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**Ensuring Sustainable Development
of Arid Lands Through Time**

Esteban A. Herrera
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Editors

NEW MEXICO ACADEMY OF SCIENCE • 1999

Additional papers examine the future of agriculture in two contexts: the use of irrigation water, and the future of biotechnology in arid land agriculture. Finally, the renowned Dr.

Gerald Thomas, President Emeritus of NMSU, looks ahead by discussing our history of use, abuse, and restoration of agriculture lands.

This issue of the *New Mexico Journal of Science* focuses on sustainable development with an emphasis on the Chihuahuan Desert. The desert is shared by two nations that realize ecosystems know no geopolitical boundaries. Thus, the environment, people, plants, and wildlife share an interdependent future.

Sustainable development requires that the region's people work together to find long-term solutions that protect the regional economy, environment, and quality of life of all inhabitants.

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Contents

Forward	xi
<i>J.G. Schickedanz</i>	
The Past	
Anasazi Agriculture: Recipe for Success?	3
<i>I.S. Cordell</i>	
Sustainability: The Long View from Archaeology	23
<i>P.E. Minnis</i>	
The Present	
The Chihuahuan Desert Ecosystem	45
<i>R.F. Beck and R.P. Gibbens</i>	
Farming in New Mexico: Soil Quality and Productivity Maintenance	86
<i>A.L. Utery and A.J. Tugel</i>	
The Evolution of New Mexico Water Law	109
<i>C.T. DuMars</i>	
Remote Sensing Technology for Development Planning Along the US-Mexico Border: Hydrogeology and Geomorphology	123
<i>A. Granadas-Olivas and H.C. Monger</i>	
Alternative and New Crops with Lower Water Consumption	138
<i>N. Puppala and J.L. Forester</i>	
Agricultural Solid Waste: Trash to Treasure	154
<i>R. Flynn</i>	
Solid Waste: Trash to Treasure in an Urban Environment	166
<i>G.W. Dickerson</i>	
Improving Sustainability of Arid Rangelands	174
<i>K.M. Haerstad</i>	

The Chihuahuan Desert Ecosystem

R.F. Beck and R.P. Gibbens³

Abstract

The Chihuahuan Desert is the least known of all the deserts in North America. It is the largest of the deserts and lies east of the Continental Divide between two mountain ranges in Mexico: the Sierra Madre Occidental in the west and the Sierra Madre Oriental in the east. On the south it borders mountains in Zacatecas and San Luis Potosi, and to the north it opens onto broad valleys, basins, and high plains in New Mexico and west Texas. Because of its high elevation, averaging 1400 m above sea level (4,593 feet above sea level), it is cooler than the other hot deserts in North America. Average precipitation is 235 mm/year (9.3 inches/year) and annual average temperature is over 18°C (64°F). Freezing temperatures in winter characterize the northern

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part of the desert, but are infrequent in the central and southern regions.

A great variety of animals and plants live in the desert and characterize the wide variety of habitats resulting from the physiographic and climatic conditions found there. Much of the vegetation is desert scrub, with grasslands and woodlands in more mesic areas, usually uplands associated with the small mountains that dot the landscape.

Large numbers of people live in and near the Chihuahuan Desert. As the human population continues to expand, more and more demands will be placed upon the limited resources of the Chihuahuan Desert. In this chapter we hope to present the wide variety of life and conditions that make the Chihuahuan Desert.

Introduction

The Chihuahuan Desert is the largest desert in North America. It is named after the state of Chihuahua in Mexico. The word Chihuahua is a Tarahumara word meaning "in the workshop" or "place of a workshop" (Medellin-Leal 1982). The first published report on the condition of the desert in the province of Coahuila was in 1812 by Ramos-Arizpe, deputy before the Cortes de Cadiz (Medellin-Leal 1982). A vague reference to a "Chihuahuan Region" was made by Hinde in 1843 (in Morafka 1977a) and a "Chihuahuan Desert Region" was delimited by characteristic vegetation by Harshberger in 1911 (in Shreve 1942). Shreve (1942) used the term "Chihuahuan Desert," as did Dice in 1943 (in Morafka 1977a), and the name Chihuahuan Desert was firmly established.

Because of its size and great variety of landscapes, there have been only a few published reports treating the whole desert. Most information about the desert comes from specific

research articles or regional reports dealing with one or only a few subjects. Morafka (1977a), using herpetofauna (amphibians and reptiles) population distributions, divided the desert into three regions. The Trans-Pecos is the northernmost region, which constitutes nearly 40% of the total area of the Chihuahuan Desert. It includes all of the US portion and a large share of the desert in Chihuahua. The middle region, Mapimian, is found in the eastern part of the Mexican states of Chihuahua, Coahuila, and part of Durango. In this region, basins and playas are common. The southern region is the Saladan, found in the states of Zacatecas and San Luis Potosi. Of all the regions it has the greatest differences in elevation, from 500 to 2500 m above sea level (1,640 to 8,202 feet above sea level).

The Chihuahuan Desert, because of its size and variations in landscape and elevations, is difficult to adequately describe in detail. In this chapter we propose to briefly describe the physical as well as the biotic portions of the desert. More emphasis will be placed on describing the Trans-Pecos region, since New Mexico is part of this region. We will describe not only current environments, but also will make reference to past climates and floras and changes that have taken place. In mentioning and describing vegetation types, plants, and animals that occur in the desert, we will use only common names (scientific names for all species are listed in the Appendix, page 84).

Dramatic changes have taken place in more recent times, such as compositional changes in plant communities, increased water use for an expanding human population, and the threatened loss of animal species across the desert. In some areas the loss of soil through erosion has been extensive. The Chihuahuan Desert is wrought with threats to its future (Havstad 1998). These threats are occurring as more and more people live in and around the Chihuahuan Desert and make demands on its limited resources. Havstad (1998) suggests three threats to the future integrity of the desert: 1) demand for water, 2) continued desertification of the land and the lack of afford

able technologies to remedy degradation, and 3) the diatribe among user groups about management and use of resources.

With this chapter we hope to inform the reader of the great complexity of this area called the Chihuahuan Desert so that people will come to appreciate its importance in the North American landscape.

Location and Size

The Chihuahuan Desert lies between 20° and 35° north latitude, and between longitude 98°45' and 109°15' west (Medellin-Leal 1982). MacMahon (1988) proposes that the desert extends further north to 36.5° north latitude. The Chihuahuan Desert is the largest in North America and is the only desert east of the Continental Divide. Van Devender et al. (1987) give a general, but appropriate, description of the Chihuahuan Desert location: "north of the highlands of the Mexican Plateau, west of the Sierra Madre Oriental, east of the Sierra Madre Occidental and south of the Rocky Mountains."

However, not all authors agree on size (table 1). The differences in estimates of size have to do with how the boundaries are defined between the Chihuahuan Desert and adjacent, more moist vegetation types. The delineation of boundaries de-

Table 1. Estimated size of the Chihuahuan Desert by different authors using different criteria.

Author	Area (km ²)	Criteria
Abell et al. 1997	629,000	Biodiversity
MacMahon 1988	453,000	Vegetation
Morafka 1977a	450,000	Herpetofauna distribution
Henrickson and Straw 1976*	378,000	Vegetation
Schmidt 1986	357,000	Climate

*in Medellin-Leal 1982

pend on the width of recognized ecotones and the purpose of the classification.

