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Vegetation changes in the Jornada Basin from 1858 to 1998

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Abstract

Notes made by land surveyors in 1858 were utilized to estimate cover of grasses and shrubs on the Jornada Experimental Range (JER) and the Chihuahuan Desert Range Research Center (CDRRC) in the northern Chihuahuan Desert in southern New Mexico, USA. Portions of these areas have been previously assessed for historical vegetation dynamics but the entire 84,271 ha assessed in the 19th century has not been examined in total. In 1858, fair to very good grass cover occurred on 98% and 67% of the JER and CDRRC, respectively. Shrubs were present throughout both properties but 45% of the JER and 18% of the CDRRC were shrub free. Reconnaissance surveys, made to determine carrying capacity for livestock were made in 1915–1916 and 1928–1929 on the JER and in 1938 on the CDRRC, show that shrubs had made large increases in area occupied at the time of the surveys. Vegetation type maps were made of both properties in 1998. Mesquite (*Prosopis glandulosa*) was the primary dominant on 59% of the JER in 1998 and creosotebush (*Larrea tridentata*) was the primary dominant on 27% of the area. On the CDRRC mesquite and creosotebush were primary dominants on 37% and 46% of the area, respectively. Grass cover has decreased greatly with the increase in shrubs and only shrub control efforts have maintained the once abundant black

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grama (*Bouteloua eriopoda*) as a primary dominant on 1% or less of the area on both properties.

1. Introduction

Understanding vegetation dynamics is an underlying tenet of plant ecology and is essential if natural resources are to be used in a sustainable manner. The arid southwestern United States has undergone extensive vegetation changes for eons, but these have accelerated since the arrival of Europeans. The impact of introduced livestock and concurrent vegetation changes have spawned a wealth of literature which began at an early date (e.g., Wooten, 1908) and extends to the present (e.g., Van Auken, 2000). Beginning in the 16th century, anecdotal accounts of early travelers traversing the Jornada Basin in the northern Chihuahuan Desert indicate that the vegetation differed greatly from what exists today (Gardner, 1951; Allred, 1996). Spatially explicit descriptions of vegetation were first provided by land surveys made in the 1850s. These surveys were used in the classic paper by Buffington and Herbel (1965) which documented the increase of three major shrubs in the Jornada Basin. The early land surveys were also used to show that encroachment of shrubs was a widespread phenomenon in the northern Chihuahuan Desert (York and Dick-Peddie, 1969, pp. 157–166).

In the northern Chihuahuan Desert the juxtaposition of two large research stations, both with extensive records of past and present vegetation, offers a valuable opportunity to reexamine vegetation change through time. A vegetation type map prepared for both research stations in 1998 shows current extent of plant communities and permits the examination of cumulative changes since 1858. We have attempted to document the extent of past and present plant communities at spatially explicit time scales.

2. Study area

The Jornada Basin is in the northern part of the Chihuahuan Desert which occurs in the Mexican Highland section of the Basin and Range Province (Hawley, 1975, pp. 139–150). On the area later to become the Jornada Experimental Range (JER), land surveys began with the survey of township lines in 1857 by the United States General Land Office. Most of the study area is in the plains of the Jornada Basin which is closed, having no external drainage, with the remainder being hills and slopes draining into the Rio Grande. The JER, established in 1912 and now administrated by the Agricultural Research Service, US Department of Agriculture, encompasses 78,266 ha. This study was restricted to about 58,600 ha which lie on the relatively level plains. Headquarters of the JER is located approximately 40 km NNE (32° 37′ N: 106° 44′ W) of Las Cruces, New Mexico, USA. The adjoining

Chihuahuan Desert Rangeland Research Center (CDRRC) was established in 1927 and is administrated by the Animal and Range Science Department, New Mexico State University. The CDRRC includes both plains and mountainous topography in its 25,671 ha. Elevation of the plains on both properties ranges from about 1300 to 1400 m. Mountains included in the CDRRC rise to an elevation of 1781 m. The CDRRC also contains the lands draining into the Rio Grande. Mean annual rainfall (1915–2002) at the JER headquarters is 247 mm, with 53% occurring in July, August, and September (Fig. 1). Precipitation at the CDRRC headquarters is slightly lower (235 mm). Summer precipitation often occurs as intense convective storms covering small areas while winter precipitation arises from broad frontal storms. Snow is infrequent. Mean maximum ambient temperature is highest in June (36 °C) and lowest in January (13.3 °C).

3. Methods

Land surveys began with the survey of township lines in 1857. Interior section lines were surveyed in 1858 and provide the first site-specific descriptions of vegetation. The original land survey handbooks are archived at the Bureau of Land Management state office in Santa Fe, NM. Because an assessment of suitability of the area for cultivation was a major consideration, notes on soils and topography were usually given first, followed by comments on grass cover and shrubs. These descriptions are the ones used by Buffington and Herbel (1965). We constructed two maps of the JER utilizing the 1858 survey notes. On one map (scale 4.8 cm per mile), the descriptions given were written on the section lines and on another map color coded dots were placed on the section lines so polygons including like species could be drawn. All mentioned species of shrubs were included. Plant nomenclature follows Allred (2003).

These early General Land Office surveys of the CDRRC have not been examined previously. The CDRRC is found in parts of seven townships. All township boundaries of the CDRRC were surveyed in the mid-1850s. However, subdivision surveys in the 1850s were only done in four of the townships. These are referred to as the 1858 surveys. The interior section lines for the other townships were not done until 1881–1884. Another subdivision survey was conducted in 1891 in the townships including the mountains and slopes in the southern part of the CDRRC. Because of Ft. Seldon adjoining the CDRRC to the southwest, there were many surveys on its lands and the adjoining CDRRC lands in the 1860–1890s. As with the JER area, a two-step process was used in creating a map with colored dots on section lines representing species mentioned. The maps of the JER and CDRRC with polygons of grouped species were digitized and polygon areas determined.

