figure 4, as compiled and graphed by the U. S. Forest Service at the Jornada Experimental Range. Five cycles, oscillating from periods of above-average to below-average precipitation, are evident. During the first cycle of 21-years, annual precipitation averaged 8 percent below the 89-year mean; during the second cycle of 21-years, mean annual precipitation was above the average; the 19-year period comprising the third cycle was one of drought; the fourth cycle, an 18-year time interval, shows precipitation again averaging above the mean; the last eleven years were 20 percent below the average.

Rainfall on the experimental range has not differed appreciably

Figure - 4. ANNUAL RAINFALL
 &
 ACCUMULATED DEVIATIONS
 FROM LONG TIME MEANS
 IN
 SOUTHERN NEW MEXICO
 (Ares 1952)

from the older, long-term precipitation pattern of the area.

Climatic data recorded on the Jornada during the 41-year period since 1915, indicate the same cyclic pattern. The period 1915 to 1926, an 11-year span of below average rainfall on the experimental range, falls within the latter part of the third dry cycle of the longer record. For the next nineteen years, precipitation on the Jornada averaged 15 percent above the mean. The present dry cycle which began in 1945 has averaged some 26 percent below the mean (Ares 1952). This same cyclic pattern was noted by Mehrhoff (1955) in his analysis of tree-ring data as an indicator of past climatic conditions in the Southwest.

During these periods of extended drought, grasses make little or no growth, and in many instances grassland areas are killed completely - literally "droughted out." Because of their relatively shallow roots, desert grassland grasses depend upon surface moisture for their water requirements; the lack of sufficient surface moisture is a major factor in their death. Shrubs, on the other hand, by virtue of their deeper and more extensive root systems, are able to sustain life by drawing moisture from deeper levels. Frequently, these shrubs continue growing, extending their coverage into the adjacent grasslands. The ability of shrubby species to withstand drought has been discussed by several investigators. Paulsen (1950) commented as follows on mesquite seedling development:

After two growing seasons, taproots had developed to approximately 27 inches and it is believed that those seedlings remaining alive at this time are

capable of surviving subsequent droughts and developing into mature trees.

Bryan (1928) reporting on changes in vegetation due to changes in ground-water level noted that mesquite was essentially dependent on ground water and relied to only a limited extent upon surface moisture.

When the drought cycle is broken and precipitation is adequate for normal grass growth, the grasses must begin growing from dormancy or seed. Those shrubs that have been actively growing are in a position to utilize more of the immediately available moisture than the grasses.

Campbell (1929) studied vegetational composition in the mesquite sand-dune areas on the Jornada, and commented as follows on the shrub-infested areas.

Mesquite begins growth in late spring when other perennials are practically dormant, and continues until autumn. Only in a period of favorable years are other plants able to survive in sand-dune areas whereas because of the deep taproot of mesquite, it draws up water from lower depths.

Parker and Martin (1952) observed the encroachment of shrubby vegetation on desert grasslands in southern Arizona. The following is taken from their report.

Southern Arizona is characterized by intermittent droughts which often result in marked death loss of the perennial forage grass. As stated earlier, drought seldom causes the death of whole mesquite plants.....

When drought occurs on mesquite-infested areas, the grass is reduced and the cover opened up for establishment of more mesquite seedlings. Also, during drought the forage grasses are grazed more closely and mesquite seed pods probably are eaten more freely. Finally, with mesquite robbing the soil of moisture, recovery of grass after a drought is more difficult. . . . The aggressive nature of mesquite, together with its low requirements with respect to sites in which it will grow, encourages its increase. Once seedlings of taprooted drought-enduring mesquite are able to reach underground moisture they attain a most favorable position for meeting grass competition.

This replacement of grass by shrubs appears to be one of the direct means by which extensive areas of grassland are being invaded and taken over during cycles of more favorable growing conditions.

Bogusch (1952) in commenting on climatic changes as a factor in brush invasion, observed:

It is our studied opinion that the effect of climatic oscillations and cycles has far less effect upon initiating brush invasion than it does in perpetuating it. During the early ecologic development of seedlings, those of the woody plants require favorable moisture conditions. These seedlings are no less vulnerable to drought than are those of the grasses. Once

the woody plants are established, however, their roots possess phenomenal penetrating powers and can reach sources of water which are often unavailable to other plants.