MacMahon (1988) notes that the boundaries are similar whether delineated for climate, herpetofauna, or vegetation. Medellin-Leal (1982) points out that some discrepancy occurs because of difficulty in identifying and excluding small mountain chains, which have more moist environments than surrounding desert lands. Whether to include or exclude has led to some of the discrepancy. Another part of the problem in defining the boundary is that not everyone agrees on the meaning of "desert," which then affects the width of the ecotones.

For the most part, trying to identify limits in general is not important, but may be critical for specific situations where one is attempting to demarcate a particular habitat or range of a species or comparing populations among areas. This is especially true for the World Wildlife Fund, which recognizes the Chihuahuan Desert as one of the most biologically rich and diverse deserts in the world (Abell et al. 1997). Because of their interest in conserving habitats to maintain this diversity, they tend to include more land forms and ecotones than other authors.

The size of the desert in New Mexico depends on criteria used to describe the desert. Brown (1982) notes that the Chihuahuan Desert is primarily scrub and is dominated by creosote-bush, and in some sites creosotebush is co-dominant with tarbush. If this is used as an indicator of the desert in New Mexico, then, according to Garrison and McDaniel (1982), the size is about 36,900 km² (14,247 square miles), which is 12% of the state's land area. Maker et al. (1974), in describing the soils of New Mexico, placed nearly 79,900 km² (30,849 square miles) into the warm desertlike soil category. Limiting the size of the desert only to lands where creosotebush occur does not take into consideration mesquite and other shrubs, and areas dominated by grasses. Dick-Peddie (1993), like Shreve (1942), considers these mesquite-grasslands to be an ecotone between desert scrub and semidesert grasslands. These mesquite-grass

lands are included in the desertic soils described by Maker et al. (1974). MacMahon (1988), in writing about the whole desert, states that desert scrub covers 70% of the Chihuahuan Desert, and the creosotebush complex covers 40% of the area. Medellin-Leal (1982) adds further confusion by stating that the small mountain ranges and areas above 1800 m (5,905 feet), which are excluded by Schmidt's (1979, 1986) definition of the desert (fig. 1), should be counted because they are highly influenced by the surrounding desertic conditions.

The size of the desert depends on one's interests. Within New Mexico the size of the desert probably falls somewhere within the extremes cited above. Much of the difference among those estimates is whether the Pecos Valley and surrounding plains are included.

Physiography

The Chihuahuan Desert is mainly in the Mexican Highland section of the Basin and Range Province (Hawley 1975; MacMahon 1988). Generally most of the Chihuahuan Desert occurs between the Sierra Madre Occidental and Sierra Madre Oriental. There are high mountains (> 3000 m, or > 9,842 feet) in northern Zacatecas and northern San Luis Potosi, forming the southern boundary (Schmidt 1986). The northern part of the Chihuahuan Desert adjoins the southern Rocky Mountains, and the Guadalupe, Sacramento, and Gila Mountains. It also adjoins the high plains of the Llano Escacado in eastern New Mexico and west Texas, and the Edwards Plateau Region.

There is a general increase in elevation progressing from 400 m (1,312 feet) in the northeast corner along the Rio Grande (Brown 1982) toward the southwestern area, where elevations exceed 2500 m (8,202 feet) (Medellin-Leal 1982). Elevational changes from north to south are less pronounced. Medellin-Leal gives an average elevation of 1400 m (4,593 feet) for the desert.

The northern parts of the desert are drained from the north by the Rio Grande and its tributary, the Pecos River, and from

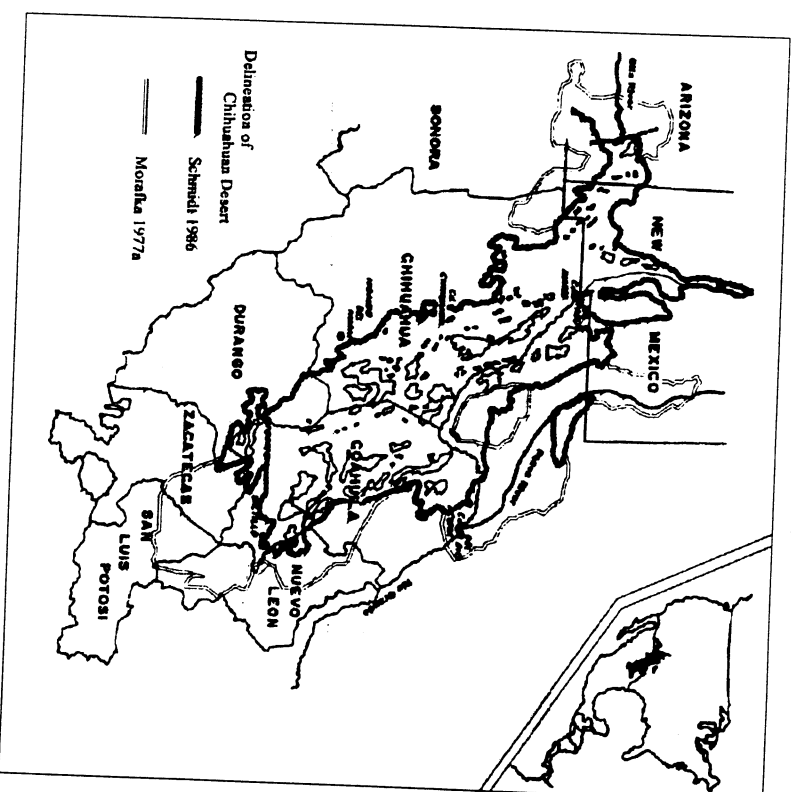


Figure 1. Two delineations of the Chihuahuan Desert: Schmidt (1986) using de Martonne's Index of Aridity, and Morafka (1977a) using biota, mostly herpetofauna distributions. Schmidt considers mountain masses above 1800 m (5,905 feet) not to have a desert environment. Morafka also considers some of the higher mountain-islands within the desert not to be part of the desert because they support different biota.

