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Fire in the Deserts and Desert Grassland of North America

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I. Introduction

A. Prevalence of Fires in Desert Areas

Because of the inescapably close correlation between prevalence of fires and amount of fuel, deserts are characteristically less affected by fire than are most ecosystems. And, as a corollary, the more arid the desert, the less fuel is produced and the less frequent and severe are any fires that may occur. Conversely, however, even though fire frequency and severity may be relatively low in any rating scale, their effect on the ecosystem may be extreme. Thus, as in portions of the desert grassland of the Southwest, even occasional fires may prevent attainment of the potential overstory climax of woody species, maintaining a grass subclimax that has often been mistaken for a true climatic climax.

B. Fire as it Affects Grasses and Woody Plants

With a few notable exceptions such as *Eucalyptus, Sequoia,* and some pines and oaks, fires are more destructive of woody species than of most grasses. This is particularly true when the woody taxa, or ligniphytes, are shrubs or small stature trees. This differential susceptibility to damage is a direct result of morphological differences in the two life forms.

Most perennial grasses die back each year to about ground level, the following year's growth developing either from peripheral or central buds in the crown of the plant or from stolons or rhizomes. Thus, unless the plant has been completely killed, and this is not usually the case, only a single year's growth, most of which has already died, is merely removed by the fire. In addition, grass fires, because of the rapidity with which they burn, are generally classed as "cool" and do not typically burn deeply into the grass crowns.

By contrast, the killed portion of a ligniphyte usually represents many years' growth which, even if the plant were a sprouter, i.e., had the ability to sprout from the base after fire, would usually require several years to regrow to a point where it would again flower and produce seed. Thus, repeated fires, even when they do not kill woody taxa outright, keep them in a juvenile, nonfruiting stage. And, as will be seen later, many of them are nonsprouters and are completely killed. For a fuller discussion of these differences the reader is referred to the chapter "Fire" in Humphrey (1962).

C. Sprouters and Nonsprouters

Shrubs are often classified by "pyrecologists" as either *sprouters* or *nonsprouters:* those that sprout from the base after a fire or those that fail to sprout and thus are killed. This sounds like an easy, simple classification. Unfortunately, however, like most such alternatives this one, too, has its problems. For example, big sagebrush (*Artemisia tridentata*) is very nearly a nonsprouter while horsebrush (*Tetradymia canescens*) and most species of rabbitbrush (*Chrysothamnus*) are strong sprouters that are harmed only temporarily by burning. Bitterbrush (*Purshia tridentata*), on the other hand, and mesquite (*Prosopis velutina*) sometimes sprout and sometimes do not. It has also been observed in the desert grassland of Arizona that burroweed (*Aplopappus tenuisectus*), although typically a nonsprouter, may sprout prolifically if burned while the plants are in the flush of new growth. As a conclusion, it would seem highly probable that most shrub species are predominantly either sprouters or nonsprouters but that many fall somewhere in between and that many even of the nonsprouters possess a latent sprouting ability under certain conditions of growth.

II. Four Deserts and the Desert Grassland

Four broad areas are usually recognized as being both geographically and floristically distinct North American deserts. These are the Great Basin, or Sagebrush, Desert, the Mojave Desert, the Sonoran Desert, and the Chihuahuan Desert. A fifth dry and distinct area, the desert grassland, is often classified either as desert or as semidesert.

The general geographical location of each of the four deserts is shown on the accompanying map. The desert grassland, because of its intricacy and interspersion in part with adjacent vegetation types, has not been shown.

All four deserts and the desert grassland have aridity as a common characteristic. All five also have a variety of low-growing woody plants as a common growth form. Although often floristically distinct, all except the Great Basin Desert have several of the same species in common.

III. Great Basin Desert

A. Location

The Great Basin Desert (also sometimes known as the northern desert shrub or the Sagebrush Desert) is essentially coterminous with the Great Basin Physiographic Province. As indicated in Fig. 1, it includes most of Nevada, southern Oregon, about the southern half of Idaho, extends into southwestern Wyoming, covers roughly the western half and the southeastern quarter of Utah, and dips irregularly into northern Arizona.

B. Climate

Precipitation in the area falls largely in the winter and spring months but has less extreme seasonal highs and lows than the other deserts. Much of it occurs as snow. In part because of the more equable distribution, in part because the bulk falls during the cooler months when evaporation is least, and in part because the relatively high elevation and northerly latitude are conducive to a cooler climate and consequent lower evaporation rate, the limited precipitation is more effective than an equal amount would be in the hotter, more southerly deserts.

C. Vegetation

The Great Basin Desert is a high- or cold-desert area characterized by a variety of shrubs, largely gray in color, with a generally sparse understory of perennial or annual grasses intermingled with a variable stand of highly seasonal forbs. Plant communities dominated by one of two species, big sagebrush (*Artemisia tridentata*) or shadscale (*Atriplex confertifolia*), are encountered more commonly than any others in the area. The sagebrush is a reliable indicator of deep, well-drained soils and is the principal fuel source for free-running fires in this ecosystem. Other sagebrush species, principally those classified as *Artemisia rigida* and *A. nova*, occur in fine-textured, poorly drained sites. The shadscale also occurs largely on low-lying, poorly drained soils but most characteristically on those with a high alkaline content.

In addition to sagebrush and shadscale there are several other locally dominant shrubs or halfshrubs whose distribution is determined by local soil and soil-moisture conditions. Each of these is usually the principal species in its own ecosystem. Most of them provide too little fuel to carry fire readily and, as a consequence, will not be discussed here. They are covered in considerable detail by Shreve (1942) and by Shantz (1924).

D. Prevalence of Fires

It may be generalized that the Great Basin Desert is more subject to burning, either as a result of lightning or man, than the other three desert areas. This is a consequence of the prevalence of big sagebrush, often with an understory of grasses that provides additional fuel, rather than because of any excess of lightning storms or people.

The Great Basin Desert lies adjacent to or is intermingled with such vegetation types as juniper or juniper-pinyon pine, the Palouse grassland, the mixed-grass or short-grass plains, or, in the Southwest, the desert grassland. These often supply considerable fuel in the form of either perennial or annual grasses that serve to carry any fires into the adjacent desert areas. And, as is true of most contiguous vegetation types, only occasionally is there a sharp species differentiation between the taxa that characterize these types and those of the Great Basin Desert types. As a consequence, many of the fuel-providing grasses may extend for long distances into the so-called desert. In addition, a number of grasses such as cheatgrass (*Bromus tectorum*), bluebunch wheatgrass (*Agropyron spicatum*), and squirrel-tail (*Sitanion hytrix*), among others, are characteristic components of much of the Great Basin Desert. Thus, either because of invasion from contiguous types or because of the suitability of much of this desert to grass growth, extensive portions of it do produce a ground cover that is adequate to carry fire from shrub to shrub.

Shrubs are dominant in most of the Great Basin Desert. Most of these are highly flammable, particularly during the hot, arid summer months. Moreover, they often grow together, not infrequently to heights of 5 ft or more. As a consequence, they provide a fuel base that is often well suited, even without grasses, to carry a spreading fire over extensive areas.

E. General Responses

In an Idaho study made near the northern limits of the Great Basin Desert, Blaisdell (1953) evaluated the effect of various intensities of burning on forage production and the response of various grasses, shrubs, and forbs to fire. Because the observations made during this study are representative of fire effects over extensive portions of the desert they are quoted at some length as follows.