The encroachment of shrubs upon grassland areas is illustrated in reviewing the vegetational changes along a 1500 foot belt transect established on the experimental range during the latter part of the fourth wet cycle. This transect extends over a short transition zone between typical black grama grassland and a mesquite sand-dune area. It has been charted twice since its establishment in 1935; the first recharting being done in 1950, the middle of the present drought period. The last charting was completed in 1956. As can be seen in Figure 5, mesquite has progressively encroached upon the grassland site during these twenty years, the past 10 of which have been a period of prolonged drought. Glendening (1952), reporting on this particular transect study, states that the action of wind on a sandy soil, and in the presence of an invading plant such as mesquite, results in dune formation. He goes on to say:

During the past 15 years the microclimate at the soil level in the black grama type has been altered enough to allow the removal of the sandy soil from that site at an accelerated rate...The presence of mesquite, with its layering habit of growth, furnishes a mechanism for the deposition and accumulation of wind-born sand particles in the form of dunes, andprompt elimination of mesquite in the black grama type, and maintenance of

Figure 5. VEGETATION CHANGES ALONG 1500 ft. BELT TRANSECT ON JORNADA EXPERIMENTAL RANGE, BY 500 ft. SECTORS.

maximum grass cover appears essential if further dune formation is to be prevented.

Unless shrub growth is curtailed either during or between droughts, it is reasonable to assume that shrubs will continue to encroach upon and eventually dominate the grasslands under the climatic conditions which prevail in the Southwest.

Grazing Pressure as a Factor in Shrub Encroachment

Early Spanish explorations, pushing northward from Mexico into the area now occupied by Texas, New Mexico, and Arizona, brought horses, cattle, and sheep into the Southwest as early as the year 1540 (Haskett 1935). As a result of these explorations numerous missions and ranches were established in the newly claimed territory. Livestock husbandry soon became an integral part of the life in these settlements, and this led to an expanding cattle population throughout the desert grassland. During the eighteenth century the increase in cattle numbers was very rapid. One ranch alone is estimated to have had 100,000 cattle, 10,000 horses and 5,000 mules (ibid). In 1822, following Mexico's independence from Spain, the military protection which had been furnished these missions and ranches was withdrawn, leaving hostile Indian tribes free to raid and pillage the settlements. Due to constant Indian depredations these establishments gradually were abandoned and their herds reverted to the wild state, roaming the grasslands at will. Records of early American expeditions into the Southwest are filled with accounts of the large herds of wild horses and cattle which were encountered. Cooke, in his Journal of the March of the Mormon Battalion, 1846-47, refers

to these animals when he writes:

Fourteen miles brought me to a very large spring, which, as usual, loses itself after running a hundred yards. . . the wild cattle are very numerous. Three were killed today on the road and several others by officers. Around this spring is a perfect cattle yard in appearance, and I suppose, I myself have seen fifty. . . . it is thought that as many as five thousand cattle water at this spring. They are much like the buffalo in their habits, etc. Are rather wilder and are more apt to attack individuals.

Many references to the abundance of wild grazing animals are to be found in the accounts of American explorations into the Southwest during the period 1840 to 1860. These animals were remnants of the vast herds which had been established by the earlier Spanish settlers; however, the consensus is that these animals did not survive to increase in sufficient numbers to seriously overgraze the area.

It was not until the late 1860's that commercial stock raising began to attain prominence as a major industry in the desert grassland. Up to this time constant raids by hostile Indians had made ranching in the Southwest quite hazardous. As more and more white settlers migrated into the area, U. S. Army Posts were established for their protection and cattle ranching flourished. Articles such as the following acted as incentives to commercial stock-raisers and drew them into the Southwest in large numbers. Brevoort (1868) says of New Mexico:

Grass abounds in every portion of this territory, and even in the forests grows luxuriantly the entire year. At great altitudes this grass is in the winter-time covered with snow, though not deadened to the ground, for as soon as the snow melts it affords excellent grazing upon the mesas (table lands), and through the valleys grows the justly celebrated grama grass, which cures as it stands affording abundant food for flocks and herds throughout the winter. From the mountains to the Texas border there is one continuous and magnificent range in any portion of which may be found water, shelter and grass.

In August, 1872 Brevoort made this entry in his Journal:

Today I have passed most of the time over plains of the black grama, one of the most nutritious of the perennial grasses of this region. It is now growing rapidly under the influence of late rains, and millions of cattle could be pastured here throughout the year.

Professor Maury, who travelled over the territory in 1858, says:

The sun never shone upon a finer grazing country than upon the three hundred miles west of the Rio Grande. The traveller has before him, throughout the entire distance, a sea of grass, whose nutritious qualities have no equal, and the stock-raiser in January sees his cattle in better condition than our eastern farmer his stall-fed ox.