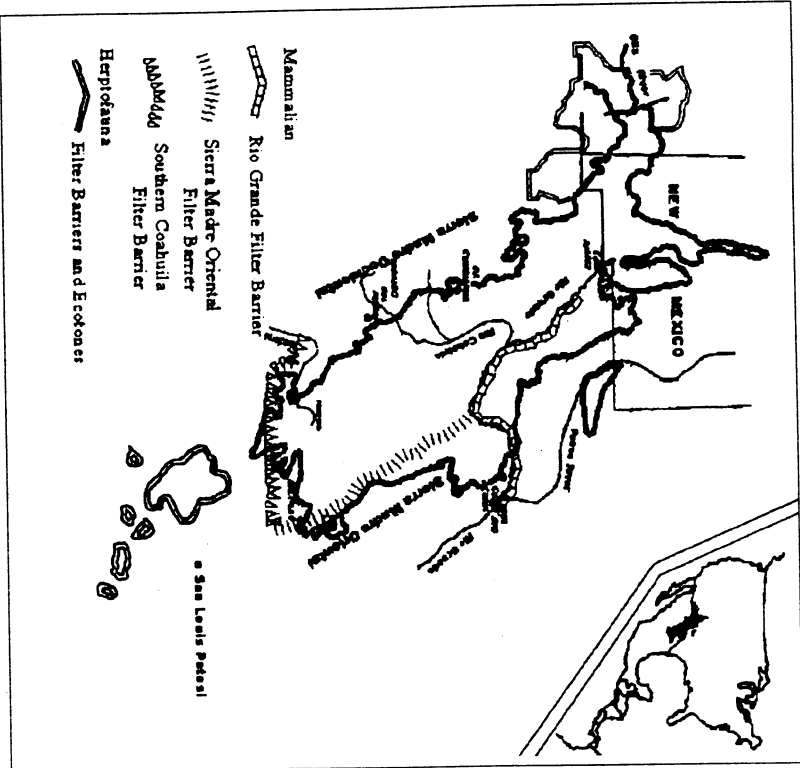


Figure 2. The major rivers and filter-barriers in the Chihuahuan Desert. Note that the central and southern parts of the desert have mostly internal drainage. The major filter-barriers for mammals are described by Schmidt (1977). The filter-barriers and ecolones for herpetofauna are delineated by Morafka (1977b). Morafka's filter-barriers in the Saladan Region are adjacent to his boundaries of the Chihuahuan Desert (see fig. 1). His filter-barrier (Cochise) in south-eastern Arizona is similar to the area called "Apachean" by Abell *et al.* (1997).

the south by the Rio Conchos (fig. 2). In the northwest corner there is drainage into the Gila River. Schmidt (1986) estimates that 85% of the desert area is covered with closed basins with no external drainage, most of which occur in the central and southern portions. Playas are frequent in these closed basins and receive run-in from the neighboring hills and slopes or bajadas. The bajadas (or piedmont slopes) are frequently dissected by rills and arroyos, few of which have perennial flowing water.

The major part of the Chihuahuan Desert lithology originated as tectonically rising sea bottom strata (Medellin-Leal 1982) at the end of the Cretaceous and beginning of the Tertiary (66 million years before present, MYBP). This is when some of the Rocky Mountains and Sierra Madre Oriental, and much of the eastern part of the Chihuahuan Desert, formed from sedimentary rocks being uplifted or exposed by a receding sea, including regions in the northern part of the desert (Mack 1997). The western part, the Sierra Madre Occidental, is of igneous origin. Volcanic activity throughout the central highlands and north into the Rocky Mountains shaped much of the landscape on the western side of the desert.

Some of the landforms in the northern Chihuahuan Desert are from major uplifts in the late Cenozoic, which resulted in fault-bound mountain ranges, volcanoes, and corresponding basins (Mack 1997). These fault-bound thrusts brought Paleozoic and Precambrian rocks to the surface. Through the next several million years, sediments eroded from the large mountain ranges into the basins.

By the middle of the Tertiary (35 MYBP) great volcanoes emerged in southern New Mexico and west Texas. These large volcanoes deposited huge amounts of ash, often more than 20 m (66 feet) thick, at distances greater than 200 km (124 miles) from the volcano; in some calderas, the ash is thousands of meters deep (Mack 1997). About 5 MYBP, there was another period of increased tectonic activity resulting from the extension of plates in the Rio Grande Rift. This resulted in the north-

to-south-oriented mountains and intervening basinal landscape, with which we are familiar today.

Starting in the Oligocene, the Rio Grande Rift had a major role in land formation that continues today (Monger and Mack 1999). The rift affects a much larger area than just the current river valley and neighboring uplands. A major factor was the eventual entrenching of the Rio Grande, which occurred near the middle of the Pleistocene about 800,000 YBP (Mack et al. 1998). Prior to this, the Rio Grande emptied into a large lake across southern New Mexico, west Texas, and northern Chihuahua. The eventual cutting by erosive action through the mountains and ridges, which dammed the river, allowed water to flow from the Rocky Mountains to the Gulf of Mexico (Hawley 1975). This entrenchment resulted in a lowering of floodplains along the Rio Grande and its tributaries. However, some intermountain basins, such as the Jornada del Muerto and Tularosa, have continued to aggrade because they have no external drainage (Monger and Mack 1999). These basins generally have alluvial fans in a stepped sequence rising from the basin floor up the piedmont slope to the neighboring mountains. This is a common landform found throughout much of the central and eastern Chihuahuan Desert.

Soils

Within the Chihuahuan Desert many soil types occur because of its vastness, physical features, and age differences (Gile et al. 1981). Because of the aridity and limited plant growth, many soils of the Holocene age are immature and not well developed. In contrast, soils of Pleistocene age have well-developed horizons. Within New Mexico, Maker et al. (1974) recognized 22 associations in the warm desertic region where the Chihuahuan Desert is found. Active sand dunes found in Chihuahua and New Mexico characterize one extreme of soils with little, if any, development. These soils are comprised of sand-sized particles,

either silica (most common) or gypsum based, such as those in the White Sands in the Tularosa Basin.

The upper parts of the bajadas and ridges surrounding the basins and the valleys along the rivers generally are coarser textured soils, which allow more water penetration. Further down the slope, soils are periodically covered by outwash from upper slopes, resulting in buried profiles. In the basins or playas, fine textures, silts, and clays accumulate from the slopes above, and silty loams and clay-textured soils are common. Gypsum and alkaline soils frequently characterize the lower slopes and run-in areas. Saline soils are common throughout many basins in the desert (Henrickson 1977). These playas are generally covered by water for at least a few days each year.

Throughout the desert, a calcium carbonate layer (accumulated from the deposition of air-borne particles and microbial precipitation) is present within a few centimeters to a meter or more of the soil surface (Gile et al. 1966; Monger et al. 1991). The depth to the calcium carbonate deposits depends on slope, texture, amount of precipitation, and total run-in.

In some locations, a surface pavement of small stones occurs. This desert pavement exists because the fine-textured particles have washed or blown away, leaving the larger particles, such as small rocks, that characterize the surface. Some surface pavements form when eolian particles accumulate beneath the stones, causing the pavement to rise (McFadden et al. 1987). On other areas, particularly in the desert scrub on the upper bajadas, a resinous material from plants, particularly creosotebush, covers the soil and cause it to be hydrophobic (Barbour et al. 1999). These conditions add to the runoff, limiting water availability for plant growth and soil development.

Climate

The climate of the Chihuahuan Desert is caused by the orography, elevation, and continentality of the region. The southern part of the Chihuahuan Desert extends into the subtropical lati-

tudes, but much of the climatic influence from the south is restricted by high mountains, > 3000 m (> 9,842 feet), in San Luis Potosi and Zacatecas. The Sierra Madre Occidental and Sierra Madre Oriental block storm paths from the west and east, respectively, and cause adiabatic cooling and precipitation near the mountains' windward sides and greater aridity on the leeward sides. The desert opens to the north through the Rio Grande Valley and high plains of west Texas and eastern New Mexico. This lack of a barrier allows polar cold fronts to extend southward into the central part of the desert. The north to south ridges of mountains in New Mexico and west Texas (Saramento, Guadalupe, Organ, and Franklin Mountains) sometimes act as barriers, keeping polar fronts on the high plains of west Texas and eastern New Mexico from reaching into the Rio Grande valley, southwest New Mexico, and northwest Chihuahua.