> During the early part of the first growing season after burning . . . damage to vegetation far outweighs the benefits. Perennial grasses and forbs are clearly lowered in vigor; old clumps are badly broken up and remaining plants are small and scattered. Although rhizomatous species are apparently damaged less than others, even these have poor vigor. Shrubs are represented by only a few sprouts. Much bare ground is exposed, but an abundant growth of annuals may fill many of the openings. As the season progresses, new shoots of rhizomatous grasses and forbs appear and tuft-forming species begin to stool out. Although greater vigor is apparent in most plants, scarcely any flower stalks are produced. Perennial grasses and forbs on burns remain green about 2 weeks longer than on unburned areas.
>
> Despite the injurious effects of burning, rhizomatous species are often able to produce an increased amount of herbage by the end of the first year, but production of most other species is still below the original level. . . .
>
> During the second year perennial grasses and forbs continue to increase and vigor is high. Sprouting shrubs are larger, but are still an inconspicuous part of the vegetation. The most noticeable feature of the burn during the second year is the abundant flower stalk production of almost all grasses and forbs. . . . The reason for this phenomenon is not known, but it may be related to a temporary increase in mineral nutrients and increased soil moisture. At any rate, this profuse flowering of grasses and forbs is typical of 2-year-old burns on sagebrush-grass ranges and supplies a source of seed for revegetation of areas that may not be supporting a full plant cover.
>
> Total herbage production of grasses and forbs generally reaches its maximum about the third year after burning, largely as a result of increases in the fire-resistant rhizomatous species. Although this increased production may persist indefinitely, more often it declines in subsequent years. This general decline in grass and forb production is accompanied by an increase in shrubs and many nonrhizomatous herbaceous perennials.
>
> Of the individual grass species occurring in the upper Snake River Plains, thickspike wheatgrass [*Agropyron dasystachyum*], plains reedgrass [*Calamagrostis montanensis*], and bluebunch wheatgrass [*A. spicatum*] are apparently least damaged by burning, for within 3 years these had recovered and were producing considerably more herbage on burned than on unburned areas. Other grasses are slower to recover. . . .
>
> The rapid increase of . . . [thickspike wheatgrass and plains reedgrass] after they overcome the initial setback from burning and the temporary decrease of most of the other grasses suggests that repeated burning of such range might produce a fire subclimax dominated by coarse rhizomatous grasses. The fact that certain decreases in bluegrass [*Poa* spp.] and fescue

> [*Festuca idahoensis*] were still evident after 12 and 15 years . . . suggests that burning sagebrush-grass ranges that have an herbaceous understory dominated by such finer bunchgrasses might result in a permanent reduction in total grass yield or a shift to a higher proportion of coarse rhizomatous grasses.
>
> Many forbs, especially the rhizomatous ones, make rapid recovery from burning and produce an increased amount of herbage within 3 years. Others, particularly the suffrutescent species, are slower to recover, but none of the perennial forbs are permanently damaged, and many apparently benefit from burning. . . .
>
> Shrubs are . . . more damaged by burning than either grasses or forbs. Not only is all of the current herbage destroyed by fire, but the above-ground, woody parts are either killed or completely consumed, resulting in destruction of stored reserves. . . . However, rabbitbrush and horsebrush [*Tetradymia canescens var. inermis*] sprout profusely following burning and are only temporarily injured. . . . Bitterbrush plants that sprout grow rapidly, and some exceed their original size. However, part of the recovery of this species comes from new plants established from seed, especially on burns of heavy intensity where most of the old plants are killed.
>
> Big sagebrush, which is completely killed and must re-establish itself entirely from seed, is much slower to recover. . . . On the upper Snake River Plains . . . the absence of sagebrush is often an indicator of past burns.

F. Subecosystem Responses

Perhaps because extensive portions of the Great Basin Desert rarely if ever burn, there has been little research on the effects of fire in the component or subsystems of this very extensive ecosystem. Some of the more clearly delineated of these, which do not indicate merely successional stages, include the following.

1. *Big Sagebrush*

Two ecosystems within the Great Basin Desert are most susceptible to being swept by wildfires. These are primarily the one dominated by big sagebrush and secondarily the one where antelope bitterbrush (*Purshia tridentata*), often intermixed with big sagebrush, is dominant. The sites where one or the other of these occurs as the dominant species are typically well drained with a deep soil and a climate that permits growth of fire-supporting grasses and forbs. Competition from the sagebrush may largely preclude the establishment of any other vegetation except a sparse understory of annual cheatgrass (*Bromus tectorum*), but in these situations the sagebrush supplemented by the grass usually provides ample fuel to carry a fire.

Because big sagebrush is a nonsprouter, has almost no value as forage for cattle, and competes effectively with valuable forage species for the limited moisture, cattlemen usually look on a sagebrush fire as a blessing. The species does have grazing value for sheep, particularly in winters when deep snows cover the shorter vegetation. In general, however, sagebrush fires benefit both cattlemen and sheepmen, either by releasing the suppressed grasses and forbs or by providing a clean, ash-covered seedbed for reseeding to more desirable species. Such reseeding is necessary in some areas, particularly in the potentially highly productive sagebrush alluvial flats where competition from the brush and/or long years of overgrazing have all but eliminated other species.

Rather typically on the upland sites, however, there are enough grasses and forbs to make a rapid recovery under the impact of removal of the competing shrubs combined with the fertilization afforded by the ashes. The grasses, with their inherent ability to withstand fires and to recover quickly will, unless overgrazed, soon produce more forage than the combination of sagebrush and grass yielded prior to burning. There tends to be a reduction in grass forage production for the first 2 years after a fire but under a program of no grazing the first year and light grazing the second, forage production is usually greater than ever by the third year. Ultimately the sagebrush will return in the absence of fire because it represents the largest growth form and best adjusted species capable of establishment as the climax under the prevailing climate.

Despite the relatively greater incidence of fires here, it should not be inferred that fires occur commonly or throughout the big sagebrush ecosystem. Extensive portions of this desert either support other species of *Artemisia* or other taxa that provide too little fuel to carry a fire. *Artemisia nova* and *A. rigida,* for example, are small in stature and occur typically in poorly drained sites with few grasses or other potentially flammable growth. As compared with the extensive stands of big sagebrush, these are often restricted in area and do not provide an opportunity for extensive burns.

2. *Antelope Bitterbrush*

From almost any point of view the antelope bitterbrush ecosystem is harmed rather than benefited by burning. *Purshia tridentata,* as distinct from other species or varieties of *Purshia,* might be classified as a variable or uncertain sprouter that is often completely killed by fire. It is, in addition, a valuable forage species used by both deer and all kinds of domestic livestock. Because it usually occurs as a dominant on light, sandy soils, exposure of these soils to wind erosion following burning sometimes results in rather severe soil blowing.

Burned areas will usually soon be revegetated, first to a cover of Russian thistle (*Salsola kali*) and or to Jim Hill mustard (*Norta altissima*), followed within a year or two by cheatgrass. After many years during which grazing has been rigidly controlled, these annuals will gradually be replaced by perennial grasses and forbs beneath a new stand of bitterbrush. These sites, however, are comparatively fragile and usually suffer much more than big sagebrush sites from the combination of grazing and burning.

3. *Rabbitbrush*

In much of the Great Basin Desert various species of rabbitbrush (*Chrysothamnus*) occur as a common component of the vegetation. The response of these to fire is highly variable. In general, however, they tend to be sprouters and, as a consequence, are harmed much less by burning than are big sagebrush or antelope bitterbrush. One of the commonest species, and one that usually indicates range deterioration, is big rabbitbrush (*C. nauseosus*). Although usually a prolific sprouter, Robertson and Cords (1957) cite two instances in which burning resulted in an almost complete kill of this species. In contrast, they also mention another instance where it made a 95% recovery.

Pechanec *et al.* (1954), in their classic study of sagebrush burning, mention only a single *Chrysothamnus* species, downy rabbitbrush (*C. puberulus*). They indicate, however, that it was undamaged by fire. Shantz (1924) recorded that little rabbitbrush (*C. stenophyllus*) and related species might occupy the ground almost to the exclusion of other plants where drought or fire have killed the sagebrush. Although not mentioning fire, he stated that where sagebrush had been destroyed, big rabbitbrush was often dominant.

Additional research is needed on the response to fire of the various *Chrysothamnus* species under a variety of phenologic and climatic conditions. For the present, however, the evidence points to fire as an uncertain and usually not a practical means of control except in those situations where the rabbitbrush occurs intermixed with a strongly dominant and unwanted stand of big sagebrush.

4. *Shadscale*

Shadscale (*Atriplex confertifolia*) occurs extensively and widely as essentially pure stands throughout the Great Basin Desert. Because the plants are short and usually occur as open, almost pure stands that provide little fuel, shadscale communities rarely burn.

5. *Budsage and Saltsage*

Two other subsystems, budsage (*Artemisia spinescens*) and saltsage (*Atriplex corrugata* and *A. nuttallii*), although limited essentially to the northern portion of the Great Basin ecosystem, are similar to shadscale in the general growth-form characteristics of their dominant taxa. And, like the shadscale communities, these also, rarely burn.

6. *Winterfat*

Winterfat (*Eurotia lanata*), although not usually occurring to the exclusion of other shrubs and grasses, is, nonetheless, typically a strong dominant and usually may be accepted as indicating a distinct ecosystem where it does grow. Its distribution is not limited to the Great Basin Desert and it is a characteristic species of many arid sites in the West from Canada into Mexico.

