TWO

Biomes and Communities of the Sonoran Desert Region

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World travelers can scarcely help but notice the great diversity of landscapes on this planet. That diversity is due as much to the vegetation as to the landforms. Closer observation reveals a mind-boggling diversity of plants and animals in these different places. Those who travel in the American Southwest or on the western side of any continent near 30° latitude will see dramatic changes within distances of only a few miles.

In apparent contrast, some widely distant parts of planet Earth show certain broad-scale similarities. The vegetation of the Mediterranean coast of Europe looks remarkably similar to the chaparral of Southern California, though no two plant species occur in both places (except some introduced weeds). Both the diversity and the similarities have the same underlying causes, namely the interactions between geography and the global climate machine that governs the biosphere on both grand and microscopic scales.

The Sonoran Desert Region has a great variety of species and habitats, the latter ranging from extremely hot, arid desert to semiarid tropical forest to frigid subalpine meadows. The focus of this book is on the Sonoran Desert in the heart of the region, but to understand it we need to know something about the other habitats within it and on its borders. These adjacent geographical features and biological communities exert profound, complex influences on the desert itself.

Ecologists who study nature on a global scale recognize about 10 basic, widespread classes of habitats that are easily identified by their dominant plant *life-forms*. (Life-forms are basic categories based on general appearance—for example, tree, shrub, annual, succulent, and so on.) Such global-scale habitats are called *biomes*, and they are determined primarily by the climatic factors of temperature and rainfall. These factors are in turn determined by latitude, elevation, and wind patterns. Biome classification is based on vegetation because plants, being generally immobile, are the most obvious and easily recognizable components of a biological community. In addition, plants are more definitive of their biomes because, since they are rooted in place, they must be adapted to that specific environment. Plants,

therefore, are often *endemic* (occurring only in the named area) to a biome or smaller community. Biomes do contain characteristic animal life as well, including many endemic insects and other invertebrates. Most vertebrates, however, are more mobile, and rather few species are restricted to a single habitat.

Almost all the world's biomes occur in the Sonoran Desert Region. This tremendous diversity in a fairly small area is due to two influences. First, our region is on the west side of a continent near 30° latitude, a position where several biomes typically occur in close proximity (this phenomenon is explained later in this chapter). Second, the great topographical relief here creates the cold, wet climates that allow northern biomes to occur farther south than they would ordinarily.

It is important to recognize that biomes and most other biological classifications are largely subjective concepts—an attempt to make sense of the unwieldy and nearly incomprehensible diversity of nature. In addition, their boundaries are rarely distinct. Wherever two biological communities or biomes meet, there is usually a zone of intergradation, which is sometimes very wide. For these reasons, classifications differ among classifiers. For example, some biologists recognize thornscrub as a separate biome while others call it an *ecotone* (transition zone) between desert and tropical forest. Some combine tropical and temperate forests into the same biome based simply on vegetation height and density. As defined here, the biomes are so distinctive that you should be able to place any terrestrial habitat on the planet within one of them at a glance.

Biomes are subdivided into a hierarchy of smaller categories, defined by the particular species that inhabit them. There are many classification systems, and the categories have many names. We use the general terms *biotic community, biological community,* or simply, *community*. The names used here for the communities are mostly those of Brown and Lowe (1982). The biomes below are listed in latitudinal order, from pole to equator.

TUNDRA is the most poleward and highest-elevation biome and is characterized by extremely cold winters. The dominant plant life-forms are ground-hugging woody shrubs and perennial herbs. Intense cold excludes trees (in this biome no plant can survive exposed above the winter snow cover) and succulents; the growing season is too short for annuals.

Everywhere on Earth, temperatures at the same elevations become warmer as one moves toward the equator (to lower latitudes). But an increase in elevation at a given latitude has the same climatic effect as traveling toward a pole: temperature decreases (and precipitation usually increases). So climates that support tundra, like those in the Arctic, can be found on the highest mountains all the way to the equator. The other cold biomes in both hemispheres also extend toward the equator, where sufficiently high elevations meet their climatic requirements. The San Francisco Peaks near Flagstaff, Arizona, rise to 12,600 feet (almost 3900 m). These are the only mountains in our region that extend above timberline (about 11,200 ft/3400 m elevation in Arizona). There, only 80 miles (130 km) from the Sonoran Desert, is a small area of alpine tundra that includes some of the same plant species found in the Arctic tundra of Alaska (see plate 2).

CONIFEROUS FOREST (also known by its Russian name, *taiga*) is dominated by cone-bearing trees, especially pines, firs, and spruces in the Northern Hemisphere. Many conifers are adapted to cold only a little less severe than in tundra. Tree heights range from a few feet (a couple of meters) near the boundary with tundra or at timberline to over 300 feet (90 m) in more temperate latitudes. Some coniferous woodlands extend into subtropical climates, for example, in the southeastern United States and southern Sonora, Mexico.