Paleontological records of vegetation and animals can describe past climates. This relation depends on the idea that vegetation reflects the climate in which it grows. Van Devender et al. (1987) warn against taking vegetation changes as highly reliable indicators of past climates. In making the connection that plants reflect climate, one has to assume that climatic gradients and landscapes in the past were similar to what they are today, which may not be the case. Also, plant communities may not change as rapidly as climate, but might lag behind a climate change. In other words, the vegetation that is present, particularly long-lived species, may not change as quickly as the climate. Thus, changes in vegetation may give an indication of direction of climatic change, but not necessarily the amount or rate of change. Van Devender et al. (1987) point out that pack rat middens are good sources of past plant assemblages that might be used as indicators of past climates. They state that modern vegetation throughout the region is much different than that present in the Wisconsin glacial period. Modern vegetation, and, therefore, current climates, have only been

present for 8900 years, and much of the vegetation type has been present for less than 5000 years.

Schmidt (1986) defined the Chihuahuan Desert as having an elevation below 1800 m (5,905 feet); anything higher he defined as desert mountain (fig. 1). He estimated that 90% of the area is between 1100 and 1500 m (3,609 to 4,921 feet). He examined long-term climatic records from 140 recording weather stations across the desert. The mean elevation of these stations is 1235 m (4,052 feet). The results of his survey show that the mean annual temperature is 18.6°C (65.5°F) with a range between 14° and 23°C (57° and 73°F). Temperature extremes greater than 50°C (122°F) to less than -15°C (5°F) are not common. Temperatures in the Trans-Pecos region are generally 3° to 4°C (5.4° to 7.2°F) cooler than in southern locations. Average high summer temperatures are similar among stations across the desert, but temperatures in the winter are much lower in the north than in the south.

Diurnal temperature changes of 15° to 20°C (27° to 36°F) from daily lows to highs are common (Schmidt 1986). Generally the greatest temperatures spread is in late spring and early summer when humidities are low and there is much cooling during the night. The differences between yearly minimal and maximums is 60°C (108°F) (Medellin-Leal 1982). Freezing temperatures occur across the northern latitudes of the desert more than 100 nights a year at some locations (Brown 1982). Frost-free periods generally last from March to October and vary from 200 to 250 days in the northern part of the desert. Frosts are less common in the southern part of the desert, but because of the high elevation, all areas may receive freezing temperatures.

Most of the desert is 400 to 700 km (249 to 435 miles) from the nearest ocean. Orographic barriers around much of the desert block moist air from the oceans. On the windward side of the mountains, the air is uplifted and most moisture is precipitated out, allowing cool, dry air to descend into the desert proper. As the air descends, it heats up, evaporating moisture

from plants and soils on the leeward side of the mountains. This evaporation, along with the rainshadow effect, is responsible for the extreme aridity along the leeward side of some mountain ranges. The average annual rainfall across the desert is 235 mm (9.3 inches) and ranges from 150 to 400 mm (5.9 to 15.7 inches) (Schmidt 1986). Sixty-six percent of the weather stations that Schmidt studied receive between 225 to 275 mm (8.9 to 10.8 inches) of annual precipitation. Most of this comes in the form of rain, though snow does fall on one or two occasions most winters in New Mexico. The snow usually melts within 24 hours. Total annual evaporation from a free-water surface is usually 10 or more times greater than the total annual precipitation at most weather stations. Greatest evaporation occurs in May and June.

Most winter storms originate in the Pacific, and much of the precipitation falls near the coast or in bordering mountains (MacMahon 1988). During spring the storm track moves north, which causes reduced easterly air flows from the Pacific. Therefore, spring is generally dry and, for the Trans-Pecos region, it is the windiest season. The reduced easterly air flow allows a westward shift of the Bermuda High from the Gulf of Mexico into eastern Mexico (Schmidt 1986). This high-pressure system causes a westerly flow of winds carrying moist air from the Gulf of Mexico into the Chihuahuan Desert. This moist air allows for cloud formation and precipitation resulting from convective activity. Thunderstorms form because of hot daytime temperatures that cause the air to rise, and because of updrafts from local desert mountains.

These summer thunderstorms generally are intense, but usually only last a few minutes and cover a limited area. Often much of this precipitation runs off and is not a reliable indication of the amount that infiltrates the soil and is thus available for plant growth. In contrast, winter rains generally are of less intensity and last longer, allowing more water to infiltrate the soil. Nearly all of the desert receives more than 70% of its annual precipitation from May through October (Schmidt 1986).

Maximum rainfall occurs in July and August. Generally, summer precipitation for the Chihuahuan Desert has been considered to be from the Gulf of Mexico (Collins 1969), while northwestern Mexico, Arizona, and southern California receive summer moisture from the Pacific. However, recent satellite images indicate that major storms originate near the equator in the Pacific. Under certain circumstances, these storms travel on a northeast path, carrying moisture across central and northwest Mexico into the Trans-Pecos region (Schmidt 1986). Scientists are learning more about ocean-surface temperature changes in the eastern tropical Pacific Ocean region. El Niño events are caused by the eastward movement of warm ocean surface waters from the western Pacific, which can be tracked with high precision, but the underlying causes are complex and not fully understood (McPhaden 1999). However, the El Niño-La Niña oscillations affect moisture content and trajectory of storms moving into Mexico and the southwestern United States and help explain anomalies in precipitation patterns.

Vegetation

Current vegetation of the Chihuahuan Desert ecosystem is the product of complex changes in both geologic and modern times. A diverse array of plants was necessary to occupy the many habitats produced by the receding seas, uplifting mountains, and volcanic deposits that eventually defined the physical setting of the desert. Many of the plants evolved in what is called the Madre-Tertiary Geoflora, which developed in the southwestern United States and northern Mexico under a drying climate from elements of the southern broad-leaved evergreen Neotropical-Tertiary Geoflora and the northern temperate, mixed deciduous Arcto-Tertiary Geoflora (Axelrod 1958). Plants of the Madre-Tertiary Geoflora are characterized by reduced leaf size (microphylls) in both the winter and drought deciduous types, with swollen stem bases for water storage. They are fleshy, with free-branching and cylindrical form (cacti), and the other nu-

merous adaptations to aridity and high temperatures that characterize desert plants today. By the beginning of the ice-ages in the Wisconsin period, most of the present-day species had developed, but were not necessarily in their present locations. There is considerable evidence to indicate that creosotebush, one of the most widespread shrubs in the Chihuahuan Desert, did not evolve in North America but is a relatively recent import, by way of avian transport, from South America (Wells 1977).

Glaciation caused widespread displacement of plants over the North American continent. Extensive studies of pack rat middens in the Southwest and radiocarbon dating of preserved plant parts have provided a good picture of plant communities as far back as the late Wisconsin-Holocene transition (Van Devender et al. 1987). Basically, at the end of the last glaciation (about 10,000 years ago), forests that presently occur at high altitudes were located at low elevations. Present-day desert species weathered the glaciation in different geographical or elevational ranges, different slopes, and in different plant communities. Pack rat middens indicate that modern desert shrub communities in the northern Chihuahuan Desert formed less than 4500 years ago (Van Devender and Burgess 1985).