Winterfat is highly relished by herbivores ranging from rabbits, deer, and antelope to sheep, cattle, and horses. As a consequence, it is often so closely grazed that little is left that might serve as fuel. Although I can find no literature on fires in this ecosystem it is probably not immune from burning. And, because it sprouts and branches freely in response to grazing, I am hazarding the guess that it would probably also sprout after fire.

G. Adequacy of the Analysis

Space does not permit more complete analysis of fire in the Great Basin Desert. The treatment given here is more in the nature of a partial synopsis than a complete discussion, but if it serves as a stimulus to a later, relatively thorough analysis its incompleteness will have served a useful end.

IV. Mojave Desert

A. Location

The smallest of the four North American desert areas, the Mojave Desert, lies largely in extreme southern Nevada and adjacent California (see Fig. 1). A small fringe area extends into northwestern Arizona where it is hardly distinguishable from the northwestern portion of the Sonoran Desert with which it intermingles. The northern boundary is also indistinct, adjoining as it does the floristically similar southern edge of the Great Basin Desert.

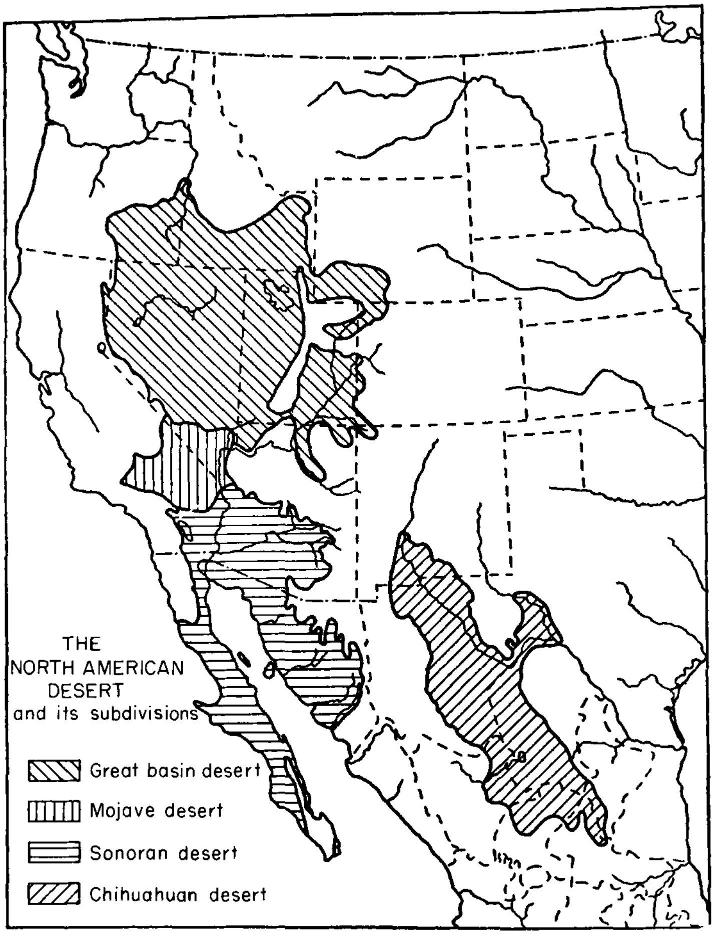

Fig. 1. The North American Desert and its subdivisions.

B. CLIMATE

The Mojave Desert probably has an average aridity greater than that of any other of the North American deserts. Limited portions of the Sonoran Desert around the head of the Gulf of California may receive even less rainfall and be as hot, but the combination of low rainfall and high temperatures over most of the Mojave Desert area would seem to give it the dubious distinction of being the most arid. As Shreve (1942) points out, the aridity is accentuated by the almost total lack of any rain in the summer months, the little that does fall being largely restricted to the winter and spring. The extreme aridity is suggested by the fact that this desert embraces Death Valley.

C. VEGETATION

Two extreme xerophytes, creosotebush (*Larrea tridentata*) and white bursage (*Franseria dumosa*), characterize the greater part of the Mojave Desert. Much of the area has a high soil-salt content that restricts both the variety and volume of plant growth. Because of the similarity of these factors with portions of the Great Basin Desert there is a considerable overlapping of species in the two ecosystems.

A characteristic plant of the Mojave Desert that is unique to this desert is the large Joshua tree (*Yucca brevifolia*) (Fig. 2). A smaller but distinctive related species, the mojave yucca (*Yucca schidigera*) is also widespread.

Most of the area has only internal drainage with the consequence that the occasional runoff drains into an almost countless number of normally dry lake beds. These are devoid of perennial vegetation and even contain no water most of the time. The high salt content of their soils and the occasional inundation preclude the possibility of the establishment of vegetation except seasonal stands of winter–spring annuals around the edges.

Fig. 2. Joshua tree (*Yucca brevifolia*) forest in Mojave County, Arizona.

Probably because of the low rainfall that is largely restricted to a single season, there are few grasses in the area. A perennial grass that is sometimes abundant, big galleta (*Hilaria rigida*), is found primarily in areas of blowing sand, along the edges of the occasional washes, or in swales with fine-textured alluvium. Except in the swales, big galleta occurs too sparsely or infrequently to be of any importance in carrying fire.

D. Prevalence of Fires

General

In the Mojave Desert, even more than in the other North American deserts, there is little in the published record concerning fires. This is understandable since the area is sparsely settled, fires are a rarity, and the few fires that do occur cause little apparent damage to the various aspects of the ecosystem that affect man and his economics.

E. Subecosystem Responses

1. *Creosotebush–Bursage*

An open zone of creosotebush and white bursage typically lies between the bare lake beds and the more rugged mountainous terrain above. The creosotebush and bursage are too sparse and the creosotebush plants are too open to carry a fire of themselves. Only in those occasional years when exceptionally heavy winter rains have produced an abnormally heavy stand of annuals is there any possibility of fire in this community. Shreve (1942) has estimated that 70% of the Mojave Desert falls within this *Larrea–Franseria* community, the remainder being either dry lake beds, areas of dune sand, or mountains. As the lakes and the sand dunes never burn, and the *Larrea–Franseria* ecosystem is essentially nonflammable, fires are most likely to occur in the mountains or in restricted alluvial flats where moisture accumulation permits a rather dense growth of big galleta and annuals.

2. *Mountainous Areas*

The mountains of the Mojave Desert are rugged, desert ranges supporting for the most part a sparse mixture of shrubs, forbs, and a few grasses interspersed between extensive areas of bare rock. In their higher portions they usually have a scattered growth of low-growing oaks and junipers. The fires that may occasionally occur usually cover limited areas but may be highly destructive of the more common suffrutescent species such as bladdersage (*Salazaria mexicana*) and shrubby buckwheat (*Eriogonum fasciculatum*). Because of the sparsity of perennial grasses, these mountain burns are slow to revegetate, and water erosion may result in considerable soil losses, particularly during the first year after a fire.

3. *Big Galleta Swales*

Small area fires that are usually man-caused not infrequently burn the big galleta flats adjacent to roads or settlements. Damage to the grass may vary from slight to severe, depending on grass dormancy. If the plants are extremely dry, with little or no new growth, damage may be severe because of burning out of the live center. Conversely, when the plants contain considerable green material, burning is more superficial and the living centers are little harmed. In this latter situation, any damage to the grass is usually temporary. Regardless of severity of damage, fires here may be of benefit by helping to control such competing shrubs as mesquite (*Prosopis juliflora*) and catclaw (*Acacia greggii*). Mojave yucca, which is often a characteristic component of the vegetation, is usually little harmed by the fire.

4. *Blackbrush*

Blackbrush (*Coleogyne ramosissima*), although not typical of most of the Mojave Desert, does occur as almost pure stands locally as well as in the southern Great Basin Desert. Perhaps because of aggressive competition for moisture by this species there are usually few forbs or grasses in blackbrush stands that might aid in carrying fire (Fig. 3). Despite this and the fairly wide spacing of the plants, blackbrush communities have been known to burn under conditions of high temperature, high wind velocity, and low relative humidity. My not entirely conclusive observations have been that blackbrush is not a sprouter and, in the event of a clean burn, is almost entirely destroyed by fire. No specific studies relative either to damage or method and rate of recovery after burning have come to my attention.

