VEGETATION CHANGES ON A SOUTHERN ARIZONA GRASSLAND RANGE - AN ANALYSIS OF CAUSES

by

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1955

Approved: R. R. 
Director of Thesis 5/5/55
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SIGNED:

[Signature]

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The author wishes to express his sincere appreciation to Doctor Robert R. Humphrey for his guidance throughout this study and for his helpful suggestions in the preparation of this paper. Appreciation is also extended to Mr. David G. Wilson for his assistance and comments on the presentation of included data. Sincere thanks are extended to Doctor Hudson G. Reynolds and staff of the Santa Rita Research Center of the Rocky Mountain Forest and Range Experiment station at Tucson for their helpful comments on the preparation of collected data and for the provision of the study area.
The Problem.

As a result of the advent of the white man into Southwestern United States and the consequent introduction of his numerous herds of cattle and flocks of sheep, most of the desert grassland ranges now produce much less palatable forage than they once produced. Even most of those ranges which, by present day standards, are furnishing abundant feed at one time furnished many times the amounts now available. A comparison of past vegetal composition with that of the present shows one startling fact: the almost complete dominance today of noxious shrubs over many millions of acres of range land that were formerly grass.

The rate and extent of invasion by shrubs has been discussed from almost every possible angle; however, there have been few instances where the actual rate has been measured. This invasion was pointed out more than 55 years ago by Bentley (1898) and Smith (1899). Since that time, many writers have commented on this spread, and the large volume of literature on the subject has resulted in research on various phases of the shrub invasion problem. Two of the more important publications dealing with the rate of spread in southern Arizona are those
by Brown (1950) and Glendening (1952).

Mesquite (*Prosopis juliflora* (Swartz) DC.) is now firmly estab-
lished on 70 million acres in Texas, New Mexico, and Arizona (Parker and Martin 1952). An earlier estimate of cacti of the genus *Opuntia* places these plants at 60 million acres in Texas alone (Dameron 1937). Since then, the cactus-infested area has continued to increase in the Southwest. The acreage of burroweed (*Aplopappus tenuisectus* (Greene) Blake), in Arizona has been placed at 5,500,000 (Upson, et. al., 1937).

As shrub invasion has taken place concurrently with grazing of the ranges by cattle, it would seem logical to conclude that cattle have been the chief factor directly responsible for the invasion. However, this assumption has met with stubborn resistance in recent years and it is currently accepted as only one of the factors in-
volved.

In this study an attempt is made to evaluate and examine the more important causes of this change in plant cover. The factors evaluated include: grazing by domestic livestock and other animals, climatic changes, competition and selection, and fire.

**History of Study Area.**

The Santa Rita Experimental Range, where this study was made, contains approximately 53,000 acres typical of the semidesert mixed grass and shrub ranges. It lies along the western base of the Santa Rita Mountains about 35 miles south of Tucson. The area slopes
gently toward the northwest and varies in elevation from 2,900 feet adjacent to the Santa Cruz River Valley to 4,500 feet near the mountains.

The plant cover on the Experimental Range consists of three major subtypes. "The semidesert type, varying in elevation from 2,900 to 3,500 feet, is essentially a shrub type. The mesa type, varying in elevation from 3,500 to 4,000 feet, is largely mesquite and some perennial grasses. The foothill type, above 4,000 feet, is a mixed grama type but has areas of mesquite and oak." (U.S.D.A. Forest Service Mimeo., 1952.)

Precipitation varies from about 11 inches at the lower elevations to 18 at the upper, with an average of about 14 inches over the entire range. The overall climate is mild and dry.

At the time of establishment of the Experimental Range in 1903, the forage was heavily over-utilized as a result of unregulated, year-long grazing. It was felt that proper grazing management would permit the vegetation to return to its previous pre-grazing status.

Description of Principal Invaders.

**Burroweed.** Burroweed, a member of the Composite family, is a low-growing shrub or half-shrub, densely branched from the base. Mature plants on the open range are usually about 15 inches in height. Burroweed is a prolific seeder but few seedlings may
survive from one year to the next. Greatest seedling mortality occurs during late spring when there is keen competition for moisture. During this time burroweed seedlings and grasses occupy approximately the same root zones (Humphrey 1937).

Mesquite. Mesquite, a member of the Legume family, is a deep-rooted, low-growing tree or shrub. Growth form varies from a many-stemmed shrub, less than 5 feet tall, to large trees 10 to 20 feet in height with a single trunk. The plants have an extensive root system that enables them to withstand adverse climatic conditions, and that increases their ability to compete with perennial grasses. The tap root may extend from 20 to 60 feet in depth, while the lateral roots extend from 40 to 50 feet from the base of the tree. The extensive root system in addition to a marked tendency to stump-sprout make mesquite difficult to eradicate.

Cholla. Cane cholla (Opuntia spinosior (Engelm. & Bigel.) Toumey) is an arborescent or shrubby member of the cactus family, usually growing 3 to 8 feet high. Cane cholla is common through a wide variety of habitats from low desert to oak woodland. The plants are typically gray, but may be purplish-green in color.