To say that present vegetation of the Chihuahuan Desert is diverse is an understatement. The elevational range from 400 m (1,312 feet) to greater than 2500 m (8,202 feet), and about 1500 km (932 miles) of latitudinal range, includes a diversity of habitats with igneous rock, limestone, and gypsum parent materials providing substrates that vary from mountain ridges, slopes, and canyons to alluvial fans, fine-textured basins, saline playas, gypsum flats, sand, and gypsum dunes as well as freshwater springs, seeps, and rivers. These habitats support plant communities that also reflect the region's high temperatures and low, erratic rainfall. The Chihuahuan Desert's distinct ecosystem contains at least 1,000 unique species of flora (Johnston 1977). Present day vegetation also reflects more

than four centuries of modification, which in some cases has been extreme, by modern people and their domestic animals.

Shreve (1942) made one of the first inclusive descriptions of the vegetation of the Chihuahuan Desert. Medillin-Leal (1982) provides a brief description of vegetation throughout the Chihuahuan Desert, as do MacMahon and Wagner (1985) and MacMahon (1988). Morafka (1977a) describes vegetation associations and associated soil features, and Brown (1982) gives vegetation associations as part of biotic communities of the American Southwest. A more comprehensive classification of Chihuahuan Desert plant communities has been prepared by Henrickson and Johnston (1986). They recognize the Trans-Pecos, Mapimian, and Saladan regions of Morafka (1977a). The plant communities recognized by Henrickson and Johnston (1986) are outlined in table 2. The following brief descriptions of the communities are extracted from Henrickson and Johnston (1986), unless otherwise referenced.

Desert Scrub and Woodlands

Henrickson and Johnston (1986) estimate that the Chihuahuan Desert scrub—characterized by creosotebush, tarbush, and a host of other shrubs and cacti—covers about 70% of the Chihuahuan Desert and provides the basic matrix community type throughout the region. The creosotebush phase makes up 40% of the Chihuahuan Desert scrub and occurs on intermontane alluvial or outwash plains and bajadas that are dry most of the year. Species diversity increases locally in minor drainages and on deeper soils.

Burke and Dick-Peddie (1973) found that creosotebush communities on three distinct geomorphic surfaces in the northern Chihuahuan Desert did not differ in net primary production, indicating that creosotebush can maintain its dominance on sites of broad ecological amplitude. Creosotebush reproduction varied between years, and its dependence on rainfall is emphasized by the fact that production of creosotebush was about half of that found by Chew and Chew (1965) on the western

edge of the Chihuahuan Desert, where rainfall was 30 to 50% higher during years of measurement.

The mixed desert scrub phase makes up about 25% of the Chihuahuan Desert scrub and generally occurs above the creosotebush phase. Creosotebush is less prominent in this phase, and a high diversity of other species occurs. This diver-

Table 2. Plant communities of the Chihuahuan Desert Region.

Adapted from Henrickson and Johnston (1986).

	Percent of area *	
I. Desert scrub and woodlands		
A. Chihuahuan Desert scrub	70	
1. Creosotebush scrub		40
2. Mixed desert scrub		25
3. Sandy arroyo scrub		2
4. Canyon scrub		2
5. Sand dune scrub		1
B. Lechuguilla scrub	7	
C. Yucca woodland, sotol scrub or woodland	5	
D. Mesquite-saltbush scrub	5	
E. Alkali scrub	2	
F. Gypsophilous scrub	2	
G. Cactus scrub	1	
H. Riparian woodland	1	
II. Grasslands		
A. Grama grassland	5	
B. Sacaton grassland	2	
C. Tobosa grassland	2	
III. Chaparral		
A. Montane chaparral	5	
IV. Montane woodlands		
A. Juniper-piñon woodland	1	
B. Oak woodland	1	
C. Pine woodland	<1	
D. Mixed fir forest	<1	

*Estimates of percent of Chihuahuan Desert covered by different plant communities. Because of rounding, total does not add to 100%.

sity forms a mosaic, with species composition varying with slope, exposure, and substrate, and blends completely into the lechuguilla community. The sandy arroyo scrub and canyon scrub phases each occupy about 2% of the Chihuahuan Desert scrub and have distinct species assemblages. Among others, apache plume, desert hackberry, and desert willow occur at the arroyo margins, while persimmon, ash, and Mexican buckeye represent canyon scrub species.

The sand dune scrub phase occupies the smallest area (1%) and occurs in sand dunes formed on the leeward side of dry lakes. These dunes have a sparse cover of creosotebush and sand-loving plants such as broom dalea and sand sage. In large dune complexes—such as the Los Medanos de Samalayuca south of El Paso-Ciudad Juárez that covers 145 km² (56 square miles) (Schmidt and Marston 1981), an impediment to travel for centuries, and the gypsum dunes at White Sands National Monument—dune mobility is so great that shrubs do not become established.

Many species of annual and perennial herbs are found in the understory of the creosotebush and mixed desert scrub areas when water conditions are favorable. Kemp (1983) found that winter-spring annual species all had the C₃ photosynthetic pathway, while all but three summer annual species had the C₄ photosynthetic pathway, which is the more efficient pathway at higher temperatures and irradiances and, perhaps, lower soil water. Thus, annual species sort themselves into groups best able to use the seasonal distribution of precipitation. The species assemblages often vary greatly from year to year (Ludwig et al. 1988). Abundances of either summer or winter annuals are seldom high in two successive seasons, indicating that some resource other than water, perhaps nitrogen, temporarily limits the population (Guo and Brown 1997).

The lechuguilla scrub occupies about 7% of the Chihuahuan Desert and prevails on well-drained limestone alluvial slopes and ridges, although it also occurs on igneous derived substrates. *Agave lechuguilla* is a rosette species spreading by rhi-

zomes; its many associated species include guayule, ocotillo, sotol, and various cacti and yuccas.

Another 5% of the Chihuahuan Desert is occupied by yucca woodland, sotol scrub, or woodland. Here are found the larger tree-like, rosette-leaved yuccas that are often conspicuous in the southern parts of the desert. Grass understories are common in this community. Historically, some of the species of the lechuguilla scrub and yucca woodland/sotol scrub/woodland communities have been exploited for commercial purposes, such as the manufacture of rubber from guayule in the Big Bend area of Texas from 1907 to 1926 (Perry 1990). The hearts of sotol plants served as food and fermented beverage in pre-historic times. With the introduction of Spanish distilling techniques, some sotol stands were devastated in the manufacture of alcoholic sotol liquor, a practice that has been largely discontinued (Tunnell and Madrid 1990). Candelilla is still harvested for wax production to some extent. Commercial collecting and looting of cacti continues throughout the Chihuahuan Desert (Burleson 1977; Medellín-Leal 1982).

Mesquite-saltbush shrub occurs where shallow water tables allow plants to grow taller and at greater densities than in true desert shrub. This 5% of the area encompassed by the desert could, in fact, be considered non-desert.

Alkali scrub with saltbushes, saltgrasses, seepweeds, and alkali saeton occur on about 2% of the desert where internally drained basins accumulate chlorides, carbonates, and sulfates. Such areas are often shallow lakes for short periods. Henrickson (1977) estimates that about 9000 km² (3,475 square miles) of saline environments occur in the Chihuahuan Desert, and he states that 25 of 40 recorded salt-tolerant (halophytic) species are found only in the Chihuahuan Desert. In other words, the saline areas have been active areas in the evolution of species.