V. Sonoran Desert

A. LOCATION

The most southwestern of the North American deserts, the Sonoran Desert, occupies roughly the southwestern third of Arizona; the south-

Fig. 3. Typical blackbrush (*Coleogyne ramosissima*) community with scattered ›shua trees in the background. The absence of vegetation between the shrubs hibits the spread of fire.

ıstern corner of California; most of the peninsula of Baja California, [exico; and the greater part of the state of Sonora, Mexico (see Fig.). Except for a narrow strip in Baja California that lies in the Pacific 'cean drainage, the entire area drains into the Colorado River or directly .to the Gulf of California.

. CLIMATE

The mean annual rainfall ranges from a low of about 2–3 inches in ıe area around the head of the Gulf of California to about 12 inches parts of Arizona. Annual distribution is largely bimodal, with a pattern winter and summer rains alternating with spring–fall periods of rought. Almost none of the precipitation falls as snow although all ccept the southern portions of the desert do receive some frost in most ɔars.

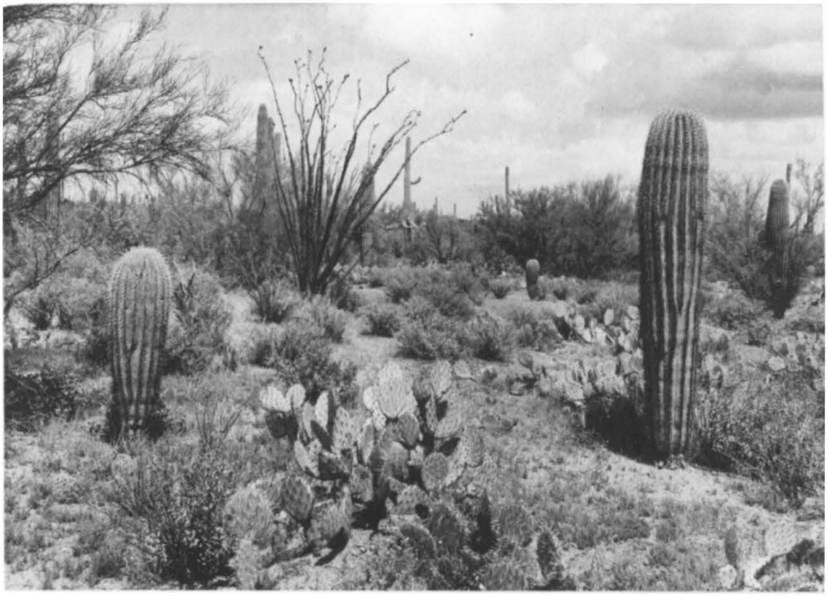

Fig. 4. Representative Sonoran Desert community in southern Arizona showing a wide variety of plant species but a sparse cover little conducive to burning.

C. VEGETATION

The Sonoran Desert is characterized by a large variety of woody species. To a much greater extent than in the other deserts, many of these are low growing trees. A second outstanding difference between this and the other North American deserts is an abundance of cacti in the Sonoran Desert (Fig. 4).

Because of the extensive area included within the Sonoran Desert (nearly 120,000 square miles) and the consequent climatic diversity, its floristic composition is highly variable. As indicated above, the characteristic species are predominantly woody and include many cacti. These vary widely, however, over the approximate 850-mile north–south extent of the desert with regard to species composition and density, as well as to frost and drought tolerance. Comparatively few plant taxa are distributed throughout the desert, but there is a small minority that tend to tie it all together. These include ironwood (*Olneya tesota*), creosotebush, jojoba (*Simmondsia chinensis*), triangle bursage (*Franseria deltoidea*), and the genus *Fouquieria*, represented over most of the Sonoran Desert by the ocotillo (*F. splendens*).

Although the area contains several typical perennial grasses, the plants usually occur too sparsely to provide a reliable fuel base for carrying fire. In years of exceptional rainfall extensive areas may support a good cover of annual grasses or forbs, and, when fires do occur, these (the grasses in particular) usually provide the necessary fuel.

D. Vegetation Characteristics as Related to Fire Frequency

General

Despite the extensive geographical area included within the limits of the Sonoran Desert and the severe lightning storms that characterize the summer rainy season, fires occur here only rarely. This is largely because of the dominance of widely spaced open-branched trees and shrubs that are poorly suited to burning, either separately or collectively. The few perennial grasses that characterize most subecosystems within the Sonoran Desert usually occur locally as a few plants beneath some of the shrubs or trees and do not provide the continuity of cover necessary to carry fire. Perennial forbs usually occupy the same type of ecological niche and, in any event, occur too sparsely to be of any importance as fuel.

In most years annual forbs and grasses do not become sufficiently dense to carry fire. In addition, they are small in size and because of their small biomass produce little fuel.

Most fires in the Sonoran Desert occur in the ecotone between the desert and desert grassland, a variable but often wide area with sufficient precipitation to grow a fairly dense stand of annuals during exceptionally wet years. Some areas of this sort are of doubtful ancestry and, although they may be classified as Sonoran Desert today, probably more correctly represent the deteriorated, lower fringes of the desert grassland. As grazing has killed the grasses or fire control has permitted invasion of certain of the Sonoran Desert ligniphytes there has been an apparent shift in the desert boundary. This feature will be discussed in some detail in Section VII.

E. Tobosa Flats

Tobosa flats, e.g., poorly drained, alluvial swales that occur primarily in the northern Sonoran Desert and also in the Chihuahuan Desert, constitute an exception to the general nonflammability of the Sonoran Desert perennial vegetation. Although tobosa grass (*Hilaria mutica*) does grow on both upland and lowland sites, only in the swales is the

Fig. 5. Pristine tobosa-grass (*Hilaria mutica*) flat on the Papago Indian Reservation in southern Arizona. Occasional fires historically maintained such ecosystems essentially free of woody plants (cf. with Fig. 6).

stand usually dense enough to carry a fire. During the last 50–100 years the vegetal composition of these "flats" has been gradually changing from essentially pure grass to a grass–shrub mixture (Figs. 5 and 6). As this change does not seem to be correlated with a reduction in grass density, some other factor, probably absence of fire, must be causative.

Because of the rather limited area of tobosa grass flats they must have burned less frequently than the more extensive desert grassland in which a fire, once started, could run for many miles before encountering a natural nonflammable barrier. In addition, surrounded, as tobosa flats usually are, by relatively sparse vegetation, they were, and are, less subject to burning than areas such as the desert grassland that adjoined other flammable types.

Tobosa flats are almost never burned today and most of them are being invaded by ligniphytes, usually mesquite and whitethorn (*Acacia constricta*). The relatively high moisture content of the soils of these sites is conducive to ready establishment and rapid growth of the invad-

Fig. 6. Tobosa-grass (*Hilaria mutica*) flat near Tucson protected from burning for many years. Note the invasion by woody species, largely velvet mesquite.

ing shrubs, and there is no reason to suppose that they will not continue to be so invaded in the absence of fire.

F. Response of Specific Taxa to Fire

The knowledge of the response of individual Sonoran Desert species to fire has been obtained largely from studies involving those sometime ecotonal taxa that have been exposed to fires from, and adjacent to, the desert grassland. The following lists the principal among these and their responses to fire.