With stockmen lured by such glowing inducements, it is no wonder that by 1890 the Southwest was so overpopulated with grazing animals that hundreds of thousands of cattle perished from starvation between 1891 and 1894 (Thornber 1910).

Ranges, severely depleted of grass cover, and subjected to extended periods of drought, were open for invasion by shrubby plants. Without the competition of dense grass stands for space and moisture and with little fuel to carry fire, shrubs rapidly encroached upon and obtained dominance over large areas in the desert grassland.

Bray (1906) recognized the effects of excessively grazing the desert grassland when he wrote:

Grazing interests have caused profound changes in the native vegetation; in density and vigor of prairie grass formations and in the species comprising them.

Ranges have been denuded which were formerly covered by a luxuriant grass formation.

In addition to depleting the grass cover, grazing animals are instrumental in dissemination of noxious plant seed. Experiments have shown that the viability of mesquite and other noxious plant seed is not adversely affected when the seed passes through the digestive tract of animals (Glendening and Paulsen, 1950). The shrub seeds which are eaten by grazing animals are transported to uninfested areas, and deposited in the feces which provide an ideal medium for germination.

Studies conducted on the Santa Rita Experimental Range in southern Arizona have shown that, once established, mesquite will increase in

density and extent under all systems of grazing management.

Brown (1950) noted a 30 percent increase in mesquite on a totally protected range over an eighteen-year period. On the other hand, the theory that grazing has been primarily responsible for shrub invasion is upheld by several other investigators (Allred, 1948, Upson, et al. 1937, Young, et al. 1948).

Correlating degree of utilization with rate of shrub invasion on the Jornada Experimental Range seems to indicate that grazing pressure may have been a factor in shrub encroachment in that area. By referring to Table 1, it is seen that the thirteen-year interval from 1915 to 1928 was one of more rapid shrub encroachment than the next eighteen-year period from 1928 to 1946. The grassland dominated area decreased by 17 percent during the earlier period and by only 14 percent during the later, longer interval.

The average stocking rate from 1915 to 1924, which was also a period of drought, was 2,724 head. In 1925, animal numbers were considerably reduced. During the next eighteen-year interval, which was one of above-average precipitation, the stocking rate averaged 1,170 head. Although shrub encroachment did not stop with this lighter use and above-average precipitation, the invasion was slower than it had been under the reverse conditions of heavy grazing and drought. Perhaps the change from drought to more favorable precipitation is responsible for the retarded invasion and the lighter degree of utilization was merely coincidental; however, the theory that grazing pressure is partially responsible for shrub encroachment is further supported by Brown's study referred to earlier in this paper. He noted a 30-percent shrub increase under total protection, and 55 percent under open grazing.

These investigations combined with historical records would seem to support the contention that grazing pressure has contributed to the encroachment of shrubby species upon semi-arid grassland ranges in the Southwest.

Fire as a Factor in Shrub Encroachment

Before the heavy influx of livestock into the Southwest, the luxuriant grasslands grew unhampered in dense stands over millions of acres. With no stock to harvest each season's growth, the grasses matured, dried and covered the ground with a thick carpet of dry litter year after year. Shrub seedlings which did become established in these areas were subjected to fierce competition for space and moisture by these dense stands of grass, and consequently made slow progress in their growth. The annual accumulation of litter, added to those of previous years, furnished hundreds of pounds of tinder-dry fuel per acre, and conditions were ideal, every three or four years, for fires to become started. These fires would often consume thousands of acres of grassland. For the most part, the periodic recurrence of wild fires was commonplace throughout the Southwest before the region was settled and developed by the white man. Kendall (1844), in his "Narrative of the Texas Sante Fe Expedition" repeatedly comments on the frequent prairie fires he observed.

Abert (1848), who travelled with a government expedition through the western states more than 100 years ago, draws attention to the burned-over grasslands he encountered.

The greatest inconvenience that we have suffered for

this march has been caused by the negligence of others with regard to their campfires; which negligence having caused the destruction of the pasture grounds, our mules would wander off and we frequently lost much of the day in catching them.