The gypsumophilous scrub occurs on the deposits of gypsum (hydrated calcium sulfate), which were formed by ancient seas and are scattered over about 2% of the Chihuahuan Desert. There are about 70 endemic species restricted to gypsum.

Some, like pitchfork weed, occur on most deposits, others on only a few deposits. Powell and Turner (1977) give a listing of facultative and obligate gypsumophiles. They suggest that some plants that evolved on gypsum substrates have since become facultative and have adapted to other habitats. A study of gypsum deposits in San Luis Potosi revealed that an endemic grass occupied bare gypsum soils and another endemic grass occupied areas where a thin veneer of alluvium permitted development of a cryptogamic crust. Where gypsum was overlain by 5 to 20 cm (2 to 8 inches) of alluvium, a highly diverse, mixed shrub-succulent community occurred, but creosotebush dominated where more than 20 cm (8 inches) of alluvium overlaid the gypsum (Meyer et al. 1992).

Arborescent cactus scrub occurs on less than 1% of the Chihuahuan Desert and is restricted to soils derived from igneous rock in the Saladan area in Zacatecas and San Luis Potosi, Mexico. Conspicuous candelabriform cacti (*Garrambullo*) are prominent in one area, and arborescent "tuna" cacti (*nopal duraznillo*, *nopal cardon*, and *nopal tapon*) in another. The tuna, or nutritious fruits, are of considerable economic importance, so human exploitation and management are extensive.

Riparian woodlands are found on less than 1% of the Chihuahuan Desert along the Rio Grande, Rio Conchos, and other permanent rivers. The original cottonwoods, ash, and willows of the narrow gallery forests are being replaced by the aggressive salcedar, an introduced species.

Grasslands

Grama grasslands of black, blue, and sideoats grama; threeawns; and other grasses occupy about 5% of the Chihuahuan Desert, and they extend beyond the desert, particularly along the lower eastern margin of the Sierra Madre Occidental. Included here is the "Desert Grassland" of Humphrey (1958), Gardner (1951), and McClaran (1995). Shreve (1942) considered these grasslands a desert-to-grassland transition area, and did not include them in the Chihuahuan Desert. Dick-Peddie

(1993) agrees with Shreve that the desert grassland is essentially a transition area, but retains desert grasslands as a community type in the northern Chihuahuan Desert, as does Allred (1996).

Unfortunately, the early Spanish conquistadors who traversed the Chihuahuan Desert had little to say about the vegetation and their expeditions did not include naturalists. Accounts of 19th century explorers and travelers indicate that black grama grasslands were much more extensive in the northern Chihuahuan Desert than at present (Gardner 1951; Humphrey 1958; Buffington and Herbel 1965; Allred 1996).

Buffington and Herbel (1965) used 1858 land surveys of the Jornada Experimental Range and early vegetation maps to show that on 58,468 ha (144,474 acres), good grass cover was present on 90% of the area in 1858, but only on 25% of the area in 1963. In 1858, 58% of the area was shrub-free; by 1963, mesquite, creosotebush, and tarbush had increased to such an extent that none of the area was shrub-free. York and Dick-Peddie (1969) also used early Land Office records to examine vegetation on townships across southern New Mexico. They found many entire townships where grasses had been completely replaced by shrubs. Gardner (1951) found shrubs, particularly creosotebush, dominant on former grasslands on uplands bordering the Rio Grande north of Las Cruces, New Mexico. Overgrazing by domestic livestock is often cited as the cause of this change in vegetation (Grover and Musick 1990; Schlesinger et al. 1990), and certainly the spread of mesquite has been accelerated by the spread of seeds in livestock feces.

Many black grama stands were decimated during the drought of the 1950s, from which they have never recovered (Herbel et al. 1972; Gibbens and Beck 1988). The increase in shrubs probably is due to a combination of overgrazing, drought, suppression of fires, perhaps climatic changes (Neilson 1986), and other influences. Regardless of the cause, long-term exclosures on the Jornada Experimental Range show that excluding livestock will not restore the grass cover (Hennessy et al. 1983).

The present intermixture of growth forms in the desert grassland has led Burgess (1995) to propose that it be called the "Apacherian mixed shrub savanna," but it is likely that the traditional name, desert grassland, will persist.

Sacaton grasslands are present on about 2% of the Chihuahuan Desert in scattered locations on deep calcareous alluvial deposits or as large tussocks interwoven with mesquite, salt-bushes, or other shrubs on a variety of substrates. Tobosa grasslands also occupy about 2% of the Chihuahuan Desert, usually as nearly pure stands on flats and internal basins, although tobosa also occurs on upland mesas, hills, and rocky substrates. Tobosa is often associated with burrograss. Long-term quadrat records on the Jornada Experimental Range indicate that both tobosa- and burrograss-dominated areas have survived recurrent droughts with little encroachment from shrubs (Gibbens and Beck 1987).

Chaparral and Montane Woodlands

Montane chaparral is found on 5% of the Chihuahuan Desert above the mixed desert, lechuguilla, and yucca woodland communities. Various oak species predominate. This community grades into the montane woodlands, which are found only on the larger, higher mountain ranges in the Chihuahuan Desert. Juniper-piñon woodland and oak woodland each occur on less than 1% of the area. Pine woodlands also occupy less than 1% of the area, but have been completely removed from some mountains in the southern Chihuahuan Desert. Mixed fir forest (with Douglas fir, pines, and oaks) is found only on the Sierra Maderas del Carmen in northern Coahuila and on the north slopes of the Sierra de la Madera in central Coahuila. Both areas are subjected to commercial logging.

Animals

Vertebrates

The numbers and kinds of vertebrates in the Chihuahuan Desert reflect the diversity of the region. Basically, animals depend on plants for cover and food, or they depend on prey that depend on plants. Vegetation is important for the animals and affects their populations and distributions. Animal populations in the region have changed rather dramatically in response to the changing environments since the Wisconsin glacial period.

During the late Pleistocene, the region was more pluvial, so more mesic vegetation grew. Schmidley (1977) suggests that this more pluvial period caused a fragmentation of populations of animal species adapted to dry environments. These species may have survived in only a few refugia caused by mountain rainshadows in some of the basins. This fragmentation of populations resulted in subspecies, and possibly even new species. These new species and subspecies exploited the expanding aridity of the desert at the end of the Pleistocene.

There was a wide variety of animals, including large mammals such as Shasta ground sloths, glyptodonts, camels, bison, horses, and smaller antelope-sized ruminants, present at this time. Janzen (1986) suggests that these large herbivores and others were responsible for the spread of some cacti and other plant species that bear large, colorful, fleshy fruits. He suggests that since the large megafauna disappeared, this role has been carried out by deer, pronghorn antelope, peccaries, and even coyotes.

With the region becoming more arid, animals adapted and used the wide variety of habitats. Many animals use the holes and cracks in the canyon walls, escarpments, and the talus at the base of mountains. Away from the mountains, animals use rocky outcrops, such as lava fields, as nesting sites and cover. Some small animals have adapted to different kinds of soil, such as in White Sands (which has 20 endemic species), or around areas of high alkalinity near playas. Others such as

pocket gophers, pocket mice, kangaroo rats, ground squirrels, and prairie dogs make burrows if the soil is deep enough and has the right texture for burrowing.