Jumping cholla (Opuntia fulgida Engelm.) is a tree-like plant commonly 3 to 12 feet high. The plants are typically straw colored because of sheaths that are retained by the spines. They occur typically in the sandy soil of mesas, valleys and plains from 1,000 to 4,500 feet, often forming dense thickets.
Creosote-bush. Creosote-bush (*Larrea tridentata* (DC.) Coville) is a branching shrub, of the Caltrop family. The plants are usually 3 to 6 feet high with the main stems branching at or below the ground surface. It is the most common and widely distributed shrub in the Sonoran desert. The crushed leaves give off an odor thought to resemble that of creosote. Creosote-bush originally occurred in the driest and hottest portions of the desert but has invaded the lower portions of the desert grasslands in many areas of New Mexico and Arizona (Gardner 1951).

The species is worthless as forage at all seasons and to all classes of livestock. As very little palatable vegetation is associated with creosote-bush in south-central and southwestern Arizona the carrying capacity of those areas is low. The plant is not a good soil builder nor does it facilitate the growth of desirable species. It frequently grows in essentially pure, open stands to the exclusion of other vegetation.
STUDY METHODS

A quadrat frame containing 4 square meters and having an inset frame one-tenth the total area, was dropped at 100-pace intervals along each east-west section line of the Santa Rita Experimental Range. At each drop, the burroweed and cholla plants in the large frame were counted and recorded. The surrounding vegetation was noted at each drop and the dominant species recorded in estimated order of importance. At least three dominant species were recorded at each stop. These were listed as the number 1, 2, and 3 dominants. For analysis purposes these data were compared with similar unpublished data obtained by Humphrey and Glendening (1934) and Clark (1950).

Inasmuch as the inset frame was one-tenth the area of the large frame the number of perennials in the small frame multiplied by ten approximates the number that would have been found in the large frame had all perennials been counted. By totaling the plants found in all the frame drops it was possible to determine the total perennial plants counted on the range. The data obtained in 1934, 1950 and 1954 were similarly summarized. From these analyses the percentage of the whole occupied by each perennial species for each of the three years studied was calculated.

From the dominant listings recorded vegetative maps were prepared
showing the range of each important species during the first and last survey. In order to make these maps more usable an abundance scale was established to permit classification of the abundance of each species as heavy, moderate, or light. These ratings were based on the number of times the species in question was classed as dominant. If a species was listed in the number one or two column 3/4ths or more of the time in any one section of land, it was considered heavy for that section. If it was listed less than 3/4ths but more than 1/4th it would be recorded as moderate; anything less than 1/4th was classed as light.

The number of plants per acre of mesquite, cholla, burroweed, and creosote-bush was determined by actual counts on acre-size plots (table 1). These plots were chosen at random in areas where each of these species had been listed as heavy, moderate, and light. From 5 to 6 plots were located in each abundance class for each of the 4 species involved.

Climatic data were obtained from the University of Arizona station of the United States Weather Bureau. Tree-ring data that permitted extension of this analysis back past recorded Weather Bureau records were furnished by the University of Arizona Laboratory of Tree-ring Research.

As much of the study was historic in nature this necessitated an extensive review of literature.
<table>
<thead>
<tr>
<th>Species</th>
<th>Heavy stand</th>
<th>Moderate stand</th>
<th>Light stand</th>
</tr>
</thead>
<tbody>
<tr>
<td>Burroweed</td>
<td>over 1500</td>
<td>500 to 1500</td>
<td>0 to 500</td>
</tr>
<tr>
<td>Cholla</td>
<td>over 350</td>
<td>100 to 350</td>
<td>0 to 100</td>
</tr>
<tr>
<td>Creosote-bush</td>
<td>over 300</td>
<td>80 to 300</td>
<td>0 to 80</td>
</tr>
<tr>
<td>Mesquite</td>
<td>over 80</td>
<td>40 to 80</td>
<td>0 to 40</td>
</tr>
</tbody>
</table>
RESULTS

Grasslands.

The first detailed description of the vegetation of the Santa Rita Experimental Range was made by Griffiths (1904). From his account a map has been prepared showing the general locations of the species that were dominant at that time (fig. 1). It will be noted that more than 3/4ths of the range was then classed as grass or had a grass understory. Today the grasslands are largely restricted to the foothill regions and occupy less than 1/5th the total area (fig. 2). As the grasses have receded they have been replaced in large part by shrubs.

Burroweed.