Gray (1856), commenting on the grassland prairies of West Texas where he was exploring possible rail routes for the Southern Pacific Railroad, has this to say regarding fire:

I question if the grass set on fire annually by the Indians, on their return from marauding expeditions into Mexico, together with the "Northers" which sweep with such violence over this plain, are not to a great degree causes of the total absence of timber. In burning the grass behind them, the object of the Indians is to accelerate the spring growth, and prevent immediate pursuers having forage for their animals. A War-Party, had a few days previously, passed along, and for many miles the fire was raging around us. As far as the eye could witness, all was ablaze, and at night appeared like a vast amphitheatre of illuminated cities.

The effect exerted by these periodic fires in stopping shrubby vegetation from attaining dominance on the grasslands is noted in historical reports. Pancoast (1930), discussing his adventures on the American frontier, makes the following statement regarding the Indian practice of firing the prairie in order to trap wild game:

This habit of the Indian has, to my mind, much to do with

the existence of the vast plains and prairies, which would never have remained devoid of woodland but for the annual fires that visited them.

Froebel (1859), reporting on seven-years travel through the Southwest, comments on fire in relation to encroaching shrubs. In describing the route he had travelled westward from the Pecos River in west Texas, he writes:

One peculiarity is the repeated occurrence of dead mesquite trees of considerable size, with the growth of young ones - there being no intermediate stage of size or age. This probably has been caused by repeated prairie fires, which destroyed the old trees and prevented the growth of fresh ones. If this is the case, it must stand in connexion with a periodical peopling of the country. At Chihuahua a man who had been a great deal in this locality told me that for a long period no Indians had lived there, during which it was covered by a thick mesquite wood. Subsequently certain hordes came here, and with them, the prairie fires began. In later times the advance of the whites into Texas has driven back the savages, and restrained their visits; and the prairie fires ceasing, trees and shrubs have again appeared.

Fire, which was started either by accident, by carelessness, or intentionally by Indians, acted as a prime factor in restricting shrub invasion on the desert grassland. Many scientific investigators have

at one time or another, in their writings, recognized the dominance of fire as a shrub inhibitor. Bray (1904) noted the effect of fire on the establishment of shrubby species in grassland areas, for he wrote:

Frequent fires, though without marked effect on old long-leaved trees, are fatal to the growth of seedlings. In consequence a condition is developed very like that which existed on the Texas prairies when the fires were free to sweep over them annually. These plains were kept pure grasslands; there was no evidence of the thickets of chaparral which now cover them.

Johnson (1931), discussed the desert grassland as a natural region of Texas noting:

The original extent of grasslands in the grazing sections of Texas was greater than at present. With the coming of ranching into various portions of the state, and the subsequent fencing of the range, fires which previously swept the plains and prairies annually were gradually reduced in extent and number. Consequently woody vegetation was no longer killed regularly by these fires and was free to develop in areas where it could compete with the grasses.

Because of their growth habits the grasses suffered very little from these fires. They sent up new shoots from blackened root stalks as soon as growing conditions became favorable. However, the shrub seedlings which had become established in these grasslands did not fare as well.

Most of them were probably killed outright. Those that survived were weakened considerably, and were in poor condition to withstand the competition afforded by the more fire-resistant grasses.

Contemporary investigations into the effects of burning shrub-infested grassland have yielded valuable information on the subject of noxious plant mortality. Humphrey (1949, 1951) noted significant decreases in semi-desert woody plants with corresponding increases in perennial grasses on burned test areas. Bohning (1955), in reporting the results of a similar study observed:

Two growing seasons later the burn was checked to determine the effects of the fire on the undesirable species. The time lapse was used to allow plants that appear to be dead to sprout. A count showed 88 percent of the barrel cactus, 44 percent of the jumping cholla and 42 percent of the cane cholla were killed. . . . No mesquite trees larger than 6 inches in diameter were killed. . . some trees 6 inches or less in stem diameter were killed by the fire. All trees under 2 inches in diameter were damaged by the fire.

No reference to fires in the Jornada area has been found in the extensive review of historical literature connected with this particular study. This might lead to the conclusion that fire, or the lack of fire, has not been a factor in the encroachment of shrubby species upon grasslands in this area. On the other hand, it has been established that the periodic recurrence of wild fire was commonplace throughout the desert grasslands of the Southwest before white settlement.

The Jornada area was an extensive grassland plain relatively free of the shrubby invaders that dominate vast areas there today. This is substantiated by Beale (1858) who travelled the Jornada approximately 100 years ago and reported:

Here we leave the water and take the much dreaded "Jornada del Muerto" . . . Nothing could exceed the beauty of the country we traveled over this morning. The whole extent, as far as vision reached ahead, was a level plain covered thickly with the most luxurious grass. . . . Hundreds and hundreds of thousands of acres, containing the greatest abundance of the finest grass in the world and the richest soil are here lying vacant. . . The road is excellent and the grass very abundant, wanting only trees and water to make the country perfect. . . . Thus we have passed the terrible "journey of death" . . . the grass, as I have before remarked, everywhere excellent and abundant.