The riparian areas in the desert allow a complete contrast of habitat from the dune fields and dry bajadas. These riparian areas allow animals to live in the "desert" without special adaptations and sometimes without life-habit changes. These riparian areas, rivers, and streams also offer a way for animals to extend their ranges; in some cases riparian areas act as corridors, allowing animals to traverse otherwise inhospitable landscapes.

Schmidley (1977) recognized three barriers (fig. 2) that restricted animal movement and kept some animals from occupying all the suitable habitat for which they were adapted. He refers to these as filter-barriers, because some animals could cross while others could not.

The Sierra del Carmen-Sierra Madre Oriental axis is north-south on the eastern side of the desert. This barrier blocked some montane species, because erosion and other geologic processes caused gaps and intervening lowlands that isolated these species into the small mountain ranges. Because of the gaps, lowland species were able to go from east to west, but few could go and compete successfully in the opposite direction.

The southern Coahuila-Rio Nazas filter-barrier cuts across the southern part of the desert, and is formed by the high escarpment created by the mountains and the deep, dissected valley of the Rio Nazas in the Sierra Madre Occidental. The Rio Grande creates a filter-barrier across the north part of the desert. It limits movement of some small animals because of its size. Other smaller barriers of localized importance are sand dunes, lava fields, and bolsons, sometimes arid and other times covered with water.

Even with all of the barriers, Schmidley (1977) lists 119 mammal species in the desert. Twenty-four are widespread across the desert and their populations appear not to be affected by the barriers. Many of these are carnivores and the others are primarily rodents. Findley and Caire (1977) listed 52

species in the Bolson de Mapimi, which is the largest bolson in central Chihuahua and is centered in the Mexican Highland. They noted that three of the species are rare or endangered, and the status of several more are unknown. Brown and Davis (1995) noted that the black-tailed prairie dog, kit fox, pronghorn antelope, and bighorn sheep have smaller ranges in the Chihuahuan Desert than in 1890, whereas the hispid cotton rat has increased its range.

There has been considerable interest in the herpetofauna. Morafka (1977a) attempted to use the population ranges of herpetofauna to mark the boundaries of the Chihuahuan Desert (see location and size section). In doing this work he studied the ranges of 170 species. Of those species with highest populations in the center of the desert, about 80% are endemic (Morafka 1977b). In the streams and along the rivers in the Chihuahuan Desert, Conant (1977) identified 19 species of semi-aquatic reptiles and amphibians.

Hubbs (1990) noted that fish populations have changed drastically in the last 150 years. He attributed the change to three factors: water impoundments, competition of native species with exotic species (most of which are generalists), and changes in waterflow resulting from both the amount and time of year the water flows. All of these have contributed to habitat changes for native fish populations. As a result, of the 86 identified species that occur in the Chihuahuan Desert, five are extinct, 25 are rare and threatened, and 43 (50%) no longer occupy the former extent of their ranges.

Rait and Pimm (1977), looking at bird populations in the Jornada Basin in New Mexico, found that in the summer, similar numbers of species use the grasslands (16 species), playas (15 species), and the bajadas (13 species). There was some overlap of the species among the three areas. They did note there was considerable turnover of species between winter and summer populations in the grasslands, while in the other two areas populations were more constant between seasons. They reported that Webster (1964) found a much richer avifauna in

the desert scrub in Zacatecas. Phillips (1977), in summarizing the avian resources in the Chihuahuan Desert, noted that little is known about the desert's bird life. In fact many areas have not been studied. Brown and Davis (1995) listed four bird species that currently occupy less range than in 1890, but noted that the breeding range for six bird species has increased in the Chihuahuan Desert in the same period. The avifaunal richness depends on the isolated mesic patches of habitat across the desert, and how much these areas have been in disturbed.

Invertebrates

Invertebrate populations are not well known in the Chihuahuan Desert, which is typical of most arid regions of the world. The invertebrates occupy all parts of the desert spectrum and populations reflect the harshness of the environment. MacMahon and Wagner (1985) mention that many insects have developed complex social systems. Others, including spiders, behave like larger desert animals in that they retreat to shady crevices and burrows by day, then emerge to hunt by night.

Invertebrate life spans range from very short to more than one season, or possibly more than a year. Some single-celled organisms, such as protozoa and bacteria, live only a few hours. Other invertebrates, such as some nematodes and insects such as aphids and thrips, only survive one or two days. Some flies produce several generations in a year. Other groups are annual, producing only one generation each year. These include grasshoppers, crickets, beetles, and spiders (Whitford et al. 1995). They found more insects associated with desert scrub than in the grasslands in the Jornada Basin in southern New Mexico. They also noted that soil microarthropods are more common in grasslands because of greater food abundance.

Crawford (1986) discussed invertebrates in relation to patterns of process functioning. He recognized the use of "non-reserve" plant biomass by arthropods that are usually short-lived and generalist feeders. Specialist feeders tend to be more restricted to perennial plants. These invertebrate specialists

may use the same cues that promote plant growth (light and temperature, for example), for triggering corresponding responses in their own life cycle. Foraging on "reserve" plant biomass is less well known in the desert except for seed predation (Crawford 1986). In some landscapes with limited plant growth, rodents and insects may compete for seed. Other processes that Crawford recognizes are omnivory and predation among invertebrates; both are important in the food chain and nutrient cycling in the desert.

Ants are the most frequently seen insect across the desert. Species composition and diversity depends on soil conditions. Generally, fewer ants are found in playas or saline-alkaline soils. Whitford et al. (1995) found the greatest abundance of ants in bunchgrass grasslands.

Termites in the desert occur primarily in underground nests, feeding in tubes constructed around stems and leaves of above-ground parts. Whitford et al. (1995) noted that the average live biomass of termites is four times greater than the weight of livestock grazing on desert grasslands in the Jornada Basin. This is probably true across the entire Chihuahuan Desert, and could be extended to include the biomass of all mammalian herbivores. Ants and termites are probably better understood than other desert invertebrates. Their role in decomposition and nutrient cycling, as well as their contributions to soil fertility and development, have been recognized and studied in detail in certain locales.

Ecosystem Function and Processes

So far we have given a brief description of the overall structure of the Chihuahuan Desert. Less well described and understood are the many processes occurring in the biotic communities that make up the desert. Noy-Meir (1973, 1974) has proposed a "pulse-and-reserve" model for desert ecosystems, wherein pulses of precipitation drive the processes of production, consumption, and decomposition that are basic to energy flow,

nutrient cycling, and formation of the reserves (such as roots, seeds, and eggs) which tide the system over to the next pulse of precipitation. This model appears to fit the water-limited Chihuahuan Desert fairly well. However, Noy-Meir (1979-80) also cautions that the dogma of a tightly defined ecosystem with built in feed-back controls may not always apply in deserts.

This means that the processes defining the function of desert communities must be determined case by case. Unfortunately, process studies are limited and largely confined to communities in the northern part of the Chihuahuan Desert.

Early research in the Chihuahuan Desert was aimed at determining the best ways to use the plant communities for grazing (e.g., Jardine and Hurr 1917). Research on grazing has continued to the present. It has provided some insight into production in plant communities. Relatively long-term studies (32-year) of perennial grass production have shown extreme year-to-year variability (Herbel and Gibbens 1996), largely due to variability in rainfall and the availability of soil water in different soil types (Herbel et al. 1994).