Fencing of the Santa Rita Experimental Range in 1903 enclosed some thick stands of burroweed. At that time, the heavy stands were limited to the lower northwest portion of the range (fig. 1). Although the range was closed to grazing from 1903 until 1915, this weed continued to increase at a rapid rate. By 1910 burroweed occupied most of the lower elevations in the eastern and northern portions of the range (Griffiths, 1910). By 1934 the entire range was covered except for a few areas in the foothill regions (fig. 3). During the period from 1934 to 1954 on the other hand, there was no
FIGURE 1

VEGETATION DOMINANTS ON SANTA RITA EXPERIMENTAL RANGE IN 1904*

* Constructed from D. Griffiths, Range Investigations in Arizona

SANTA RITA EXPERIMENTAL RANGE

BURROWEED

CHOLLA

CREOSOTE BUSH

GRASSLAND

MESQUITE
FIGURE 2

VEGETATION DOMINANTS ON SANTA RITA EXPERIMENTAL RANGE IN 1954

BURROWEED, CHOLLA, CREOSOTE BUSH, MESQUITE

GRASSLAND
RELATIVE ABUNDANCE OF BURROWEEED ON
SANTA RITA EXPERIMENTAL RANGE IN 1934

FIGURE 2

SANTA RITA EXPERIMENTAL RANGE

R.14E. RI5E.

HEAVY INFESTATION (OVER 1500/ACRE)
MODERATE INFESTATION (500 to 1500/ACRE)
LIGHT INFESTATION (0 to 500/ACRE)
appreciable increase in total area occupied (fig. 4). This would seem to indicate that the plant had reached its maximum distribution prior to 1934. Forest Service research personnel feel that the distribution peak was probably reached in the late 1920's or early 1930's.

A comparison of the acreages covered by this species also shows the relatively small increase of the heavily infested area from 1934 to 1954 (fig. 5). In 1934 heavy stands covered some 26,500 acres, moderate stands 11,500 acres and light stands 15,000 acres. By 1954 heavy stands occupied some 27,800 acres, moderate stands 10,900 acres, and light stands 14,300 acres.

Cholla.

In 1904, cholla occurred on the Santa Rita Range only in restricted areas in the northeast and central portions of the range (fig. 1). The plant was not considered much of a problem or was even considered as desirable because it supplied feed for cattle during drought.

By 1934 the stands of all species of cholla had thickened and increased in area (fig. 6). The spread of these species from 1 or 2 thousand acres in 1904 to about 30,000 acres in 1934 would seem to indicate that growth conditions during this 30-year period must have been exceptionally favorable. In contrast with the behavior of burroweed, cholla continued to spread during the 20-year period from
RELATIVE ABUNDANCE OF BURROWED ON SANTA RITA EXPERIMENTAL RANGE IN 1954

Figure 4

SANTA RITA EXPERIMENTAL RANGE

HEAVY INFESTATION (OVER 1500/ACRE)
MODERATE INFESTATION (500 to 1500/ACRE)
LIGHT INFESTATION (0 to 500/ACRE)
FIGURE 5

AREA ON THE SANTA RITA EXPERIMENTAL RANGE SUPPORTING BURROWEED AND CHOLLA 1934 and 1954

<table>
<thead>
<tr>
<th>Year</th>
<th>Burroweed 1934</th>
<th>Burroweed 1954</th>
<th>Cholla 1934</th>
<th>Cholla 1954</th>
</tr>
</thead>
<tbody>
<tr>
<td>1934</td>
<td>12</td>
<td>26</td>
<td>20</td>
<td>12</td>
</tr>
<tr>
<td>1954</td>
<td>26</td>
<td>28</td>
<td>20</td>
<td>14</td>
</tr>
</tbody>
</table>

Legend:
- Heavy
- Moderate
- Light
RELATIVE ABUNDANCE OF CHOLLA ON SANTA RITA EXPERIMENTAL RANGE IN 1934

HEAVY INFESTATION (OVER 350/ACRE)
MODERATE INFESTATION (100 TO 350/ACRE)
LIGHT INFESTATION (0 TO 100/ACRE)
1934 to 1954 (fig. 7). In 1934 the cholla infestation was classed as heavy on some 10,000 acres, as moderate on 21,400 acres, and as light on 21,900 acres. By 1954 the heavy stands occupied 20,100 acres, moderate stands 19,500 acres, and light stands 13,400 acres (fig. 5). This represents a 100 percent increase during the last 20 years in heavy stands alone. However, much higher percentages of increase have been observed and recorded for selected sites on the Experimental Range (Glendening, 1952).

The 1954 survey indicated that even the upper foothills had some cholla sprinkled along the ridges. Although these plants did not appear as healthy as those in the lower regions it is important to note that they had invaded the last stronghold of the grasses.

Mesquite.

As early as 1904 the Santa Rita Experimental Range supported a population of mesquite. For the most part the trees were confined to the lower portions of the range (fig. 1). Throughout the area, however, the major drainages contained some trees and these became seed sources for rapid movement onto the intervening mesas.