Although no early travellers on the Jornada reported evidence of fire, the fact that fires were prevalent throughout the desert grassland and the area in question was being somehow maintained as desert grassland dominant, might well lead one to conclude that periodic fires, although not reported, did sweep the area and were a factor in restricting or preventing the spread of shrubs.

Man as a Factor in Shrub Encroachment

It is estimated that half of the desert grassland now occupied by noxious plants has been invaded since 1850, a date which marks the advent of white settlers into the Southwest. As White population increased rapidly in the area particularly from 1870 on, his customs, policies, and propensity to exploit for profit triggered a combination of factors that led to an accelerated decrease in grassland coverage and to encroachment of shrubby, noxious plants. Lack of sound land management policies by the Government facilitated abuse and misuse of the public domain. Excessive numbers of livestock utilized the "free grass" in the Southwest. The Indian was subdued and placed on reservations, hence his practice of "firing" the plains was curtailed.

Homesteads were filed on the grasslands, and thousands of acres unsuited to cultivation were hopefully plowed up and planted to crops. These ill-fated farms were fenced, which resulted in halting the free movement of grazing animals through many areas. Subsequently the majority of these sub-marginal farms were abandoned and the plowed land they occupied was virtually destroyed for grazing purposes. In some instances several adjoining homesteads in an area were sold to large cattle corporations, and tremendous herds were concentrated on the lands until the ground was completely barren of vegetation.

By the time government policy makers became aware of this depletion of our grassland resources, the damage was already done. Foster (1917), writing about the timbered areas in Texas shortly after the beginning of this century, presented arguments that attribute the spread of these timbered areas directly to the interferences

of man. Bogusch (1952) reported his investigation of brush invasion in southwest Texas, and noted that land management policies of white men were apparently a strong factor in this shrub encroachment.

Eight years prior to Beale's observations of 1858, Marcy travelled the Jornada del Muerto on a government exploratory mission, and although reporting the grass to be abundant, made no mention of shrubs covering the area to any appreciable extent.

As the encroachment has taken place concurrently with white settlement of the area, it seems reasonable to conclude that the influence of man has contributed to shrub invasion on the Jornada.

The Desert Grassland as Climax

There is diversity of opinion regarding the seral status of the desert grassland. Clements (1920), Whitfield and Beutner (1938), and others consider this grassland area to represent a true climax. Others, while willing to accord it status as a fire climax, regard woody plants as the true climatic climax.

Campbell (1929) presented arguments that he felt indicated desert grassland to be the true climax vegetation in mesquite sand dunes of southern New Mexico. He proposed that black grama, if given the benefit of more favorable growing conditions, would eventually replace honey mesquite as the dominant vegetation in these areas. Gardner (1951), who also classed southern New Mexico as desert plains grassland climax, observed that much of the area was dominated by desert-shrub type, but concluded this was a disclimax due to grazing.

Brown (1950), noted vegetational changes from grassland to shrub type in southern Arizona, and concluded that the desert grassland in

southern Arizona was subclimax to a desert shrub climax. Humphrey (1953) regarded the desert grassland region as a fire subclimax to a desert shrub climax. In support of his argument he called attention to the earlier works of Griffiths (1910), Thornber (1910), Gleason (1913), Wooten (1915) and others in the Southwest's desert grassland, citing also the work of Phillips (1935) in South Africa. He concluded from his study of historical and vegetational data:

The desert grassland of southwestern United States and northern Mexico is not a true Climax. Rather, it is a subclimax maintained by fire. Today, with fires largely a thing of the past, the true climax of low trees, brush and cacti, with an understory of grasses and low-growing shrubs is developing extensively on areas that were once grassed.

The scope and nature of this paper are too limited to allow one to draw from it any definite conclusions about true climax vegetation in the area studied. However, the historical records describing the area as extensive grassland plains, relatively free of shrubs 100 years ago, and the extent of present-day shrub encroachment, appear to indicate a vegetation of shrubs as the climatic climax.