On both the JER and CDRRC, the early surveys used Spanish names for shrubs. Exceptions were mesquite (*Prosopis glandulosa*), greasewood [creosotebush, (*Larrea tridentata*)], and sedgebush. We could not find any reference to sedgebush, so like Buffington and Herbel (1965), we interpreted it as *Ephedra* spp. Other names used included the following: "Palmias", and "Spanish Dagger" for *Yucca* spp.; "Ardilla"

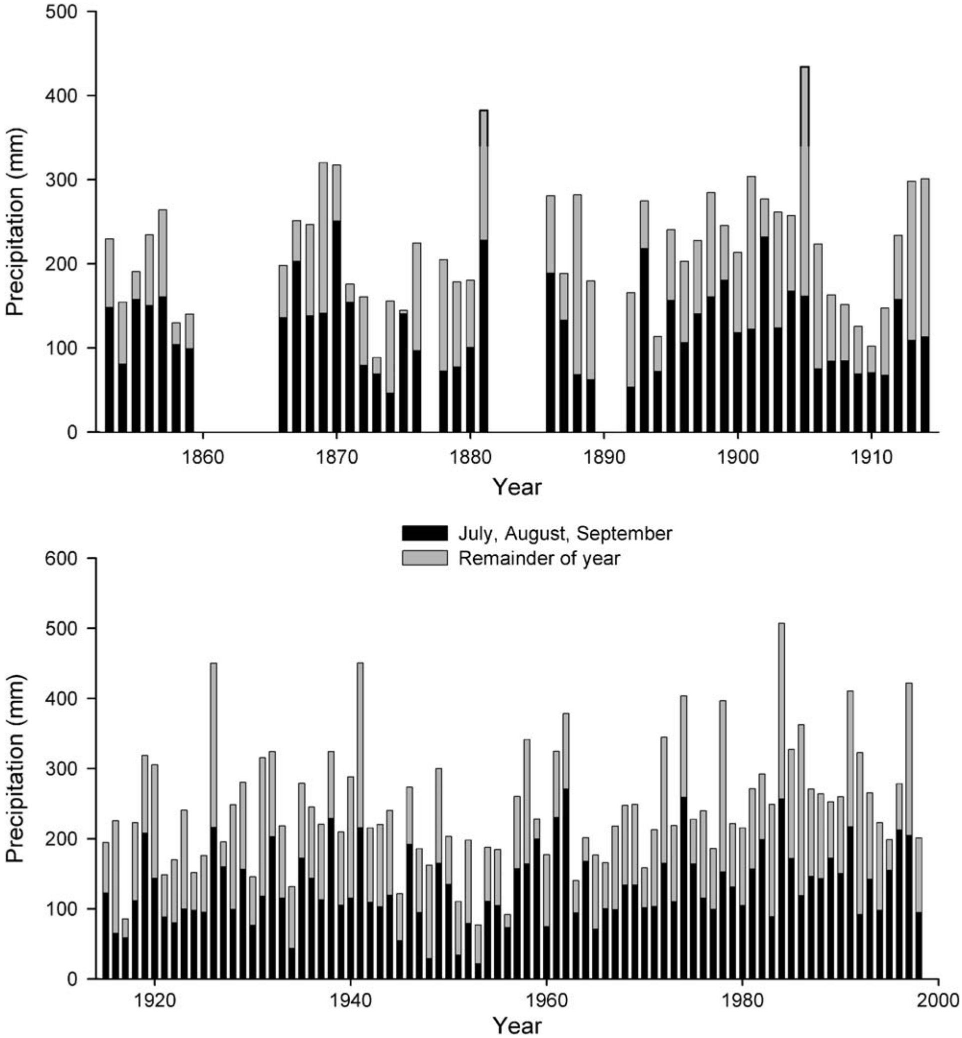

Fig. 1. Seasonal and total precipitation from 1853 to 1889 was measured at US Army forts and towns in the Rio Grande Valley and at New Mexico State University in Las Cruces, NM from 1892 to 1914. These locations are all within 50 km of the Jornada Experimental Range headquarters where the 1915–1989 measurements were made.

for tarbush (*Flourensia cernua*); ‘‘Chamisal bushes’’ for four-wing saltbush (*Atriplex canescens*). We followed the lead of Buffington and Herbel (1965) and called most cases of unidentified ‘‘shrubs’’ or ‘‘bushes’’ tarbush on the JER. On the CDRRC some areas with unidentified shrubs were classed as ‘‘mixed brush’’. We believe these unidentified shrubs may have included littleleaf sumac (*Rhus microphylla*), southwestern rabbitbrush (*Ericameria pulchella*), and feather-plume (*Dalea formosa*). The term "grama grass" apparently included many grasses besides black grama (*Bouteloua eriopoda*) because the term was used for areas which were undoubtedly covered with tobosa (*Pleuraphis mutica*) or other grasses in 1858. Usually the surveyors qualified grass cover as "very good", "good", or "poor". Where they did not include a modifier and just listed "grass" or "grama" we have assumed that there was a "fair" amount of grass. Separate maps were prepared for grass and shrub cover for clarity.

The surveyors were not consistent, recording vegetation on some section lines but not on others. Also we do not know whether they always integrated observations over the entire mile or just at the point they wrote up their notes. The surveys were made from fall through spring when plants were dormant, not the best time of year for the identification of herbaceous plants. Although the shortcomings are numerous, the 1858 surveys (and latter surveys on the CDRRC) do give the first descriptions of vegetation which can be tied to landscape positions.

A desire to determine livestock carrying capacity led to other assessments of vegetation cover on both the JER and the CDRRC. Reconnaissance surveys using the forage-acre approach to determine carrying capacity for livestock were used by the US Forest Service in preparing vegetation maps of the JER in 1915–1916 and in 1928–1929. The calculation of forage acres required that the percentage composition of weeds (forbs), grasses and shrubs be estimated by species so that palatability factors could be applied. Hypothetically, a forage acre is one acre with 100% cover of species with 100% palatability. Field sheets included a section outline upon which boundaries of vegetation types were sketched and the information later compiled into maps showing vegetation types and forage acres. In the 1930s, funds from the National Industrial Recovery Act permitted the compilation of a vegetation map based on the 1927–1928 survey and to reconcile estimation differences between the 1915–1916 and 1927–1928 surveys (Bomberger, 1936).

A hand-colored vegetation map at a scale of 1 in. = 1 mile based on the 1915–1916 survey and a vegetation map at a scale of 2 in. = 1 mile based on the 1928–1929 survey were digitized during 1999–2001 and the species information on the field forms entered into a data base. Dominant species for a type were usually given, or, if not, dominants were estimated from the percentage composition of species. For large polygons there were often several field sheets and an average of species compositions were used in designating dominants for the area as a whole. The early surveys usually did not distinguish between species within the threeawns (*Aristida* spp.) and within the dropseeds (*Sporobolus* spp.)