By 1934, mesquite was firmly established on the Experimental Range (fig. 8). Infestation on some 14,200 acres was classed as heavy, on 17,000 acres as moderate, and on 21,700 acres as light (fig. 9). Since 1934 the plant has continued to spread and increase in density at a rapid rate; almost the entire range is now covered
FIGURE 7

RELATIVE ABUNDANCE OF CHOLLA ON
SANTA RITA EXPERIMENTAL RANGE IN 1954

SANTA RITA EXPERIMENTAL RANGE

HEAVY INFESTATION (OVER 350/ACRE)
MODERATE INFESTATION (100 TO 350/ACRE)
LIGHT INFESTATION (0 TO 100/ACRE)
FIGURE 8

RELATIVE ABUNDANCE OF MESQUITE ON SANTA RITA EXPERIMENTAL RANGE IN 1934

SANTA RITA EXPERIMENTAL RANGE

HEAVY INFESTATION (OVER 80/ACRE)

MODERATE INFESTATION (40 TO 80/ACRE)

LIGHT INFESTATION (0 TO 40/ACRE)
FIGURE 2

AREA ON THE SANTA RITA EXPERIMENTAL RANGE SUPPORTING MESQUITE AND CREOSOTE-BUSH
1934 and 1954

- Heavy
- Moderate
- Light

<table>
<thead>
<tr>
<th>Year</th>
<th>Mesquite</th>
<th>Creosote-Bush</th>
</tr>
</thead>
<tbody>
<tr>
<td>1934</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1954</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
in some degree by mesquite (fig. 10). Of the 53,000 acres included in the 1954 study, infestation was heavy over 19,000 acres, on 22,800 acres it was moderate, and on 11,200 light (fig. 9). The areas classed as lightly infested are essentially the foothill grassland ranges.

Creosote-bush.

The spread of creosote-bush on the Santa Rita Range has been small when compared with that of the other dominant shrubs. However, its tendency to grow in almost pure stands makes it important in those areas where it does occur. In 1904 this shrub was confined almost entirely to the northeast portions of the range (fig. 1). By 1934 its range had increased somewhat (fig. 11). At that time infestation on 1,700 acres was classed as heavy, on 2,600 acres as moderate, and on 7,600 acres as light (fig. 9). The greater portion of the range (41,100 acres) contained no creosote-bush. During the twenty-year period from 1934 to 1954 there was no appreciable change either in total area occupied or in stand density. Some 2,300 acres contained heavy growth, 2,700 acres were moderately covered, and 8,000 had light stands (fig. 12). The remaining 40,000 acres supported none of the species.

Changes in Plant Cover - 1934 to 1954.

A species analysis of the plants recorded in each of the 3 surveys shows that although the total number of perennials has been
RELATIVE ABUNDANCE OF MESQUITE ON SANTA RITA EXPERIMENTAL RANGE IN 1954

- HEAVY INFESTATION (OVER 80/ACRE)
- MODERATE INFESTATION (40 TO 80/ACRE)
- LIGHT INFESTATION (0 TO 40/ACRE)
FIGURE 11

RELATIVE ABUNDANCE OF CREOSOTE-BUSH ON SANTA RITA EXPERIMENTAL RANGE IN 1934

SANTA RITA EXPERIMENTAL RANGE

R.I4E.  R.I5E.

HEAVY INFESTATION (OVER 300/ACRE)
MODERATE INFESTATION (80 TO 300/ACRE)
LIGHT INFESTATION (0 TO 80/ACRE)
NONE
RELATIVE ABUNDANCE OF CREOSOTE-BUSH ON SANTA RITA EXPERIMENTAL RANGE IN 1954

FIGURE 12

- HEAVY INFESTATION (OVER 300/ACRE)
- MODERATE INFESTATION (80 TO 300/ACRE)
- LIGHT INFESTATION (0 TO 80/ACRE)
- NONE
materially reduced, there has been a sharp increase in number of shrubs. In the 1934 survey there was an average of 56.3 perennial plants of all species per quadrat drop; the 1954 survey showed an average of only 15.6 plants, a decrease of 360 percent (table 2). Plants classed as desirable for forage made up 70 percent of the vegetation sampled in 1934 but only 49 percent in 1954 (fig. 13), a decrease in these species of 70 percent. These changes are shown most emphatically by Rothrock grama (*Bouteloua rothrockii* Vasey) which comprised 30 percent of the perennials in 1934 but only .81 percent in 1954 (table 3). Marked differences of this sort, however, particularly when they reflect changes in grasses or forbs, may be due in part to climatic influences prior to each survey. Rothrock grama reacts rapidly to rainfall conditions and this is doubtless reflected in these widely differing figures. During the 4-year period preceding 1934 above-average rainfall conditions generally prevailed. The period prior to the 1954 survey, on the other hand, was one of the lowest rainfall periods on record.