Shrub increase (discussed above) led to many studies of how to suppress shrubs (e.g., Valentine and Norris 1960) and a study of the life history of creosotebush (Valentine and Gerard 1968). The success of shrubs—particularly mesquite, creosotebush, and tarbush—in replacing grasses is in part due to their deep (> 5 m, or > 16.4 feet) and extensive root systems, which readily penetrate petrocalcic horizons (rock-like calcium carbonate layers) and can exploit a wide variety of geomorphic situations (Gile et al. 1995, 1997, 1998). Differences of surface energy balance components (evapotranspiration) between grass and shrub communities were found to be small and more related to surface characteristics (e.g., leaf area) and water supply than to photosynthetic pathway or vegetation type (Dugas et al. 1996; Gibbens et al. 1996).

However, in trying to understand surface energy relations and water balance between shrublands and grasslands, it is critical to include cryptogamic crusts (Metting 1991). In some

arid regions, these crusts are the dominant biological feature. The wide variety of microenvironments across the desert offer opportunities for a gradient of microbial and cryptogamic communities. Cryptogamic crusts generally improve water conditions and reduce erosion, and they are valuable in contributing nitrogen to the system. Disturbance and destruction of these crusts may lead to desertification (Metting 1991).

The role of rodents and rabbits in desert communities was first studied in relation to their effect on forage supplies. It was found that exclusion of these animals could increase production of perennial grasses 4 to 5 times (Norris 1950). Recent studies have shown that long-term (50 year) rabbit exclusion coupled with shrub removal can cause a 30-fold increase in the cover of spike dropseed, and exclusion of rabbit herbivory can increase the cover of mesquite, tarbush, and mariola (Gibbens et al. 1993). Rabbits also make significant contributions to litter in creosotebush communities by pruning woody stems but consuming only a fraction of the pruned material (Chew and Chew 1970; Steinberger and Whitford 1983b).

Exclusion of a "keystone" guild of three kangaroo rat species in a shrub-grassland transition area caused conversion of the habitat from shrubland to grassland (Brown and Heske 1990), although one of the principal grass increasers was the introduced Lehmann's lovegrass. The mounds of bannertailed kangaroo rat burrows support more annual plants than intermound areas (e.g., Moroka et al. 1982) and the mounds can have positive effects on creosotebush growth long after the kangaroo rats leave in response to the invasion of creosotebush (Chew and Whitford 1992). From these examples it is obvious that the relationships between vegetation and native fauna in desert communities can be very complex.

There have been many studies of litter decomposition in the creosotebush community (e.g., Whitford et al. 1982a; Whitford et al. 1982b). There is a high correlation between litter accumulation and microarthropods (Whitford et al. 1982a), and microarthropods enhance decomposition (Santos and Whitford

1981a). Termites are instrumental in the decomposition of various materials (e.g., Whitford et al. 1982b), and rodents also contribute to decomposition (Steinberger and Whitford 1983). Carbon and nitrogen dynamics during decomposition of litter and roots of annual plants have been explored (Parker et al. 1984). Soil respiration rates were used to estimate soil organic matter turnover, which was 20 years using both summer and winter data (Parker et al. 1983). The effect of water and nitrogen additions on annual and perennial vegetation have also been explored (e.g., Cunningham et al. 1979; Ludwig et al. 1989; Mun and Whitford 1989). Although creosotebush is a very successful shrub, it can be shaded out by bush mully, a grass that commonly grows under the canopy of creosotebush (Welsh and Beck 1976).

The examples included in this last section are by no means an inclusive list, but give an idea of the range of ecosystem processes that have been studied and will continue to be studied in the future to enhance our understanding of the Chihuahuan Desert.

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Appendix 1. List of scientific names for plants and animals mentioned in the text.

Plants

alkali sycamore	<i>Sporobolus airoides</i>
apache plume	<i>Fallugia paradoxa</i>
ash	<i>Fraxinus</i> spp.
black grama	<i>Bouteloua eriopoda</i>
blue grama	<i>Bouteloua gracilis</i>
broom dalea	<i>Psoralemmus scoparius</i>
burro grass	<i>Scleropogon brevifolius</i>
bush mully	<i>Muhlenbergia porteri</i>
candelilla	<i>Euphorbia antisiphilitica</i>
cottonwood	<i>Populus</i> spp.
creosotebush	<i>Larrea tridentata</i>
desert hackberry	<i>Celtis pallida</i>
desert willow	<i>Chilopsis linearis</i>
Douglas-fir	<i>Pseudotsuga menziesii</i>
fir	<i>Abies</i> spp.
garambullo	<i>Myrtillocactus geometrizans</i>
guayule	<i>Parthenium argentatum</i>
juniper	<i>Juniperus</i> spp.
lechuguilla	<i>Agave lechuguilla</i>
Lehmann's lovegrass	<i>Eragrostis lehmanniana</i>
marfola	<i>Parthenium incanum</i>
mesquite	<i>Prosopis glandulosa</i>
Mexican buckeye	<i>Ungnadia speciosa</i>
nopale cardoni	<i>Opuntia streptocantha</i>
nopal duraznillo	<i>Opuntia leucotricha</i>
nopal tapon	<i>Opuntia robusta</i>
oak	<i>Quercus</i> spp.
ocotillo	<i>Fouquieria splendens</i>
persimmon	<i>Diospyros texana</i>
pitchfork weed	<i>Dicranocarpus parviflorus</i>
pinon	<i>Pinus</i> spp.
saltbush	<i>Atriplex</i> spp.
saltgrass	<i>Distichlis</i> spp.
sand sage	<i>Artemisia</i> spp.
seepweeds	<i>Suaeda</i> spp.
sideoats grama	<i>Bouteloua curtipendula</i>
sotol	<i>Dasylirion</i> spp.
spike dropseed	<i>Sporobolus contractus</i>

Appendix 1, continued

Plants

tarbush	<i>Flourensia cernua</i>
tobosa	<i>Pleuraphis mutica</i>
yucca	<i>Yucca</i> spp.

Animals

bannertailed kangaroo rat ..	<i>Dipodomys spectabilis</i>
bison	<i>Bison bison</i>
black tailed prairie dog	<i>Cynomys ludovicianus</i>
camels	<i>Camelus</i> spp.
coyotes	<i>Canis latrans</i>
deer	<i>Odocoileus</i> spp.
glyptodents	<i>Glyptodent</i> spp.
ground squirrels	<i>Spermophilus</i> spp.
hispid cotton rat	<i>Sigmodon hispidus</i>
horse	<i>Equus</i> spp.
kangaroo rats	<i>Dipodomys</i> spp.
kit fox	<i>Vulpes macrotis</i>
peccaries	<i>Dictyyles tajaicu</i>
pocket gophers	<i>Geomys</i> spp.
	<i>Pappogeomys</i> spp.
	<i>Thomomys</i> spp.
	<i>Perognathus</i> spp.
pocket mice	<i>Cynomys</i> spp.
prairie dogs	<i>Antilocapra americana</i>
pronghorn antelope	<i>Sylvilagus</i> spp.
rabbits	<i>Lepus</i> spp.
Shasta ground sloths	<i>Notthrotheriops shastense</i>