Reconnaissance surveys were performed on the CDRRC in 1935 and 1938. The 1938 survey was used in this paper because the efforts were so close in time and the 1935 survey followed the very severe drought of 1934. The vegetation type map which was prepared shows the three most abundant species and livestock carrying capacity. The map (scale 2 in. = 1 mile) was digitized and dominants associated with each polygon placed in a database.

In 1998 we made a vegetation type map for the JER and CDRRC using 1996 color infrared (CIR) aerial photographs as a base. Transparent overlay material was placed over 90 × 90 cm prints (approximate scale, 11.4 cm = 1.6 km) and boundaries of vegetation types delineated with water soluble ink so corrections could be made easily in the field. Vegetation types were envisioned as areas greater than 10 acres where one to four species, rarely five, were dominant. Designation of multiple dominants allowed relatively large areas to be included in a single type. A few vegetation types of less than 10 acres with very prominent signatures were delineated. Intensive ground reconnaissance utilizing available roads, tracks, cleared fencelines, and some cross-country driving was used to verify vegetation signatures on the photographs. An all-terrain vehicle was utilized in the mountainous portion of the CDRRC. Dominants on Mt. Summerford were obtained from a detailed study made by Mata-Gonzalez et al. (2002).

The field sheets were digitized and polygon areas determined. There was some distortion involved in this rendition because edges of photos were involved. A single, seamless digital orthophoto rendition of the 1996 aerial photographs of the JER and CDRRC was eventually produced. The vegetation polygons were refitted to the signatures on the orthophoto rendition and Global Positioning System (GPS) locations of roads, fences, structures, research sites, and other prominent physical features incorporated into a Geographic Information System (GIS).

4. Vegetation in 1858

The distribution in 1858 of abundance classes of grasses on the JER and CDRRC is shown in Fig. 2. On the JER, very good grass, good grass, fair grass, and poor grass occupied 9%, 70%, 19%, and 2% of the area, respectively. One of the areas of poor grass was a large prairiedog town. On the CDRRC, very good grass, good grass, fair grass, and poor grass occupied 18%, 43%, 5% and 33% of the area, respectively. The relatively large area of poor grass on the CDRRC includes the area where interior section lines were not surveyed until the 1880s. It is quite likely that in this sector the intervening 20-odd years saw relatively heavy livestock grazing by herds brought in by homesteaders from the east.

Although only eight shrub or shrub-like species were identified separately in 1858, they occurred singly or in various combinations and 23 separate areas could be delineated (Fig. 3). We did not attempt to estimate shrub cover or abundance in any area. The order of species listed in a combination is based on the number of listings for each and does not imply an order of dominance. Areas with no shrubs comprised 18% and 45% of the CDRRC and JER, respectively. *Yucca* spp. occurring singly occupied 24% of the CDRRC and 27% of the JER. Mesquite occurring singly occupied 12% and 4% of the CDRRC and JER, respectively. However, mesquite singly and in combination occurred on 25% and 46% of the CDRRC and JER, respectively. One of the striking features of the 1858 vegetation is the fact that very good and good grass cover was frequently recorded for areas with shrubs present. Also, the term "prairie", which normally denotes an area where grasses dominate, was sometimes used in areas where shrubs were listed. We think that in most areas shrub densities were much less than present day densities.