BIBLIOGRAPHY

- Abert, S. W. 1848. Report of the Secretary of War. Senate Ex. Doc. 23.
- Aldrich, L. D. 1950. A Journal of the overland route to California and Gold mines. Dawsons Book Shop. Los Angeles, California.
- Allred, B. W. 1948. Distribution and control of several woody plants in the western gulf region. USDA. Soil Cons. Serv. (mimo). Fort Worth, Texas.
- Ares, Fred N. 1952. Climatic variations in southern New Mexico. USDA. Forest Serv. (mimo). Ranch Day Program, Jornada Experimental Range. Las Cruces, New Mexico. pp. 3-7.
- Avents, Ernest. 1936. Pluvial and post-pluvial fluctuations of climate in the southwest. Carnegie Inst. Yearbook No. 35.
- Audubon, J. W. 1906. Audubon's western journal. The Arthur H. Clark Co.
- Avents, Ernest. 1952. Arroyo cutting and filling. Jour. Geol. 60:375-385.
- Bailey, Vernon. 1913. Life zones and crop zones of New Mexico. USDA. Bur. Biological Sci. North American Fauna No. 35.
- Bartlett, John R. 1854. Personal narrative of explorations and incidents in Texas, New Mexico, California, Sonora, and Chichuhua. D. Appleton & Co. New York. Vol. 1.
- Beale, Edward F. Lt. 1854. Wagon road from Fort Defiance to the Colorado River. House Ex. Doc. No. 124.
- Bell, H. M. and E. J. Dyksterhuis. 1943. Fighting the mesquite and cedar invasion on Texas ranges. Soil Conservation. 9(5):111-114.
- Benson, Lyman. and R. A. Darrow. 1944. A manual of southwestern desert trees and shrubs. Univ. Ariz. Biological Sci. Bull. 6.
- Bentley, H. L. 1898. Cattle ranges of the southwest. USDA. Farmers Bull. 73.
- _____. 1898. Grasses and forage plants of central Texas. USDA. Div. Agrostology Bull. 10.
- Bogusch, E. R. 1952. Brush invasion on the Rio Grande plain in Texas. Texas Journal of Science. No. 1. pp. 85-90.
- _____. 1950. A bibliography On mesquite. Tex. Jour. Sci. Vol. 11. No. 4

- Bohning, John W. 1955. The effects of prescribed burning on a grass shrub range on burroweed, cholla, pricklypear, mesquite and other shrubs. USDA. Agri. Res. Serv. (mimeo). Ranch Day Program, Jornada Experimental Range. Las Cruces, New Mexico. pp. 11-13.
- Bolton, H. E. 1930. Anza's California expedition. Univ. Calif. Press. Berkeley, California.
- Bray, William L. 1901. The ecological relations of the vegetation of western Texas. Bot. Gaz. 32:99-291.
- _____. 1904. The timber of the Edwards Plateau of Texas; its relation to climate, water supply and soil. USDA. Bur. Forestry. Bull. 49.
- _____. 1904. Forest resources of Texas. USDA. Forest Serv. Bull. No. 47.
- _____. 1906. Distribution and adaption of the woody vegetation of Texas. Univ. Texas. Bull. 82. Sci. series 10.
- Brevoort, Elias. 1874. New Mexico, her natural resources and attractions, being a collection of facts mainly concerning her geography, climate, population, schools, mines, minerals, agriculture, pastoral capacities, prospective railroads, public lands, and Spanish and Mexican land grants. Santa Fe.
- Brown, Albert. 1950. Shrub invasion of southern Arizona desert grassland. Jour. Range Mgmt. 3:172-177.
- Bryan, Kirk. 1925. Date of channel trenching (arroyo cutting) in the arid southwest. Science News. 62:338-344.
- _____. 1928. Change in plant associations by change in ground water level. Ecology 9:474-478.
- _____. 1940. Erosion in the valleys of the southwest. New Mexico Quarterly. 10:227-232.
- Campbell, R. S. 1929. Vegetative succession in the Prosopis sand dunes of southern New Mexico. Ecology 10(1):392-398.
- _____. 1931. Plant succession and grazing capacity on clay soils in southern New Mexico. Jour. Agri. Res. 43(12):1027-1051.
- _____. and E. H. Bomberger. 1934. The occurrence of Gutierrezia sarothrae on Bouteloua eriopodia ranges in southern New Mexico. Ecology 15(1):49-61.
- Catlin, George. 1926. North American Indians; their manners, customs and conditions. John Grant. Endinberg. Vol. 11.