Burroweed made up 7.8 percent of the perennial vegetation measured in 1934; in 1954 it constituted 16.5 percent (table 3). Inasmuch as these figures represent percentages of the total perennial vegetation present, they should not be construed as meaning a proportional increase in numbers of burroweed plants. A reduction of associated perennials results in an apparent relative increase in the amount of burroweed.
### TABLE 2

**RELATIVE ABUNDANCE OF PLANTS ON THE SANTA RITA EXPERIMENTAL RANGE FOR THREE STUDY PERIODS**

<table>
<thead>
<tr>
<th>Item</th>
<th>1934</th>
<th>1950</th>
<th>1954</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total number of drops</td>
<td>1,711</td>
<td>1,454</td>
<td>1,023</td>
</tr>
<tr>
<td>Total number of plants</td>
<td>96,460</td>
<td>21,295</td>
<td>16,015</td>
</tr>
<tr>
<td>Average number of plants/drop</td>
<td>56.3</td>
<td>14.6</td>
<td>15.6</td>
</tr>
<tr>
<td>Percent desirable species</td>
<td>69.65</td>
<td>53.07</td>
<td>48.49</td>
</tr>
<tr>
<td>Percent undesirable species</td>
<td>22.66</td>
<td>46.30</td>
<td>49.66</td>
</tr>
</tbody>
</table>
COMPARISON OF UNDESIRABLE AND DESIRABLE SPECIES ON THE SANTA RITA EXPERIMENTAL RANGE FOR EACH OF 3 STUDY PERIODS

Figure 12: Summary of the comparison of undesirable and desirable species on the Santa Rita Experimental Range for each of 3 study periods.
<table>
<thead>
<tr>
<th>Species</th>
<th>1934</th>
<th>1950</th>
<th>1954</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acacia constricta</td>
<td>0.00</td>
<td>0.09</td>
<td>0.18</td>
</tr>
<tr>
<td>Acacia greggii</td>
<td>0.03</td>
<td>0.61</td>
<td>0.56</td>
</tr>
<tr>
<td>Andropogon barbinodis</td>
<td>0.03</td>
<td>0.18</td>
<td>0.18</td>
</tr>
<tr>
<td>Aplopappus tenuisectus</td>
<td>7.85</td>
<td>12.37</td>
<td>16.53</td>
</tr>
<tr>
<td>Aristida glabrata</td>
<td>11.23</td>
<td>3.47</td>
<td>3.62</td>
</tr>
<tr>
<td>Aristida spp.</td>
<td>2.97</td>
<td>3.00</td>
<td>3.30</td>
</tr>
<tr>
<td>Atriplex canescens</td>
<td>0.02</td>
<td>0.09</td>
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DISCUSSION

Climate as a Factor Affecting Changes in Vegetation.

The earliest known weather records for the Southwest go back no further than 100 years, and the existence of a definite climatic trend cannot be clearly shown in so short a period. As a supplement to recorded climatic data, tree-ring analyses have proved to be a reliable indicator of past growing conditions. For the 60-year period, 1891-1950, unpublished data (Schulman, 1955) show a correlation coefficient of .7 between representative southern Arizona Douglas fir trees and Tucson rainfall (fig. 14). This high correlation, supplemented by additional study of tree-ring and rainfall records, indicates that tree-rings may be used as reliable indicators of annual rainfall in the Southwest over a period greatly antedating the relatively short period of recorded precipitation.

There is no evidence to indicate that climatic change has been a major factor in effecting the change from grass to brush. Analysis of tree-ring data from 1600 to 1870 (the first period when there was a large influx of white men into the Southwest) does not indicate any appreciable increase or decrease in precipitation. During the 350 years from 1600 to 1950 likewise, there seem to be no growth periods essentially different from those of today. There were periods of above- and below-normal growth, but apparently no consistent climatic
FIGURE 14

RELATION OF TREE GROWTH TO PRECIPITATION IN SOUTHERN ARIZONA

Tree-ring data (Schulman, 1942 and Unpublished data, 1955)

Precipitation (University of Arizona station U.S. Weather Bureau)
change. Although the last 75 years in particular show some extended periods of drought and above-average precipitation, these deviations from normal are not materially different from others that preceded. Yet, it has been during this 75-year period from 1880 to 1955 that most of the changes of vegetation described in this paper have taken place.

Neither wet nor dry periods have apparently affected the rate of invasion of noxious plants. Tree-ring records and precipitation data both show that during the period, 1885 to 1904, the rangelands of the Southwest were subjected to a minimum growth period (fig. 14). During this period, however, the shrubs continued to invade (Griffiths, 1904). The period from 1905 to 1921 received above normal rainfall for almost the entire 18-year span and, although desirable vegetation recovered somewhat, the downward trend of the grasses continued (Griffiths, 1910). From 1921 to 1930 drought again plagued the ranges, yet noxious shrubs and weeds continued to increase.

The period, 1825 to 1860, is of interest not only from the climatic viewpoint, but also from historical happenings. During most of this 35-year period above-average tree growth was recorded. The favorable moisture conditions indicated by this record must have given a tremendous boost to the grassland vegetation and this, in turn, may have been responsible in part for the many reports of the unlimited supplies of forage credited to the western ranges in the early years (Wislizenus, 1847 - Senate Ex. Doc. 64, 1850). As a
consequence of these reports ranchers and business men visualized an easy fortune from the area and descended upon it with thousands of cattle and sheep.