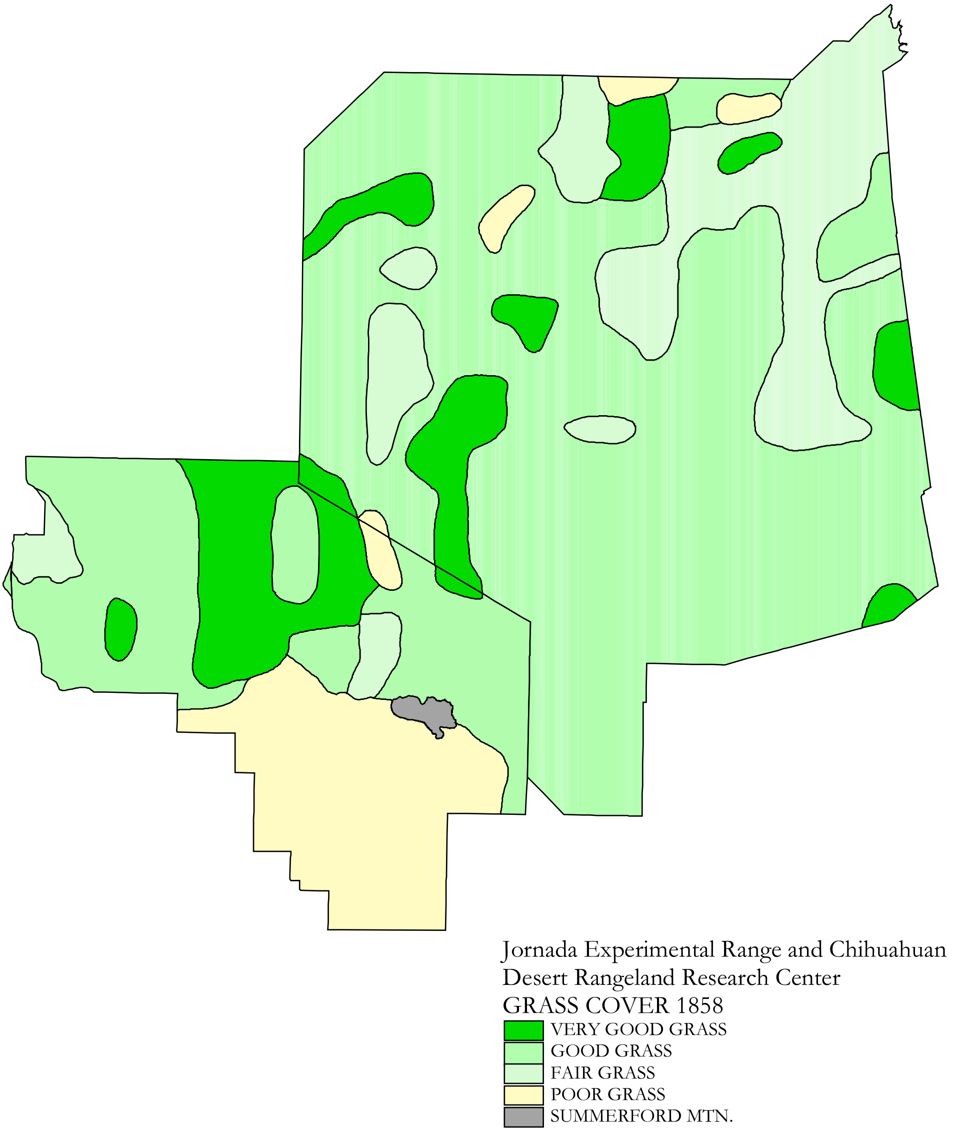

Fig. 2. Grass cover classes on the Jornada Experimental Range and the Chihuahuan Desert Range Research Center (CDRRC) in 1858. The large area of poor grass on the CDRRC was not mapped until the 1880s and could have received heavy use from herds of settlers in the Rio Grande Valley and horses of troops stationed at Ft. Seldon which was an active post from 1865 to 1891.

5. Post-1858 vegetation on the JER

Of all shrubs, mesquite made the largest gains since 1858 in area occupied. By 1915–1916 it was the primary dominant on 26% of the area and by 1998 the primary

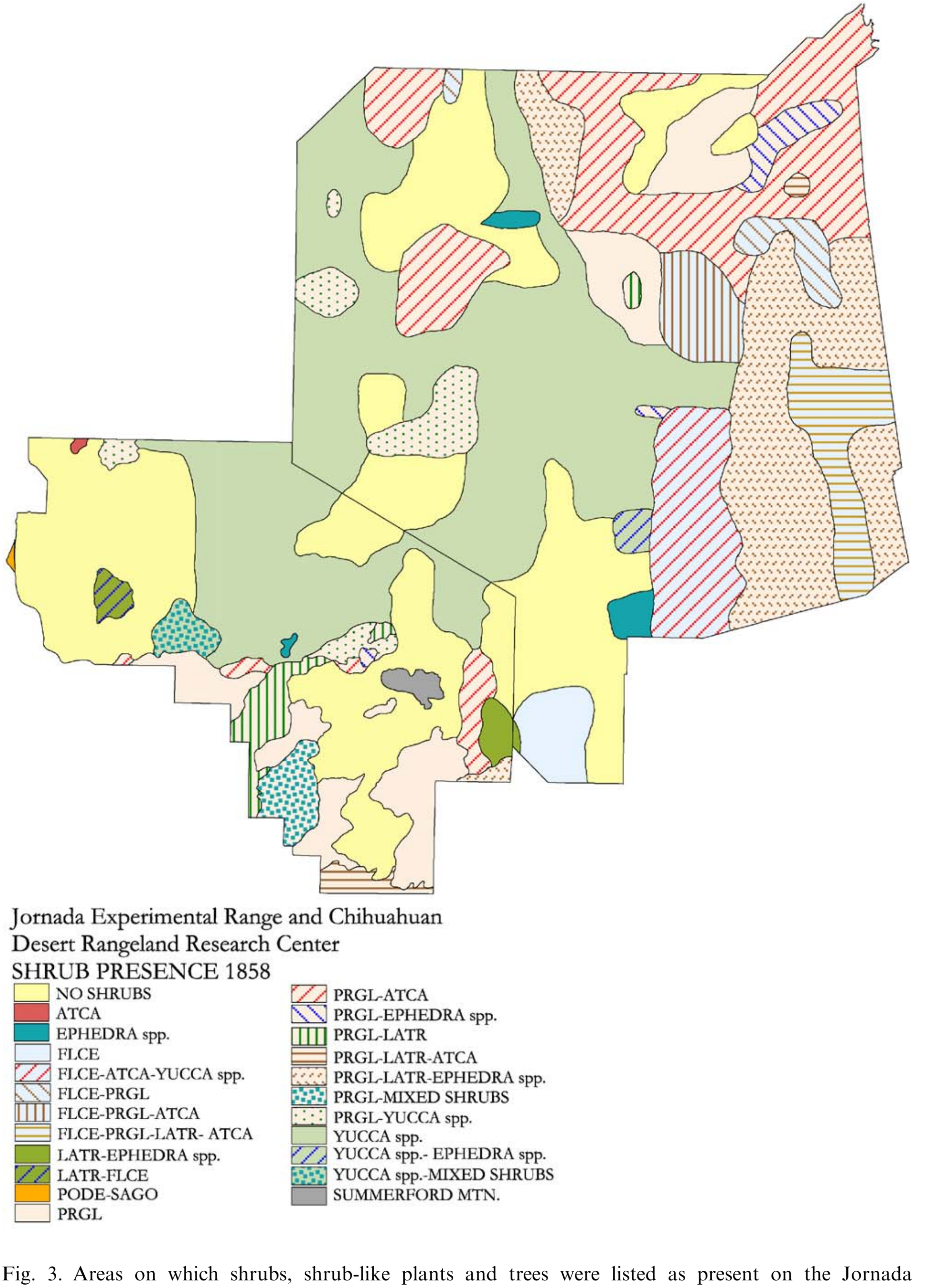

Fig. 3. Areas on which shrubs, shrub-like plants and trees were listed as present on the Jornada Experimental Range and the Chihuahuan Desert Research Center in 1858 and portions of the CDRRC in the 1880s. Symbols for shrubs and trees are as follows: cottonwood (PODE, *Populus deltoides*), creosotebush (LATR, *Larrea tridentata*), four-wing saltbush (ATCA, *Atriplex canescens*), tarbush (FLCE, *Flourensia cernua*), mesquite (PRGL, *Prosopis glandulosa*), willow (SAGO, *Salix gooddingii*).

dominant on 59% of the area (Table 1). If areas in which mesquite played a subdominant role are added to the area of primary dominance, it was present on 84% of the area in 1998. Buffington and Herbel (1965) show mesquite as occurring on 79% of the area in 1963. Repeated sampling has shown that mesquite continues to increase (Gibbens et al., 1992) even though mesquite has been the primary target of shrub control measures with about 10,000 ha being treated on the JER. The areas occupied by mesquite sandhills (Fig. 4) include those areas on which mesquite was present in 1858 (Fig. 3) and in 1915–1916 (Fig. 4). There is some correlation between size of coppice mesquite dunes (nabkha) and age (Gadzia and Ludwig, 1983). However, depth of material available for dune formation also plays an important role and the mesquite sandhills are on landforms with deep sand deposits. Also, relatively long periods of time are required to build the sandhills. Buffington and Herbel (1965) speculated that mesquite was present in the northeastern part of the JER, where the majority of the mesquite sandhills occur, for centuries or millennia. Mesquite would have been an important food item for indigenous populations, and they were present in this region until the latter part of the 13th century.