1. (Velvet mesquite (*Prosopis juliflora* var. *velutina*): a facultative sprouter; thin-barked, with low resistance to the heat of fires (see additional discussion in Humphrey, 1962, Chapter 9).
2. Creosotebush (*Larrea tridentata*): a facultative sprouter; thin-barked, small-stemmed, and highly susceptible to fire damage or killing.
3. Burroweed (*Aplopappus tenuisectus*): an obligate nonsprouter with a dense crown of resinous leaves and stems; burns readily. Despite its

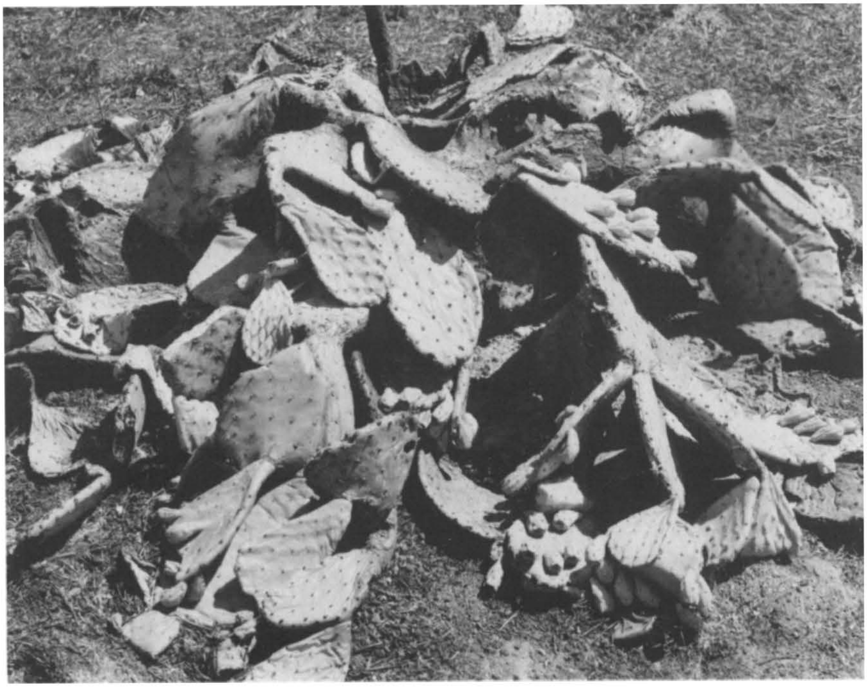

Fig. 7. Prickly pear (*Opuntia*) killed by a ground fire. Bacterial rot and foraging animals usually finish the job the fire begins.

susceptibility to fire the genus is difficult to control because of the abundant production of wind-disseminated seeds.

4. Snakeweed (*Gutierrezia lucida*): fire reactions essentially identical with those of burroweed. The synonym "matchweed" suggests its almost explosive flammability.

5. Cholla cactus (*Opuntia fulgida*): most of the plants, particularly in young stands, may be largely controlled by fire. After burning of the spines the plants are unprotected from grazing animals. Fire is sometimes used in severe drought years to supplement the limited forage with cactus, a practice that effects some degree of control of the cholla.

6. Prickly pear (*Opuntia* spp.): the effect of burning is variable, depending on fire intensity. In a hot fire the plants are completely killed (Fig. 7). The stems are incombustible of themselves and without adequate fuel will be little harmed.

7. Bisnaga, barrel cactus (*Ferocactus* spp.): plants 1 or more feet tall are rarely killed since only the spines are combustible. Burning off of the spines, however, makes the plants susceptible to destruction

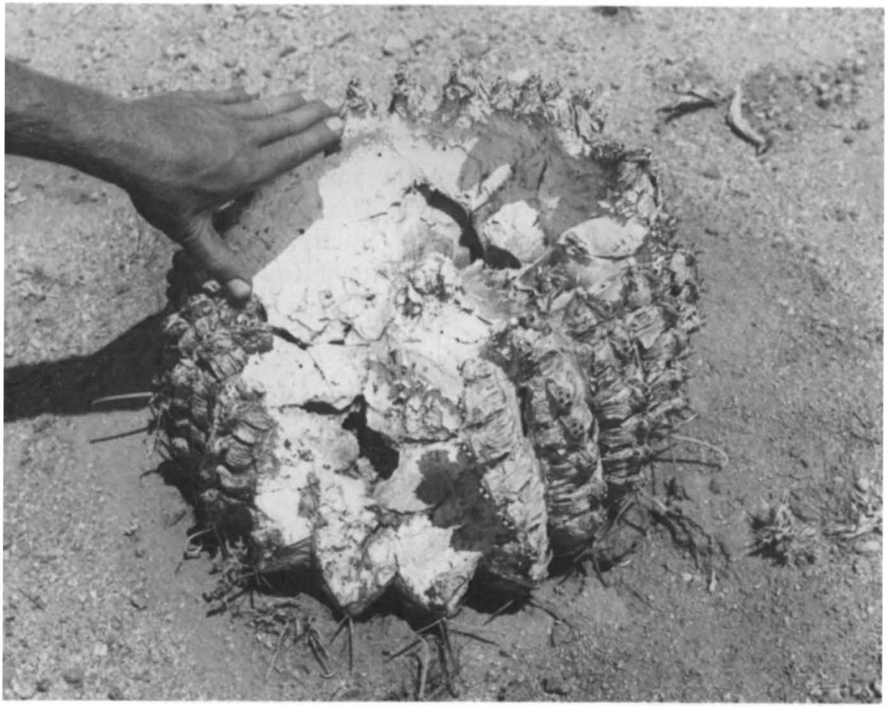

Fig. 8. Barrel cactus (*Ferocactus*) from which most of the spines have been removed by fire, rendering the plant largely defenseless against foraging animals. This individual has been eaten by jackrabbits and cattle.

by cattle, horses, and rabbits (Fig. 8). Those plants less than about 1 ft tall may suffer 75% or higher mortality either as a direct result of burning or from subsequent grazing damage.

VI. Chihuahuan Desert

A. Location

The Chihuahuan Desert lies largely in Mexico, principally in the states of Chihuahua and Coahuila, but including parts of Durango, Zacatecas, Nuevo Leon, and San Luis Potosi. The relatively small portion in the United States lies largely in south central New Mexico and southwestern Texas (see Fig. 1). In addition to the area delineated on the map there are smaller but almost as typical segments in southeastern Arizona and southwestern New Mexico (Shreve, 1942).

B. Climate

This is an area with great extremes in mean annual precipitation. These range from as little as 3 inches in parts of Coahuila to 12–16 inches in the higher elevations near the western and southern edges of the desert. About 65 to 80% of the rain falls during the summer months from June through September. This results in a long, 8-month dry season in which the period from January to May is exceptionally dry. The lower areas typically receive light frosts particularly during December, January, and February. The higher elevations may be subjected to severe freezing during this same period (Shreve, 1942).

C. Vegetation

The Chihuahuan Desert is essentially an area of medium-size shrubs, few cacti, and a moderate understory of grasses at the higher elevations. Although creosotebush, ocotillo (*Fouquieria splendens*), and mesquite are common both here and in the Sonoran and Mojave deserts, other shrubs that are essentially restricted to the Chihuahuan Desert provide it with its primary floristic individuality. These are principally tarbush (*Flourensia cernua*), sandpaperbush (*Mortonia scabrella*), mariola (*Parthenium incanum*), and whitethorn (*Acacia vernicosa*).

The upper boundaries of the Chihuahuan Desert become indistinct because of its floristic intergradation with the desert grassland and the instability of the ecotone. Both fire and grazing appear to have played a part in the successional flexibility of this boundary.

D. Vegetation Characteristics as Related to Fire Frequency

General

Despite their geographical, climatic, and floristic differences, the Sonoran and Chihuahuan desert ecosystems are somewhat similar in respect to the prevalence of fire. Of the two the Chihuahuan Desert is slightly more susceptible to burning. A greater proportion of the component shrubs are low growing and have a relatively dense crown. In addition, the woody plants are more often interspersed with perennial grasses than in the Sonoran Desert. As a consequence the occasional fires that do occur have a greater opportunity to run.

Despite these characteristics, however, there are few fires in the Chihuahuan Desert. This is in part a result of a natural insufficiency of fuel and in part a side-effect of the close grazing and fire control that have gradually changed the composition of the vegetation from a grass–shrub mixture to one consisting primarily of shrubs.

Like the Sonoran Desert, the Chihuahuan Desert is most subject to burning in the ecotone where it borders on the desert grassland. And, similarly, the original boundaries of the Chihuahuan Desert have probably shifted to include former grassland areas during the past 100 years as grazing and fire control have favored the natural woody plant climax (Humphrey, 1953, 1958).

E. Tobosa Flats

As in portions of the Sonoran Desert, so also in the Chihuahuan Desert, tobosa flats are a characteristic of poorly drained, alluvial areas that provide ample fuel for burning. I know of no published records of the effect of such fires, which probably go largely unnoticed because of their limited areas. Fires in these grasslands are probably less prevalent than formerly, and, as in the Sonoran Desert, the tobosa swales are being invaded by woody species, largely mesquite and whitethorn.

F. Response of Specific Taxa to Fire

Because fires in the Chihuahuan Desert have not been a topic of research either in the United States or Mexico, it is difficult to obtain factual data on any aspects of burning in this ecosystem. Included in the knowledge gap is information on the reaction of individual taxa to fire. In the absence of more precise information the following limited observations are submitted.