In our region, coniferous forest occurs in the higher mountain ranges, to the north and east of the Sonoran Desert. Our most widespread coniferous community is Petran Montane (Rocky Mountain) forest, the dominant vegetation of the cold-temperate Rocky Mountains. It

is found at increasing elevations as one moves southward into Mexico, until it is pushed off the tops of the mountains by excessive aridity and warmth. In the mountains west of the Sonoran Desert are isolated islands of Sierran (as in Sierra Nevada) coniferous forest, characterized by different conifer species.

TEMPERATE BROADLEAF FOREST is characterized by dense stands of broadleaf trees that drop their foliage in winter. The temperatures are milder than those of most conifer-dominated climates, though still too cold for plants to grow in winter. Summers are typically warm and humid. More species occur in this biome than in the two more poleward biomes (tundra and coniferous forest). The herbaceous perennial life-form is well represented here, along with trees and shrubs. Pure deciduous forest is rare in our region; there are only scattered aspen groves and ribbons of riparian trees.

The foothills and lower mountain slopes on the eastern boundary of the Sonoran Desert support oak woodlands mixed with pines at slightly higher elevations (see plate 3). The oaks, however, are mostly evergreen species; they are only ephemerally deciduous in spring except during severe droughts. This community, called Madrean evergreen woodland in the Brown-Lowe-Pase classification, is a warm-temperate community of the Sierra Madre Occidental. It extends as far north as central Arizona, where it is squeezed out by the cool-temperate Rocky Mountain forests above it and the more arid grassland and desert below. (Though its official name is woodland, in its southern part it's actually a forest; i.e., the tree canopies overlap.) This is a semiarid community that experiences a dry season in spring. The Madrean evergreen woodland has been split into two communities: oak woodland and Mexican pine-oak woodland. The term "Madrean" was dropped because, at least in the Sky Island Archipelago, the communities contain almost as many Rocky Mountain as Madrean species.

In the Sonoran Desert Region, tundra, coniferous forest, and temperate broadleaf forest are restricted to mountains that rise well above the intervening basins, and in the great gap between the highlands of the massive Rocky Mountains and the Sierra Madre Occidental, they occur only on the higher Sky Islands (see chapter 3).

MEDITERRANEAN WOODLAND AND SHRUBLAND is a semiarid biome that occurs on the west coast of every continent between about 30° and 40° latitude. This smallest biome is unique for its Mediterranean climate: mild, moist winters and hot, dry summers. In North America this biome is called *chaparral*. Mature chaparral consists almost solely of woody, evergreen shrubs with small, leathery leaves. The numerous species form impenetrable thickets from 5 to 8 feet (1.5–2.5 m) tall. During the long, dry summers, the typically resinous foliage and dry, woody stems become explosively combustible. Wildfires raze large areas to ash-covered earth every few decades. Fires are not harmful to this community; its species are well adapted to periodic blazes. Following fires the bare ground is briefly colonized by a large number of annual species, but the land is soon reclaimed by the shrubs that sprout from seeds or root crowns. Trees and succulents are rare life-forms in chaparral because they are more vulnerable to destruction by the very hot fires. This young biome evolved from early Tertiary tropical forest during the Pliocene and Pleistocene. The uplift of the great mountain ranges of western North America blocked the summer monsoon moisture from reaching the far west, creating a summer dry season (see chapter 9).

The main area of chaparral occurs west of the Coast, Transverse, and Peninsular Ranges and is called *Californian chaparral* (see plate 5). Disjunct patches of chaparral occur inland of these ranges and are called *interior chaparral*. Interior chaparral differs in having only a few species; it is often made up largely of manzanita and shrub live oak. Interior chaparral also receives substantial summer rainfall, though the plants do not respond to it—that is, they don't grow or flower in response to the rains.

Californian chaparral borders the western edge of the Sonoran Desert in California and

Biomes of the Sonoran Desert Region

	Tundra	Coniferous Forest	Temperate Broadleaf Forest	Chaparral	Grassland	Desert	Thornscrub	Tropical Dry Forest
Trees	None	**Many**	**Many**	None to Few	Few	None to Some	Many	**Many**
Woody Shrubs	**Few**	Some	Many	**Many**	Some	**Many**	**Many**	**Many**
Subshrubs	Few?	Few	Some	Many*	Some	Many	Many	Some
Annuals	None	None	Some	Many* after fires	Many	**Many**	Some	Some
Herbaceous Perennials	**Some**	Some	Many	Many* after fires	Many	Many	Some	Some
Grasses	Few	Some	Many	Many* after fires	**Many**	Some	Some	Some
Succulents	None	Few	Few	Few	Some	**Many****	**Many**	**Many**
Vines	None	Few	Few	Few	Few	None to Some	Many	**Many**
Flowering Epiphytes	None	None	None	None	None	None	Some	Some

Boldface signifies dominant plant life. *In mature chaparral, these would be "Few." **In cold deserts, "None to Few."