Both creosotebush and tarbush have increased in area of occurrence since 1858. The area where creosotebush was the major dominant increased over 20% from 1915–1916 to 1998 (Table 1). It can be seen in Fig. 4 that much of this increase occurred at the expense of tarbush on the bajada slopes at the eastern side of the mapped area. Tarbush declined in area where it was the primary dominant (Table 1). However, it made some gains in area of occurrence on areas formerly dominated by

Table 1
Hectares and percentages of area occupied for vegetation types on the JER where the listed species are the primary dominant in 1915–1916, 1928–1929, and 1998

Vegetation type	Year					
	1915–1916 (ha)	1928–1929 (ha)	1998 (ha)	1915–1916 (%)	1928–1929 (%)	1998 (%)
Bare	60	61	67	0.1	0.1	0.1
Aristida spp.	3344	1601	71	5.7	2.8	0.1
Black grama	11,126	11,235	700	19.0	19.3	1.2
Burrograss	4706	4598	1797	8.0	7.8	3.0
Sporobolus spp.	68	946	1219	0.1	1.6	2.1
Tobosa	2415	2401	87	4.0	4.2	1.4
Other grasses[a]	0	167	42	0	0.3	0.1
Broom snakeweed	3568	2209	34	6.1	3.8	0.1
Creosotebush	2605	8221	14,459	4.5	14.1	24.6
Mesquite not duned	12,275	19,558	8832	26.1	33.5	15.1
Mesquite dunes (1998)			15,840			27.0
Mesquite sandhills (1998)			10,116			17.2
Tarbush	14,812	6519	3900	25.3	11.2	6.7
Other shrubs[a]	621	772	733	1.1	1.3	1.3
Total hectares	58,600	58,288	58,580			

Total areas are very similar so percentages of area occupied are comparable among years.
[a]See text for list of other species.

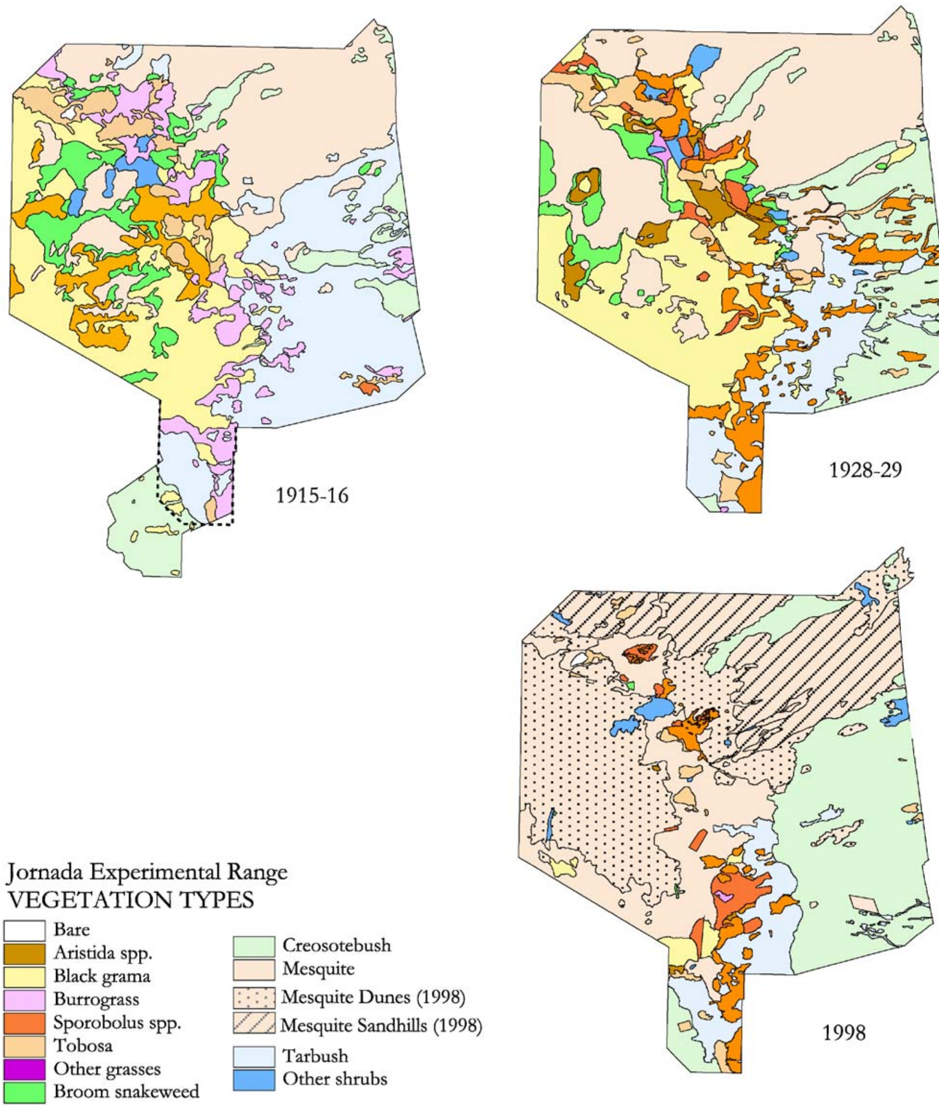

Fig. 4. Vegetation types on the Jornada Experimental Range where the listed species were the primary dominants in 1915–1916, 1928–1929, and 1998. A larger area was fenced at the southern end of the range in 1915–1916 but the area outside the dotted lines was not included in calculation of area.

burrograss (*Scleropogon brevifolius*) and tobosa and remains as a subdominant on much of its former range. The suffrutescent broom snakeweed (*Gutierrezia sarothrae*) has been classified as a shrub. It declined in area where it was the primary dominant from 1915–1916 to 1998 (Table 1). However, total area where it was a significant component of the plant community was 37%, 34%, and 26% in

1915–1916, 1928–1929, and 1998, respectively. Broom snakeweed is relatively short-lived and populations fluctuate widely among years (Campbell and Bomberger, 1934).