Allthorn (*Koeberlinia spinosa*): probably a sprouter, although rarely growing in situations where it might be exposed to fire.

Creosotebush: as indicated previously, this is a facultative sprouter that has extended its original range into adjacent desert grassland areas during the last 75–100 years.

Honey mesquite (*Prosopis juliflora* var. *torreyana*): a sprouter that, because of its characteristic multistemmed habit and frequent occurrence in areas of blowing sand, is either highly resistant to fire damage or is rarely exposed to burning.

Mariola, sandpaper bush, and tar bush: sprouting reactions unknown.

Tobosa grass (*Hilaria mutica*): a species that, like most grasses, is highly resistant to fire damage. However, a slow burning fire in a protracted period of severe drought can be highly damaging. Intentional burning of tobosa flats should be restricted to periods when rains have initiated regrowth in crowns of the plants, thus reducing damage to the live center.

Whitethorn (*Acacia vernicosa*): a sprouter that is set back only temporarily by fire. The species may even be stimulated to produce supplemental plants from roots and additional stems at the original crown by this kind of natural pruning.

VII. Desert Grassland*

A. Location

The desert grassland lies primarily in southeastern Arizona, south central and southwestern New Mexico, and southwestern Texas. The area does not include the entire portions of the states mentioned but occurs as local grasslands rather widely interspersed with other types. Although to a considerable extent occupying extensive plains areas, it also typically lies as broad belts around the bases of the many southwestern mountain ranges, principally at elevations of 3000–3500 ft. South of the border it extends far into Mexico and, as Clements (1920) suggests, the center of the desert grassland probably lies in Mexico.

B. Climate

Although the desert grassland is the most arid of all North American grassland regions, it is more correctly classified as semidesert than as a true desert. Mean annual precipitation ranges from about 12–18 inches in the west to 20–30 inches in the east. Over most of the area this falls largely during two seasons, summer and winter. Wind velocities and summer temperatures are high and consequently evaporation rates are also high.

C. Vegetation

The desert grassland concept used here corresponds essentially with that of Shantz' desert grassland and desert savanna (Shantz 1924). Shreve's desert grassland transition (Shreve, 1917) is identical in part but also includes rather extensive areas, largely in eastern New Mexico and the Staked Plains area of western Texas that are classified

* Excerpted in part from "The Desert Grassland" (Humphrey, 1958). The reader is referred to this publication for a more complete discussion.

Fig. 9. Excellent-condition desert grassland with *Yucca elata* in southern New Mexico. The good ground cover of perennial grasses provides a good fuel base for the occasional fires that still occur.

as short grass or tall grass by Shantz. Clements' desert plains (Clements, 1920) includes much the same area as Shantz' desert grassland.

Three genera, *Bouteloua, Hilaria,* and *Aristida,* provide most of the grass species in the type. Although *Bouteloua* is represented by many perennial species, *B. eriopoda, B. gracilis,* and *B. curtipendula* are probably the most abundant. In the genus *Hilaria,* three species, *H. mutica H. belangeri,* and *H. jamesii,* are most common. Although several species of *Aristida* are prevalent, four of the most common are *A. divaricata, A. hamulosa, A. glabrata,* and *A. longiseta.* Other grass genera characteristic of at least part of the area are *Andropogon, Eragrostis, Heteropogon, Leptochloa,* and *Trichachne* (Fig. 9).

The woody plant growth is extremely diversified, being derived in part from the southern desert shrub below, in part from the chaparral, pinyon-juniper, and oak woodland above. Although shrubs, low-growing trees, and cacti were always present to some extent in the desert grassland, they were originally largely restricted to drainages that supported little grass or to rocky or shallow soil areas.

In spite of the large number of woody taxa, only a few comprise the bulk of the trees and shrubs; three varieties of *Prosopis juliflora* are outstanding. As classified by Benson (1941), these are the varieties: *velutina*, *torreyana*, and *glandulosa*. Other shrub taxa that are locally or generally abundant include *Larrea tridentata*, *Acacia*, *Opuntia*, *Yucca*, *Flourensia cernua*, *Aplopappus*, and *Gutierrezia*.

D. Vegetation Changes in Relation to Fire

Prior to the introduction of large numbers of domestic livestock into the Southwest, fires at rather frequent intervals appear to have been a characteristic feature of much of the desert grassland (Bracht, 1848; Bray, 1901, 1904a,b; Nunez, 1905; Cook, 1908; Thornber, 1907, 1910; Griffiths, 1910; Wooton, 1916; Humphrey, 1953, 1958). Although the buildup of large livestock numbers (primarily cattle) in the Southwest during the latter part of the nineteenth century somewhat antedated the development of an acute fire-control consciousness, there was, nonetheless, a reduction in fires dating back to this large increase in livestock. Many of the ranges were overstocked; some of them heavily so, by about 1880 (Wagoner, 1952). The resultant removal of forage or potential fuel must have reduced both the area and intensity of range grassland fires. Even so, the historical record shows that they still occurred frequently enough to have been an important factor in determining the plant composition of the desert grassland.

Within about the last 25–50 years the change in dominant life form has been so marked in some portions of the desert grassland that few or no vestiges of the original vegetation remain. And, were it not for early photographs, there would be little record today of many of the changes that have taken place. These changes have resulted in no little confusion in attempts to classify certain of these areas. For example, velvet mesquite is often popularly considered to be a characteristic dominant of the Sonoran Desert. Although a component of the Sonoran Desert vegetation, its presence on upland sites as the dominant woody species, very often with an understory of burroweed is a reliable indication of former grassland. Figures 10 and 11 show one instance of a complete change from the grasses that were at one time dominant to the mesquite and burroweed that are there today.

The historical and recent records of fires in the desert grassland and a knowledge of the physiological responses of grasses and woody plants to fire seem to me to leave little doubt that the invasion of the area by ligniphytes can be attributed largely to too few fires and too many cattle and horses.

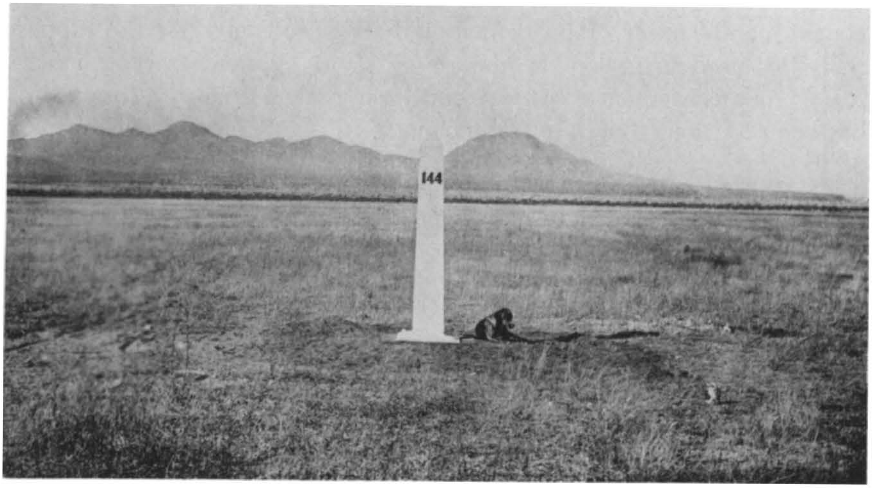

Fig. 10. Area along the United States–Mexico international boundary west of Tucson as it appeared in 1893. The line of trees in the background is growing on a major drainage channel. Compare this with Fig. 11.