Grazing as a Factor Affecting Changes in Vegetation.

Initial introduction of livestock into the Southwest occurred during the period 1540 to 1542. During those years Francisco Vasquez de Coronado brought his military expedition into southwestern Arizona, Nex Mexico, northwestern Texas and Oklahoma in search of the seven cities of Cibola. He took with him some 1000 horses, 500 cows and 5000 sheep. Although some of these livestock either strayed away or were stolen, it is doubtful whether many of them survived (Wagoner, 1952). Not until 1598, when Juan de Oñate crossed from Mexico into what is now southwestern United States with large herds of livestock, was there any marked increase in the number of cattle, horses, or sheep. With the establishment of missions, other settlers began pushing up from Mexico with herds and flocks. Settlers, realizing that there would be frequent Indian attacks, formed villages and congregated at ranches for protection. In doing this, their livestock grazed the immediately surrounding areas so heavily that they were generally barren of palatable forage.

Father Eusebio Francisco Kino figured prominently in the establishment of many ranches in the Southwest during the period 1687 to 1700. As a result, he has often been referred to as the cattle king
of his time.

Prior to 1870, the number of cattle in the Southwest was relatively small. After 1870, as the West opened up and the Indians were gradually pushed into more obscure regions, the number of cattle began to increase. Comparative safety from Indian attack had much to do with this, since the cattle could now be allowed to graze in an almost unlimited area. This increase culminated in 1891, when a drought, coupled with lack of vegetation, caused a "starve-out" on the ranges. An estimated 250,000 cattle out of 800,000 perished on Arizona ranges during the three-year period from 1891 to 1894 (Thornber, 1910).

Humphrey (unpublished manuscript, 1955) and others have pointed out that when ranges are overstocked, livestock, through their selection of the more palatable plants, influence the vegetation on a given area. As grazing removes the more palatable species from an area, the less desirable have more moisture and space available. Clements (1923) has stated that under climax grassland conditions, grasses are able to maintain their dominance in competition with forbs, but that in case of overgrazing or other disturbance, the forbs gradually get the upper hand. He goes on to say:

When the area is protected or grazing reduced the advantages of the grass life form again come into play in the competition and the herbs disappear or become sub-dominant. Half-shrubs, like other weeds, can best be eliminated by protecting the area or only allowing light grazing. Areas badly infested with these half-shrubs should be burned, for the quickest and most economical restoration to grassland ranges.
Griffiths (1910), commenting on shrub invasions on the Santa Rita Experimental Range, had this to say about the influence of grazing:

It will doubtless be impossible to depict all the agencies that are bringing about these changes. It is quite certain that the operations here of the Bureau of Plant Industry have had no influence, for the shrubbery has thickened up on the outside of the inclosure, where the grazing has been very heavy, apparently as much as on the inside. The probability is that neither protection nor heavy grazing has much to do with the increase of shrubs here, but that it is primarily the direct result of the prevention of fires.

In studies conducted on the Santa Rita Experimental Range by the U. S. Forest Service the rate of spread of mesquite was found to double regardless of grazing treatment (Glendening, 1952). Three different methods of treatment were employed: "(1) Cattle and rabbits excluded - grazing by small rodents, (2) Cattle excluded - grazing by rabbits and small rodents, (3) Yearlong grazing by cattle, rabbits, and small rodents." Results showed that during the 17-year period, 1932 to 1949, the numbers of mesquite more than doubled on all plots. Glendening says, "In fact, the increase was greater, both numerically and percentage wise, on the protected than on the unfenced plots."

It would seem from this study that the rate of spread of mesquite is not affected by grazing once the seed source is available. In the case of cholla, however, the study showed a direct relationship between grazing activity and plant numbers as shown by average increases of 18, 72, and 149 plants per acre on plots protected from cattle and rabbits, cattle only, and unfenced, respectively.
In concluding the study, Glendening states:

It is improbable that moderation in livestock grazing will prevent the loss of grass cover within mesquite stands where the trees have gained sufficient size and density to completely utilize or materially reduce the moisture supply, and where the population of seed planting rodents is high.

There is little doubt that mesquite invasion has been greatly increased by the ability of the seeds to retain their viability after passing through the digestive tract of cattle and horses (Smith, 1899. Griffiths, 1904. Fischer, 1947. Reynolds and Glendening, 1949.). This ability is of great importance in the rapid spread of mesquite since it insures a large supply of seed on almost every part of our cattle ranges.

In addition to mesquite, cattle also spread other southwestern plants. Jumping cholla is spread almost entirely by the action of grazing animals and rodents. The fruit of both cane cholla and jumping cholla is readily taken by cattle and in their eagerness to reach the fruit, the animals often brush against the terminal joints. As a result many of these joints remain hanging to the head, neck, and shoulder regions. The joints eventually fall off, or are rubbed off on bushes and trees and, if they fall in a suitable area, take root and form new plants. In most arborescent Opuntias (often all loosely called chollas) joints commonly fall to the ground as a natural process, and from these new plants arise.