In 1915–1916 ''other shrubs'' (Table 1) included sand sage (*Artemisia filifolia*), *Ephedra* spp., broom dalea, (*Psorothamnus scoparius*), four-wing saltbush, *Yucca* spp. In 1928–1929 ''other shrubs'' (Table 1) included the species of 1915–1916 and in addition mariola (*Parthenium incanum*), crucifixion thorn (*Koeberlinia spinosa*), silver wolfberry (*Lycium berlandieri*), and wait-a-minute bush (*Mimosa aculeaticarpa* var. *biuncifera*). Added to the preceding list of ''other shrubs'' in 1998 were winterfat (*Krascheninnikovia lanata*), crucillo (*Condalia warnockii*), feather-plume (*D. formosa*), *Opuntia* spp., desert shrub oak (*Quercus turbinella*), littleleaf sumac (*R. microphylla*), and prickle-leaf dogweed (*Thymophylla acerosa*).

Yucca spp. [primarily soaptree yucca (*Yucca elata*)], is included in the ''other shrubs'' in Table 1. It was classed as a primary dominant on a very small area in 1998 (Fig. 4). However, as a dominant and subdominant it occurred on 17% of the area in 1998. This is a large reduction from the area of occurrence in 1858. Photographs in the Jornada files provide evidence that the establishment of mesquite was followed by mortality of stands of soaptree yucca.

Black grama was still the primary dominant on relatively large shrub-free areas in 1916 (Fig. 4). In both 1915–1916 and 1927–1928, black grama was the primary dominant on 19% of the area. In 1998, black grama dominated only 1.2% of the area (Table 1). Black grama was estimated to occupy a subdominant position on 26%, 9%, and 4% of the area in 1915–1916, 1928–1929, and 1998, respectively. All of the areas where black grama is now the primary dominant have been treated to control shrubs and this is probably the primary reason that it has been able to persist in a dominant position. Records from $1 \times 1\,m^2$ quadrats, which were sampled fairly continuously from 1915 until the 1970s, indicate that the greatest decrease in black grama cover occurred following the severe drought of the 1950s (Gibbens and Beck, 1988).

Mesquite now dominates many areas formerly dominated by *Aristida* spp. which were dominant on a very small area in 1998 (Table 1). In 1915–1916, *Aristida* spp. occupied a subdominant position on 26% of the area but this had declined to 3% by 1928–1929 and was 7% in 1998. *Sporobolus* spp. show some gains in area where they were the first dominants from 1915–1916 to 1998 (Table 1). Surprisingly, gyp dropseed (*Sporobolus nealleyi*) was not recorded in the 1915–1916 survey but in 1998 it was estimated to be the primary dominant of 0.4% of the area. Probably it has always been present on the gypsum soils where it now occurs. *Sporobolus* spp. was estimated to occupy a subdominant position on 14%, 24%, and 18% of the area in 1915–1916, 1928–1929 and 1998, respectively. The major *Sporobolus* species is mesa dropseed (*Sporobolus flexuosus*) which is relatively short-lived and populations fluctuate widely among years (Wright and Van Dyne, 1976; Gross, 1984). Burrograss and tobosa both declined in area dominated from 1915–1916 to 1998 (Table 1) but not nearly as much as black grama. Quadrat records indicate that burrograss and tobosa did not experience large decreases in vegetative cover during the 1950s drought and losses were generally due to encroaching shrubs (Gibbens and Beck, 1987). In 1998, the "other grasses" category (Fig. 2, Table 1) includes bush muhly (*Muhlenbergia porteri*). Bush muhly did not occur as a dominant but occupied a subdominant position on 11% of the area. Bush muhly is most abundant on areas dominated by creosotebush. Also included in "other grasses" is the introduced Lehmann lovegrass (*Eragrostis lehmanniana*), which has expanded outward from seeded areas and now occurs on 0.3% of the area. Continued spread of Lehmann lovegrass could profoundly alter existing plant communities (McClaran, 2003, pp. 16–33).

When evaluating or studying present-day plant communities of the JER, one needs to be aware of past shrub control efforts. Several nearly square or rectangular areas are visible in the 1998 vegetation map (Fig. 4) where the dominant species is different from the surrounding area. These are areas where either chemical or mechanical treatment killed most of the dominant shrub species, allowing a different plant community to develop. Even where treatments did not change the dominant species there could be changes in species diversity or subtle changes in ecosystem processes.

6. Post-1858 vegetation on the CDRRC

By 1938, creosotebush dominated more area on the CDRRC than any other shrub (Fig. 5, Table 2). Areas where creosotebush was present as a dominant or a subdominant made up 43% and 59% of the area in 1938 and 1998, respectively. This is a large increase from the 16% of area where creosotebush was estimated to occur in 1858. Mesquite was second in area occupied and made the largest gain in area dominated between 1938 and 1998 (Table 2). Total area on which mesquite occurred was 44% and 51% in 1938 and 1998, respectively. Broom snakeweed was the primary dominant on about 3% of the area in both 1938 and 1999 (Table 2). However, broom snakeweed occupied a subdominant position on an additional 25% and 31% of the area in 1938 and 1998, respectively.

In 1938 the "other shrubs" in Table 2 included sand sage, four-wing saltbush, winterfat, sotol (*Dasylirion wheeleri*), *Ephedra* spp., Berlandier's wolfberry, *Opuntia* spp, Rio Grande cottonwood (*Populus deltoides* spp. w*islizenii*), screwbean mesquite (*Prosopsis pubescens*), littleleaf sumac, and *Yucca* spp. In 1998 the following species were included in "other shrubs" (Table 2) in addition to those listed above: Western whitethorn (*Accacia constricta*), beebush (*Aloysa wrightii*), seep-willow (*Brickellia laciniata*), desert willow (*Chilopsis linearis*), sotol, apache-plume (*Fallugia paradoxa*), ocotillo (*Fouquieria splendens*), wait-a-minute bush, mariola, broom dalea, salt-cedar (*Tamarix ramosissima*), prickleleaf dogweed, and desert zinnia (*Zinnia acerosa*). The multitude of slopes and exposures in the mountainous terrain accounts for the relatively higher diversity of shrubs and shrub-like plants than recorded on the JER.