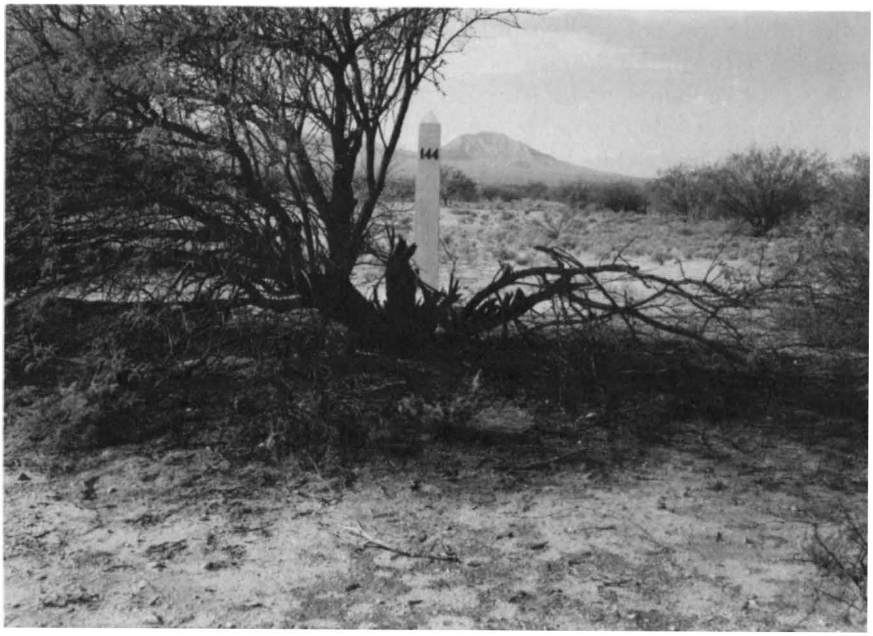

Fig. 11. Same view shown in Fig. 10, as it appeared in 1956, 63 years later. The grasses that dominated in 1893 are all gone, replaced by burroweed (*Aplopappus tenuisectus*) and velvet mesquite (*Prosopis juliflora* var. *velutina*).

All who have studied the situation, however, do not agree with this. Hastings and Turner (1965) conclude that "there is no reason to suppose that fires used to sweep the desert grassland frequently or on a large scale." As a consequence they "reject the hypothesis that fire suppression has been a primary cause of the changes" in plant composition. In place of fire they propose the hypothesis that the shrub increase and grass decrease are primarily a result of a gradual trend toward higher temperatures and lower precipitation. Space does not here permit a detailed discussion of Hastings and Turner's conclusions, but their publication will be of no little interest to those who wish to explore their analysis more deeply.

E. Vegetation Characteristics as Related to Fire Frequency

The line of demarcation between the desert grassland and the Sonoran and Chihuahuan deserts seems to have been determined in large part by the ability of the vegetation to carry fire. Where precipitation or soil moisture permitted the growth of enough grass to carry fire, periodic burning kept the shrubs in check. Where fuel was inadequate the shrubs grew unchecked. Thus, it might be said that shrubs in this area occurred where there was not enough precipitation to grow enough grass to carry enough fire to kill the shrubs.

Fires in timbered areas leave signs that may persist for decades or even centuries; the evidence of grassland fires is usually soon gone. As a consequence, while historical records are only one of several sources of information on early fires in forests, they are almost the only means of determining the occurrence of former grassland fires. Fortunately, the historical record is fairly adequate and generally appears to be reliable.

F. The Historical Record

1. *The Early Record*

The earliest account of grassland fires in the Southwest that has come to my attention is an account by Cabeza de Vaca relating to his travels in southeastern Texas in 1528. In the words of de Vaca (Nunez, 1905):

> The Indians go about with a fire brand, setting fire to the plains and timber so as to drive off the mosquitos, and also to get lizards and similar things which they eat, to come out of the soil. In the same manner they kill deer, encircling them with fires, and they do it to deprive the animals of pasture, compelling them to go for food where the Indians want.

The U.S. Department of Agriculture had a number of workers in the Southwest in the late nineteenth and early twentieth centuries studying range problems. The observations of these men are particularly valuable, coming as they did, at a time when the pressures of settlement were beginning to be expressed in vegetational changes. Three of the early workers in southern Arizona, David Griffiths, botanist with the Arizona Agricultural Experiment Station and the U.S. Department of Agriculture; E. O. Wooton, with the U.S. Department of Agriculture; and J. J. Thornber, botanist at the Arizona Station, were all active in southern Arizona about the beginning of the twentieth century, and all studied or commented on the effect of fires in the desert grassland. W. L. Bray and O. F. Cook were equally active with the U.S. Department of Agriculture in Texas at about the same time.

The conclusions reached by these early workers as set down in their own words provide us with a credible record. Note, as we examine these, the degree to which they agreed on the general effect of grassland fires, even though they did not all work in the same areas.

First, quoting Bray (1901) in his observations and conclusions on Texas ranges:

> Regarding the establishment of woody vegetation it is the unanimous testimony of men of long observation that most of the chaparral- and mesquite-covered country was formerly open grass prairie. . . . 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.

Bray was familiar with the Edwards Plateau of Texas at a time when parts of it were still primarily grassland in spite of the rapid encroachment of shrubs. Note, for example, his comments on this area at about the turn of the century (Bray, 1904a):

> If the Edwards Plateau were an uneroded highland, its vegetation would, under natural condition, be open grass prairie. As a matter of fact . . . it is in process of transformation from a grass prairie to timberland. This transformation is being hastened by the interference of man. Both agriculture and grazing have operated to prevent the recurrence of prairie fires, which, so long as they were periodic, kept the field swept clean of woody vegetation. The grass throve under this burning; seedlings of trees were killed.

And Bray (1904b):

> This struggle of the timberlands to capture the grasslands is an old warfare. For years the grass, unweakened by overgrazing of stock, and with the

> fire for an ally, held victorious possession. Now the timber has the advantage. It spreads like infection. From the edge of the brush each year new sprouts or seedlings are pushed out a few feet farther, or, under the protection of some isolated live oak or briar or shrub, a seedling gets its start, and presently offers shelter for others. This has been going on all along, but in former days these members of the vanguard and the scattered skirmishers were killed by the prairie fires, and the timber front was held in check or driven back into the hills.

Cook (1908) also writing primarily of Texas, and at about the same time, concluded:

> 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 that swept over these prairies were very besoms 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. That such fires were evidently the cause of the former treeless condition of the southwestern prairies is also shown by the fact that trees are also found in all situations which afford protection against fires. . . . Nor is there any reason in the nature of the climate or the soil why trees should not thrive over the vast areas of open prairie land.

In the same publication he comments as follows on the use of fire by the early white settlers:

> Settlers in south Texas early adopted the practice of burning over the prairies every year; partly to protect their homes against fires, partly to give their cattle readier access to the fresh growth of grass. The fires were often set near the coast, the strong breeze which blows in from the Gulf spreading the flames over many square miles. While the grass was still abundant these annual burnings were able to keep the woody vegetation well in check. . . .

The conclusions reached by Bray and Cook in Texas had their essential counterpart in southern Arizona studies at about the same time (Griffiths, 1910):

> 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. . . . Previously, before the country was stocked, it probably produced more grass than it does now, and was frequently burned over, the fire extending down as far as vegetation would permit. Such burning did comparatively little injury to the grasses, but was very destructive to all small shrubs; consequently, these were able to exist only along the sandy washes where the grasses were least productive, and upon the lower areas, where fires did not molest them. . . . The main factor, through, 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 to-day be covered with brush and trees. . . . In short, the same laws apply here that govern in our great prairie states . . . where the treeless plains were kept so by frequent fires.

Thornber (1907), writing of the same area, noted that even at that time fires were not infrequent, two of them occurring within a space of about 5 years. One of these he recorded as burning unchecked for 2 days. A variety of shrubs was killed by these fires including creosotebush, burroweed, mormon tea (*Ephedra trifurca*), desert hackberry (*Celtis pallida*), velvet mesquite, and palo verde (*Cercidium*). In conclusion he stated: "That such fires burning over the mesas and foothills have not been uncommon in times past may be judged by the fact that in many places abundant remains of charred stumps of at least 10 years duration are frequently met with."

Roughly 30 years later I had the idea that some vestiges of charring might still be found if one looked in the right places. With this in mind, I examined a number of the older mesquite trees along some of the major washes in the same area where Thornber's observations had been made. Thirty-two trees with a basal diameter of 12 inches or more were examined, 17 with a diameter of 12–14 inches, and 15 with a diameter greater than 14 inches. Out of the 17 in the smaller size class only one bore visible charcoal scars as contrasted with two-thirds of those in the 14-inch-plus class (Humphrey, 1953). These trees were growing on the rock banks or bottoms of washes where grass growth had apparently been too sparse to burn with enough heat to kill the trees. The fires had, however, damaged the trees enough to leave evidence of their occurrence when I examined them in 1935.

Although fires in this area (The Santa Rita Experimental Range, which lies about 40 miles south of Tucson) are almost unknown today, the written record indicates that they occurred rather frequently as late as 1916. Wooton (1916) has provided us with the last known statement of the prevalence of fires on this experimental range:

> The complete protection of the reserve for a number of years has resulted in a rather heavy crop of dry grass, which burns readily, especially in the dry hot weather of May or June, just before the summer rains begin. Several such fires have occurred, due to lightning, carelessness of passers, or incendiarism. . . . In June, 1914, occurred one of the largest and hottest fires, which burned over about four sections [2560 acres] of the heaviest grass.