Jumping cholla is not usually propagated by establishment of seedlings (Johnson, 1918). Examination of large numbers of the
fallen fruits showed no sign of germination. This was established in part from greenhouse studies, in part from range observations. Cane cholla, on the other hand, was found to be largely propagated by seed.

Soil Disturbances.

Excessive numbers of cattle damage the soil by compacting the surface and by grazing the protective plant cover. The soil, because of constant trampling during wet and dry weather, loses the loose, friable structure desirable for vigorous plant growth. The reduction of cover allows the full impact of raindrops to seal over the surface soil and flood it with an almost impervious paste. This colloidal mud enters and seals the pores and cracks in the soil (Ellison, 1950), effectively checking infiltration. In addition, numerous trails made by cattle facilitate the starting of rills which lead to the formation of gullies (Duce, 1918). Thus, the condition of the damaged range is worsened by the accelerated runoff and the drastic lowering of the ground water table which accompanies trenching and channeling of the valley floors (Anteves, 1952).

The resultant excessive runoff greatly reduces the amount of moisture that gets into the ground and results in a more droughty habitat (Humphrey, 1955).

Rodents as a Factor Affecting Changes in Vegetation.

Many rodents of the Southwest transport seed to unseeded areas. Principal among these is the Merriam Kangaroo rat (Dipodomys merriami

...
merriami Mearns). This small rodent buries large quantities of seeds in underground burrows and food caches (Reynolds and Glendening, 1949). The ability of most seed-storing animals to relocate their buried seeds is very low (Martin, et al., 1951). As a consequence, many seeds remain undisturbed and may eventually germinate. Many of the caches are located at some distance from the seed tree, a fact that facilitates the increase of mesquite onto adjacent areas.

Cholla joints also are carried by the woodrat (Neotoma albicula albicula Hartley) to their nests and dens, and are often dropped in sites where they take root and grow.

Fire as a Factor Affecting Changes in Vegetation.

Fires have long been recognized as instrumental in maintaining the former treeless conditions of our grasslands (Stewart, 1953). The effects of fires in the southern prairie states were commented on over 100 years ago when Gregg (1844) noted changes taking place in the grasslands of the great plains. He was also aware of the effect of these fires on the vegetation, for he wrote:

It is unquestionably the prairie conflagrations that keep down the woody growth upon most of the western uplands. The occasional skirts and fringes which have escaped their rage have been protected by the streams they border. Yet, may not the time come when these vast plains will be covered with timber? . . . Indeed there are parts of the southwest now thickly set with trees of good size that within the remembrance of the oldest inhabitants were as naked as the prairie plains and the appearance of the timber in many other sections indicates that it has grown up within less than a century. In fact, we are now witnessing the encroachment of the timber upon the prairies wherever the devastating conflagrations have ceased their ravages.
Other travelers commented on the fires which were encountered on their journeys. The following paragraph was taken from a report to the 32nd Congress, 2nd Session (1856):

After travelling about five miles, our progress was suddenly arrested by a burning prairie. The grass was tall, thick, and dry. The wind had driven the widespread flames over the crest of a hill, directly towards us; and they now came leaping into the air, roaring in the distance, and crackling fearfully as they approached. There seemed to be no safety except in flight. The train, therefore, counter-marched in double quick time, and took refuge behind a watery ravine, where the grass was too green to burn freely. Taking advantage of a comparatively bare spot, the flames were fought, and a temporary opening made, through which the train passed to the black-burned prairie, which we traversed in safety. Mile after mile we trod nothing but cinders.

Marcy (1866), a veteran of many years on the frontier, made this comment on a prairie fire:

For two days past we have seen an extensive fire on the prairie to the southwest, and suppose it was made by some of Pah-hah-eu-ka’s band, who our Delawares say, are ranging somewhere in this vicinity.

Cook (1908), a well known agrostologist, had this to say about the destructive force of the range fires:

Before the prairies were grazed by cattle the luxuriant growths of grass could accumulate for several years until conditions were favorable for accidental fires to spread. With these large supplies of fuel the fires which swept over these prairies were very b east of destruction not only for man and animals but for all shrubs and trees which might have ventured out among the grass and even for any trees or forests against which the burning wind might blow.

From these reports it is evident that although the fires burned with almost white-hot intensity they moved rapidly over the ground, and did not burn deeply into the soil. It is a matter of common
knowledge that grasses are better adapted than shrubs to withstand the effects of fire. This has been pointed out by various writers. Bray (1910) stated:

Apparently under the open prairie regime the equilibrium was maintained by more or less regular recurrence of prairie fires. This, of course, is by no means a new idea, but the strength of it lies in the fact that the grass vegetation was tolerant of fires and the woody vegetation was not. It was only after weakening the grass floor by heavy pasturing and ceasing to ward off the encroaching species by fire that the latter invaded the grasslands. Once the equilibrium was destroyed everything conspired to hasten the encroachment of chaparral--droughts, pasturing, trampling, seed-scattering, etc.