Only a few of the shrubs listed above occupied any appreciable area. Although mariola was not listed in 1938, it was the primary dominant on 2% of the area and a subdominant on an additional 13% of the area in 1998. *Ephedra* spp. were present on 9% of the area in both 1938 and 1998. Four-wing saltbush increased in area of

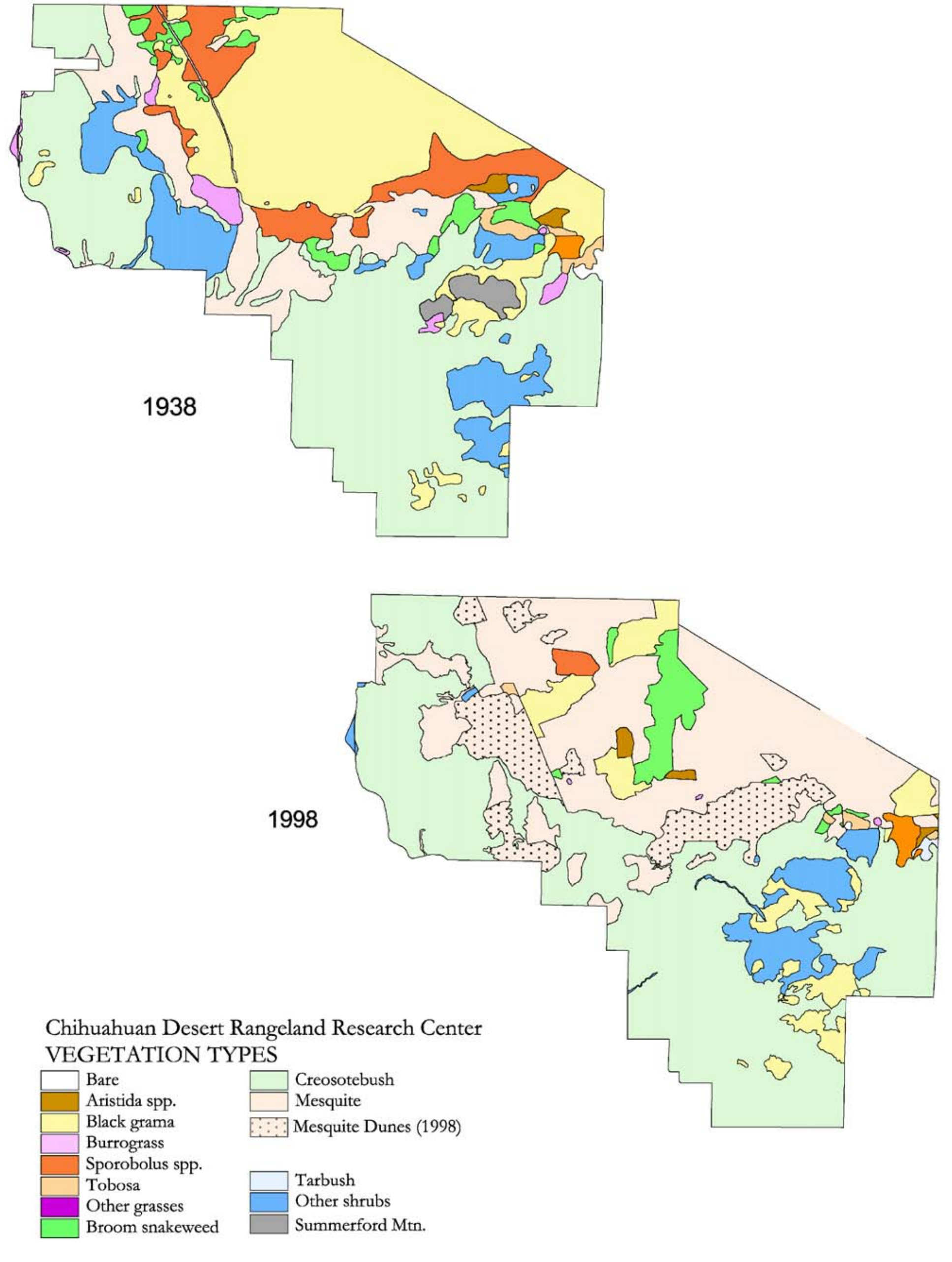

Fig. 5. Vegetation types on the Chihuahuan Desert Research Center where the listed species were the primary dominants in 1938 and 1998.

Table 2
Hectares and percentages of area occupied for vegetation types on the CDRRC where the listed species are the primary dominant in 1938 and 1998

Vegetation type	Year			
	1938 (ha)	1998 (ha)	1938 (%)	1998 (%)
Bare, mountains and other	329	7	1.3	<0.1
Aristida spp.	112	117	0.4	0.5
Black grama	6732	1822	26.3	7.1
Burrograss	81	148	0.3	0.6
Sporobolus spp.	1731	130	6.8	0.5
Tobosa	220	83	0.9	0.3
Other grasses[a]	347	12	1.3	0.1
Broom snakeweed	672	764	2.6	3.0
Creosotebush	10,245	11,757	40.0	45.8
Mesquite not duned	2702	7262	10.6	28.3
Mesquite duned (1998)		2311		9.0
Tarbush	57	39	0.2	0.1
Other shrubs[a]	2383	1218	9.3	4.7
Total hectares	25,563	25,670		

Total hectares are very similar so percentages of area occupied are comparable among years.
[a]See text for list of other species.

occurrence from 3% in 1938 to 9% in 1998. *Yucca* spp. also increased in area of occurrence from 10% in 1938 to 21% in 1998 occupies far less area than in 1858.