Although there are no known photographs showing fires in this area, there are several that show the vegetational changes that have taken place (Figs. 12 and 13).

Fig. 12. Cutting hay on the Santa Rita Experimental Range in 1903. Trees in the background occur largely along drainages. Compare this photograph with Fig. 13 (U.S. Forest Service photo.)

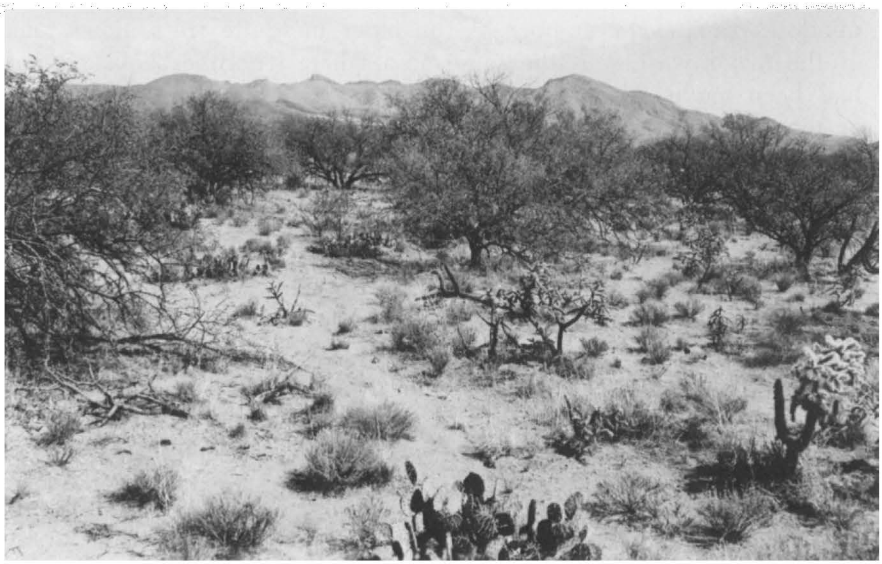

Fig. 13. Same area shown in Fig. 12 but rephotographed in 1964, 61 years later. An intermediate photo taken in 1941 only 38 years after the first, showed an equally dense stand of woody plants and little grass, much as in 1964 (U.S. Forest Service photo.)

2. *More Recent Studies*

A study was made in this area (Reynolds and Bohning, 1956) to determine the effect of fire on specific species of shrubs and grasses

The ground vegetation, although rather sparse, was sufficiently heavy to permit a fire to run and give a fairly complete burn. The effects of the fire, as expressed in percent mortality of individual species, showed the following: burroweed, 88; barrel cactus (*Ferocactus wislizeni*), 67; jumping cholla (*Opuntia fulgida,* 44; cane cholla (*O. versicolor*), 42; prickly pear (*O. engelmannii*), 28; and velvet mesquite, 9. *Calliandra eriophylla,* the most valuable browse plant in the area, was burned to the ground, but none of the plants was killed. Four years later the *Calliandra* plants had a greater crown density than on the adjacent unburned check area.

It might seem, offhand, that the kills reported in this study might not be sufficient to maintain a range essentially free of woody plants. The authors point out, however, that difficulty was experienced in obtaining a uniform burn due to inadequate fuel in the vicinity of mesquite trees. Previously, when fires occurred frequently, there were apparently no mature mesquites on this and similar areas. As a consequence, the grasses grew unhampered by competition from trees, and the fires would have been hot enough to be much more destructive than they now are. An additional feature of importance was the relative frequency of occurrence of fires, a frequency that prevented most of the woody plants growing to larger than seedling or near seedling size. These would have been more readily killed than larger, more mature plants. In addition, only occasionally would they have matured sufficiently to produce seed. This would have further reduced the potential number of new plants.

Cable (1967) studied the effects of burning in an area similar to and adjacent to the one investigated by Reynolds and Bohning. His observations were in part as follows: "Mesquite seedling establishment was significantly higher on the unburned area than on the burned area. Burroweed was easily killed by burning," the kill ranging between 92 and 98%. From 32 to 64% of the cactus plants were killed by one burn, few by a second.

Photographs of this area taken in 1903 show an open grassland with a dense stand of grasses capable of carrying a hot fire (Fig. 12). By the time of Cable's 1967 study the area had for many years been dominated by a variety of woody species. The remaining grasses were often too sparse to carry a fire. Thus fire effectiveness as a medium for controlling most woody plants must have been far different than it had been some 50–60 years earlier.

A nearby study by Blydenstein (1957) indicated the relationship between velvet mesquite mortality and size. He concluded that although a single fire does not result in a high mesquite mortality it does reduce the size of many of the larger trees by killing them back to ground level and that there is a high correlation between tree size and fire damage, i.e., fire is most efficient in controlling newly established stands.

G. Conclusions

There still remain in the desert grassland extensive areas that are essentially free of woody plants. The question is sometimes raised whether these uninvaded grasslands may not refute the universality of the fire-control theory for the desert grassland. Whether they do or not cannot be stated with certainty. It is unfortunate that the answer to a question of this sort must be based on opinion, no matter how well-considered such an opinion may be. However, with the assumption that an opinion based on many years of study may be largely objective and consequently of value, my opinion and supporting facts are given for what they may be worth.

In contrast to much of the Great Plains area, most of the open, grassy portions of the desert grassland appear to have a soil and a climate suited to growth of woody plants. Insofar as data are available no caliche or other hardpan layer seems consistently to typify these grasslands. The precipitation is similar to that on adjacent areas that do support shrubs. As further evidence that these grasslands are capable of growing ligniphytes, many of them are being encroached upon by trees and shrubs from nearby drainages, hillsides, or other areas.

Occasional fires still occur in the desert grassland. Although infrequent, these fires do act as a deterrent to shrub invasion. An additional point that may explain in part today's still rather extensive ligniphyte-free desert grassland ranges, and one that is rarely considered is that very little time has elapsed in the brief period since the days of the Indian and uncontrolled fires. Fires have been controlled in this area largely only during the last 60–70 years, a short period in terms of invasion and establishment of the trees and shrubs involved.

Initial invasion of the open grassland may be seen in many areas even today. This invasion is usually linked with cattle movements from mesquite-infested areas. There seems to be little doubt that lack of invasion is often due to failure of seeds to be transported to the open grasslands. Recent invasions often are an indication of a change in the grazing pattern that results in seeds being brought in where none were before.

The fire history of the desert grassland raises the question: Is fire a practical tool to use today in controlling woody plant invasion in this type? The answer cannot be given as a clear-cut yes or no. Many aspects of the total picture have changed during the last 75–100 years. When the desert grassland ranges were grazed only by deer, antelope.

and other game animals, much of the annual production of forage was left ungrazed and served as a source of fuel that carried fires readily and produced a flame hot enough to kill most woody plants that might lie in its path. By comparison, today the grasses usually do not have either the density or volume to carry a hot fire, or often, any fire at all. Grazing removes much of the growth that is produced, further reducing the possibility of obtaining an effective burn.

The size of the plants that must be controlled today adds to the difficulty of obtaining effective control by fire. Previously, when fires were frequent, it is probable that few trees or shrubs in the grassland survived long enough to develop much beyond the seedling stage. As small plants they were highly susceptible to killing by fire and rarely lived to be old enough to set seed. This restriction of a potential seed source must, in itself, have been of no little importance in maintaining the grassland in an essentially shrub-free state.

It takes little imagination to visualize the change that has taken place in the potential for control of the woody plants by fire. Instead of the occasional small shrublike plants lying in the path of the hot fires of former years, today we have mature trees, often with stem diameters up to 10 and 12 inches and possessing relatively thick, fire-resistant bark. The former hot fires that might have been effective in killing even these large trees are today too weak to be lethal. On the other hand, they will kill new reproduction, thus not only reducing the rate of shrub invasion but actually reversing the trend. In many situations recurrent burning at 5- to 10-year intervals would probably be an effective and cheap method of control. A long-term study is needed to determine not only the broader aspects of this problem but also specific items such as the most desirable fire frequency, effectiveness with various kinds of grasses and woody plants, and the relationship between fire and size of woody plants.

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