- Clarke, A. B. 1852. Travels in Mexico and California. Boston. Wright and Hasty's steam press.
- Clements, Frederic E. 1920. Plant indicators, the relation of plant communities to process and practice. Carnegie Inst. New York.
- Cook, O. F. 1908. Changes of vegetation on the south Texas prairies. USDA. Bur. Plant Industry. Cir. No. 14.
- Cooke, P. St George. Lt. 1846. "Journal of the march of the Mormon battalion, 1846-1847". Exploring Southwestern Trails 1846-1854. Ralph P. Bieber and A. B. Bender (editors). The Arthur H. Clark Co. Glendale, California.
- Costello, D. F. and G. T. Turner. 1941. Vegetation changes following exclusion of livestock from grazed ranges. Jour. Forestry 39(3): 310-315.
- Darton, W. A. 1922. Geologic structure of parts of New Mexico. U.S. Dept. of Interior. Geol. Survey Bull. 726-E.
- Dayton, William A. 1931. Important western browse plants. USDA. Misc. Bull. No. 101.
- Duce, J. T. 1918. The effect of cattle on the erosion of canyon bottoms. Science News. 67. NO. 1219:450-452.
- Ellison, W. D. 1950. Soil erosion by rainstorms. Science. 111:245-249.
- Emory, W. H. Lt. Notes of military reconnaissance from Fort Leavenworth in Missouri, to San Diego in California, including parts of the Arkansas, Del Norte, And Gila Rivers. 1848. H. Long and Brother. New York.
- Ferguson, David. Maj. 1863. Letter of the Secretary of War communicating copy of Maj. Ferguson, on country, its resources and the route between Tucson and Lobos Bay. Senate Ex. Doc. 1. 37th Congress special session.
- Fisher, C. E. 1947. Present information on the mesquite problem. 1056 progress report, Tex. Agri. Exp. Sta. A&M College of Texas.
- _____. 1950. The mesquite problem in the southwest. Jour. Range Mgmt. 3(1):60-70.
- Foreman, Grant. 1939. Marcy and the gold seekers. Univ. Okla. press. Norman, Oklahoma.
- Foster, J. H. 1917. The spread of timbered areas in central Texas. Jour. Forestry. 15:442-445.

- Frobel, Julius. 1858. Seven years travel in Central America, Northern Mexico, and the far west of the United States. Richard Bentley. London.
- Gardner, J. L. 1950. Effects of thirty years of protection from grazing in desert grassland. Ecology 31(1):44-50.
- _____. 1951. Vegetation of the creosote bush area of the Rio Grande Valley in New Mexico. Ecolo. Mono. 21:379-403.
- Glendening, G. E. 1952. Some quantitative data on the increase of mesquite and cactus on a desert grassland range in southern Arizona. Ecology 33:319-328.
- _____. 1952. Climate in relation to shrub invasion and control. USDA. Forest Serv. (mimo). Ranch Day Program, Jornada Experimental Range. Las Cruces, New Mexico.
- _____. and H. A. Paulsen. 1950. Recovery and viability of mesquite seeds fed to sheep receiving 2,4-D in drinking water. Bot. Gaz. 111(4):486-491.
- Gray, A. B. 1856. Survey of a route for the Southern Pacific R.R. on the 32nd parallel for the Texas Western R.R. Company. Cincinnati, Ohio. Wrightson and Co. Railroad Record.
- Griffiths, David. 1901. Range improvements in Arizona. USDA. Bur. Plant Industry. Bull. 4.
- _____. 1904. Range investigations in Arizona. USDA. Bur. Plant Industry. Bull. 67.
- Haskell, Horace S. 1945. Successional trends on a conservatively grazed desert grassland range. Jour. Agron. 37(2):978-990.
- Haskett, Bert. 1935. Early history of the cattle industry in Arizona. Ariz. Hist. Rev. 6(4):1-42.
- Humphrey, R. R. 1949. Fire as a means of controlling velvet mesquite, burroweed, and cholla on southern Arizona ranges. Jour. Range Mgmt. 2(4):175-182.
- _____. 1951. Effect of fire on a mixed grass-shrub range in southern Arizona. Jour. Range Mgmt. 4(4):264-266.
- _____. 1953. The desert grassland, past and present. Jour. Range Mgmt. 6:159-164.
- Huntington, Ellsworth. 1914. The climatic factor. Carnegie Inst. Pub. Washington, D. C.