Shantz (1924) in writing about the great plains regions, and giving reasons for their status as grasslands, said:

In the eastern portions of the area fires have in all probability protected the grassland from the encroachment of the forests. Aided by high winds, these fires swept with great rapidity across the grasslands of the prairies and plains. Trees and shrubs are killed by fires, and as a consequence the grasses are able to maintain themselves on lands which would support a good forest growth if the trees were adequately protected. Since the settlement of these lands and the consequent checking of prairie fires, tree growth has been gradually extended, either by planting or natural seeding, and trees now grow throughout the whole prairie region.

Early workers in Arizona reached the same conclusions regarding the treeless nature of our grasslands as those in the great plains regions (Griffiths, 1910; Thornber, 1910). In commenting on the cause of the encroachment of woody species on our grasslands Griffiths says:

The main factor, though, in the opinion of the writer, has been that of fire. It is firmly believed that were it not for the influence of this factor the grassy mesas would
today be covered with brush and trees, the same as the canyons, except that the growth would be smaller, owing to a more limited supply of moisture. In short, the same laws apply here that govern in our great prairie States, . . . where treeless plains were kept so by frequent fires.

Reports from other portions of the Southwest show that the writers and research men from those sections concur with observations made in Arizona. Foster (1917) commenting on the forests of Texas wrote:

The causes which have resulted in the spread of timbered areas are traceable directly to the interference of man. Before the white man established his ranch home in these hills the Indians burned over the country repeatedly and thus prevented an extension of forest areas. With the settlement of the country grazing became the only important industry . . . Overgrazing has greatly reduced the grass density. The practice of burning has during recent years disappeared. The few fires which start are usually caused by carelessness, and . . . burn only small areas. These conditions operated to bring about a rapid extension of woody growth. Almost unquestionably the spread of timbered areas received its impetus with the gradual disappearance of grassland fires and has been hastened by the reduction of the grass cover itself.

A study of the range vegetation in Texas by Buechner (1944) also supports the early observations that grassland fires were the main influence in suppressing the invading woody species.

In most parts of the North American continent, before the advent of the white man, man probably had little or no influence on the vegetation or animal life, indeed, he himself was an integral part of the animal life. . . . But the Edwards Plateau was a notable exception to this general scheme, since the Indian burned the vegetation periodically to facilitate hunting by routing out the game and increasing its visibility. The effect of this practice was to destroy tree and shrub seedlings and produce a grassland in regions that would otherwise have supported arborescent vegetation. . . .
As a result of the elimination of fires and the introduction of livestock, profound changes took place in the vegetation. What was once a waving sea of grass as far as the eye could see was changed to a diversified arborescent vegetation.

Recent research on the subject is of interest. Studies indicate that the percentage of survival of older shrubs after grassland fires is much higher than of young seedlings of the same species. Reports from workers on the Santa Rita Experimental Range show a 36 to 40 percent kill on mesquite seedlings less than 1/2 inches in ground diameter but only an 11 to 16.5 percent kill on larger plants (Unpublished data, Santa Rita Research Center, 1953).

Humphrey (1949), reporting on fire as a means of controlling burroweed, mesquite, and cholla, found that an approximate 50 percent kill was observed on cholla, mesquite, and bismaga (Echinocactus wislizeni Engelm.) and almost a 100 percent kill on burroweed. In addition to this high kill on the noxious plants, the number of grass plants after burning was considerably higher on the burned area than on the unburned area. A later study gave almost a 100 percent kill on burroweed and snakeweed and a 30 to 50 percent kill on cholla (Humphrey and Everson, 1951). No reference was made to mesquite in this analysis but it would appear from this study and from others of a similar nature that individual large mesquites are frequently killed outright by fire. Even though the trees may not be completely killed, they may be reduced to basal sprouts and these are more readily subject to browsing injury. If an area is swept by frequent fires, the trees may be reduced to this less prominent position or be entirely eliminated.
CONCLUSIONS

1. There have been no changes in the climate of Southern Arizona that would permit the invasion of grasslands by shrubby species.

2. Introduction of grazing animals has had an adverse effect on the grassland vegetation, not only because of the large herd numbers, but also because of the effects on soil and the reduction of litter and dry grasses which formerly carried range fires.

3. Cattle and rodents are important factors affecting the rate of shrub invasion in that they act as a medium for the dissemination of seeds and vegetative joints of some invading species.

4. Fires maintained the grasslands, as such, prior to the introduction of livestock. After livestock introduction, fires could not repel the invading shrubby species because of the lack of necessary fuel.

5. Shrub invasion on southern Arizona semidesert grassland ranges is due primarily to the reduction of range fires.
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