There was a large decrease in area dominated by black grama on the CDRRC from 1938 to 1998 (Fig. 5, Table 2). As on the JER, we believe shrub control efforts on about 6800 ha of the CDRRC have played an important role in maintaining black grama. Total area on which black grama occurred was 44% and 23% in 1938 and 1998, respectively. Pre- and post-drought studies of black grama forage production and cover showed that the severe drought of the 1950s adversely affected black grama (Lohmiller, 1963; Parker, 1963). The areas with *Aristida* spp. as the primary dominant were equal in 1938 and 1998 (Table 2) but total area of occurrence increased from 5% in 1938 to 11% in 1998. Areas with *Sporobolus* spp. as the primary dominant declined from 1938 to 1998 (Table 2). Total area of occurrence of *Sporobolus* spp. was 32% and 16% of the area in 1938 and 1998, respectively.

7. Discussion

It is evident that the vegetation change in the Jornada Basin has been from abundant grasses to abundant shrubs. Long-term records have revealed similar changes in the Sonoran Desert (Hastings and Turner, 1965; Martin and Turner 1977; McClaran, 2003). Even in areas of the southwestern United States receiving more precipitation than the Chihuahuan and Sonoran deserts there has been an encroachment of shrubs into former grasslands and savannas (Archer, 1988; Archer, 1994, pp. 13–68). Mesquite has been the principal encroaching shrub in all areas and all increasing shrubs are indigenous species which have been present in greater or lesser abundance for thousands of years.

The 1858 surveys show that good grass cover was present prior to any major disturbance by Europeans and their livestock. There does not appear to have been any loss of grass species given that all species identified in early 20th century surveys are still present. What has changed dramatically is the role of grasses in present-day plant communities. Grasses retain a dominant position on very restricted areas and some species, notably black grama, have been extirpated from large areas. Heavy grazing has been almost universally cited as a cause for reduction in grass cover (Buffington and Herbel, 1965; Grover and Musick, 1990; Archer, 1994). Droughts, characteristic of the Southwest, also played an important role in reduction of grass cover. Surveyors mapping the meanders of the Rio Grande in 1892 noted that crossing the river was easy because of four years of drought. Other droughts of shorter duration occurred in the early 1900s (Fig. 1). The drought of the 1950s remains the most severe and long-lasting and caused large reductions in grass cover in the Jornada Basin (Herbel et al., 1972). Loss of black grama was greatest on deep sandy sites and least on shallow sandy sites, perhaps because water was held within reach of plant roots by indurated caliche layers. The current drought starting in the 1990s (Fig. 1) has also reduced herbaceous plant cover in many areas.

The 1858 surveys show that shrubs were present throughout the Jornada Basin but it is likely that in most areas of occurrence shrubs were at relatively low densities. It appears that four-wing saltbush and *Ephedra* spp. may be less widely distributed now than in 1858. Both shrubs are browsed by livestock and heavy use may have caused plant mortality or weakened plants so that they succumbed to competition from their unbrowsed associates. This would be especially true if stocking was heavy during winter months when the evergreen shrubs would be sought out by livestock.

Mesquite has increased the most since 1858 although creosotebush and tarbush have also made substantial gains in area occupied. Spread of mesquite seed by livestock is undoubtedly one reason for the wide distribution of mesquite. Mesquite became established at a very early date along the EL Camino Real (the trail from Chihuahua City to Santa Fe) through the Jornada Basin and the route of the trail is still visible on the CDRRC based on the presence of larger and presumably older plants. Buffington and Herbel (1965) explored correlations between soils and shrub cover using a somewhat simplified version of the 1962 soils map of the Jornada that was prepared by the Soil Conservation Service. They found that mesquite dominates on sandy soils but occurs on practically all soil types except pure gypsum. Creosotebush also occupies a wide range of soil types. Tarbush has been replaced by creosotebush, but has invaded heavier soils formerly dominated by tobosa and burrograss. The 1962 soils map is quite detailed and still valid today (H.C. Monger, personal communication). It is likely that a more detailed study of soil–vegetation relationships would provide further insight into these dynamics.

There can be little doubt that heavy grazing in the latter part of the 19th and early 20th centuries helped trigger the encroachment of shrubs. Besides heavy grazing, the suppression of fires, climate change, and elevated CO_2 concentrations have been extensively debated as contributors to shrub increase (Grover and Musick, 1990; Idso, 1992; Johnson et al., 1993; Polley et al., 1994, Archer, 1994; Archer et al., 1995; McClaran, 2003). There is no evidence in the data presented here to support or refute fire, climate change or CO_2 as causative factors. Whatever factor or combination of factors is responsible for the shrub increase, it is clear that the process has been relatively rapid and is continuing. It has been hypothesized that redistribution of soil resources and feedback mechanisms have contributed to the spread and dominance of shrubs (Schlesinger et al., 1990). It has also been hypothesized that black grama grasslands were established under and adapted to ''little ice age'' type climate (which ended about 1900) and are only marginally adapted to the present, warmer climate (Neilson, 1986).

An important question is what the area would look like today if it had been used at moderate grazing intensities or had not been used by domestic livestock. We believe shrubs would have increased under moderate grazing or if not used by domestic livestock. Shrubs were widely distributed on both the JER and CDRRC in 1858 and would have been able to increase whenever grass cover was reduced by grazing or recurring droughts. Root systems of the major encroaching shrubs have wide-spreading shallow roots and also roots which penetrate to 5 m depths or more while roots of grasses rarely extend beyond 1 m depth (Gibbens and Lenz, 2001). Thus, shrubs, with both shallow and deep roots, have a distinct advantage over grasses during droughts. Shrubs might not have attained their present densities but would probably occupy a dominant position on most of the area.

It is recognized that specific ecological sites within the Jornada Basin have different characteristic vegetation states, and these differ in their resistance and resilience to disturbances (Bestelmeyer et al., 2003). However, most of these ecological sites include the potential for transition to a shrub-dominated state. To varying degrees that is what has occurred across sites and the landscape. The change from grassland to shrubland has passed a threshold (Friedel, 1991) and manipulation of grazing pressure will not reverse the process (Hennessy et al., 1983) Shrubs are obviously the most successful plant life form in the Jornada Basin and barring an extreme climatic or fire regime change are likely to continue their dominance for many years. More than 40 years of shrub control efforts on the JER and CDRRC have slowed but not eliminated shrub increase (Gibbens et al., 1992). We believe there is still a potential to improve grass cover on sites where grasses have maintained a dominant or subdominant position since 1858 and present-day remediation efforts should be confined to such sites.

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