- Johnson, E. H. 1931. The natural regions of Texas. Univ. Texas Bull. No. 3113.
- Kearney, T. H. and R. H. Peebles. 1951. Arizona Flora. Univ. Calif. Press. Berkeley and Los Angeles, California.
- Kendall, George W. 1844. Narrative of the Texas Santa Fe Expedition. Vol. 1. Harper and Brothers, New York.
- Marcy, R. B. Col. 1850. Report of exploration and survey of route from Fort Smith, Arkansas to Santa Fe, New Mexico made in 1849. House Ex. Doc. 45. 31st Congress, 1st session.
- _____. 1866. Thirty years of army life on the border. Harper and Brothers. New York.
- Maury, Professor. 1858. in Brevoort, pp. 160-161.
- McGinnies, W. G. 1940. As it once was. Land Policy Rev. 3(6):26-29.
- Mehrhoff, L. A. 1955. Vegetation changes on a southern Arizona grass-land range - An analysis of causes. Master of Science thesis. Univ. Ariz. Tucson, Arizona.
- Merriam, C. H. 1905. Biological survey of Texas. North American Fauna. No. 25.
- Muencher, Walter C. 1951. Poisonous plants of the United States. The Macmillian Co. New York.
- Norris, J. J. 1951. A summary of mesquite control trials on the College Ranch. USDA. Forest Serv. (mimeo). Ranch Day Program, Jornada Experimental Range. Las Cruces, New Mexico.
- Pancoast, Charles E. 1930. A Quaker forty-niner. The adventures of Charles E. Pancoast on the American frontier. Anna Paschall Hamum (editor).
- Parker, Kenneth W. and S. Clark Martin. 1952. The mesquite problem on southern Arizona ranges. USDA. Cir. No. 908.
- Paulsen, H. A. 1950. Mortality of velvet mesquite seedlings. Jour. Range Mgmt. 3(4):281-286.
- _____. 1955. Changes in grazing capacity on the Jornada Experimental Range. USDA. Agri. Res. Serv. (mimeo). Ranch Day Program, Jornada Experimental Range. Las Cruces, New Mexico.
- Rich, J. L. 1911. Recent stream trenching in the semi-arid region of southwestern New Mexico, a result of removal of vegetative cover. Am. Jour. Sci. 4th series. 32:237-245.

- Streets, R. B. and E. B. Stanley. 1938. Control of mesquite and noxious plants on southern Arizona grassland ranges. Univ. Ariz. Agri. Ex. Sta. Tech. Bull. 74.
- Shreve, Forest. and A. L. Hinckley. 1937. Thirty years change in desert vegetation. Ecol. 18:463-478.
- Thompson, J. W. 1942. A history of livestock raising in the United States. 1607-1860. USDA. Agri. History series No. 5.
- Thornber, J. J. 1910. The grazing ranges of Arizona. Univ. Ariz. Agri. Ex. Sta. Bull. 65.
- Upton, Arthur, W. J. Cribbs, and E. B. Stanley. 1937. Occurrence of shrubs on range areas in southeastern Arizona. Univ. Ariz. Agri. Ex. Sta. (mimeo).
- USDA. Forest Service. 1937. Range plant handbook. U.S. Govt. printing office. Washington, D. C.
- USDA. Forest Service. 1951. The Jornada Experimental Range. Southwestern Forest and Range Exp. Sta. (mimeo). Tucson, Arizona.
- Valentine, K. A. 1955. A summary of mesquite control experiments on the College Ranch. USDA. Agri. Res. Serv. (mimeo). Ranch Day Program, Jornada Experimental Range. Las Cruces, New Mexico.
- Weaver, J. E. and F. E. Clements. 1938. Plant Ecology. McGraw-Hill Book Co. New York, and London.
- Whitfield, C. S. and E. L. Beutner. 1938. Natural vegetation in the desert plains grassland. Ecology 19(1);26-37.
- Wislizenus, A. 1847. Memoir of a tour to northern Mexico in 1846 and 1847. 30th Congress, 1st ses. Misc. 26
- Wilson, H. K. 1944. Control of noxious plants. Bot. Review. 10-5-42.
- Wooten, E. O. 1908. The range problem in New Mexico. New Mex. College of A. and M.A. Exp. Sta. Bull. 66
- Young, V. A., F. R. Anderwald and W. G. McCully. 1948. Bruch problems on Texas Ranges. Tex. Agri. Exp. Sta. Misc. Pub. 21.
- 32nd Congress, 2nd Session. 1856. Reports of explorations and surveys to ascertain the most practicable and economical route for a railroad from the Mississippi River to the Pacific Ocean. House Ex. Dec. 91. Vol. III.
- 74th Congress, 2nd Session. 1936. The Western Range. Senate Doc. 199.