Tropical Wet Forest is not included on this chart; this biome does not occur in the Sonoran Desert Region, but a couple of canyons in southern Sonora support vegetation that is intermediate between dry and wet tropical forests. Savanna, a biome of the Eastern Hemisphere, is also not included. Chaparral is the term used in North America for Mediterranen Woodland and Shrubland.

the northern Baja California Peninsula, and interior chaparral is scattered along the desert's northeastern edge, where it meets the Mogollon Rim of Arizona. Interior chaparral also occurs in isolated patches on the lower slopes of some Sky Islands.

GRASSLAND is a semiarid biome characterized by warm, humid summers with moderate rain and cold, dry winters. (The Central Valley of California is an exception; it is a winter-rainfall grassland at a lower-than-typical elevation.) Grass is the dominant life-form, and scores of species form a nearly continuous cover over large areas. Other well-represented life-forms are annuals and *geophytes* (herbaceous perennials such as bulbs, which die to the ground each year). Populations of trees, shrubs, and succulents are kept at low levels by periodic fires during the dry season.

Most of the grasslands in the western states are intermediate between the true prairies of the Midwest and deserts. They are called *semidesert* or *desert grasslands*. (Again, the California grasslands are an exception. They are heavily influenced by the unique California floristic province and not much by the Midwest prairies.) Compared with Plains grassland, the grasses in desert grassland are shorter and less dense, and the land supports more shrubs and succulents (see plate 4). Desert grassland or

chaparral borders the northern Sonoran Desert on the east.

DESERT is the driest biome; its vegetation is determined solely by the extreme aridity. Temperature and seasonality of rainfall determine the specific vegetation and fauna, but all desert vegetation looks more or less similar; most plants are widely spaced and have small or absent leaves (see plate 6). A detailed discussion of deserts follows in this chapter.

TROPICAL SAVANNA is a warm, semiarid biome characterized by flat land covered with continuous herbaceous vegetation, usually dominated by grasses, with some trees and other woody plants. It is an extensive biome in Africa, and it also occurs in Australia, India, and South America. It is usually not recognized as a biome in North America. Our region has fairly small areas of grass with sparse trees, which we consider to be ecotones between the grassland and temperate broadleaf forest biomes. Most of these ecotones are warm-temperate, not tropical. A small part of the Plains of Sonora subdivision of the Sonoran Desert is sometimes called a savanna biocommunity, because there are open patches dominated by grasses in wet years.

THORNSCRUB is intermediate between the desert and tropical forest biomes. The vegetation consists largely of short trees (10–20 feet/3–6 m tall) and shrubs, with cacti also being common in the New World communities. It is generally denser and taller than desert vegetation, and many species are thorny (see plate 7). Annuals and herbaceous perennials are abundant, and vines—a primarily tropical life-form—are well represented. During the dry season most perennial plants are drought-deciduous (as opposed to plants of more temperate regions that are cold-deciduous). In contrast, the rainy season, though short, is moderate and dependable and the vegetation grows lush. The climate is nearly frost-free (tropical), so temperature is not limiting; the vegetation is determined by the alternating dry and wet seasons.

TROPICAL DRY FOREST is determined by the absence of freezing temperatures and a dry season that lasts three to nine months, during which time many of the plants become deciduous. In our region this biome is labeled *tropical deciduous forest*. Many of the tree species flower during the winter-spring dry season, while leafless. In the dependable rainy season the dense vegetation grows luxuriantly and forms closed canopies of foliage (see plate 8). The upper canopy ranges from 15 to 30 feet (4.5–9 m) above ground. Almost all life-forms are represented. Flowering *epiphytes* (plants that grow on other plants or rocks but are not parasitic) are almost completely restricted to tropical habitats. There are also many vines, another life-form that is most common in tropical habitats.

At its southern limit, the Sonoran Desert merges almost imperceptibly into thornscrub in central Sonora, and thornscrub in turn merges with the northern limit of tropical dry forest in the southern tip of that state. A major proportion of the Sonoran Desert's biota evolved from ancestors in these tropical biomes; examples are noted in the species accounts.

TROPICAL WET FOREST is determined by the absence of both freezing temperatures and a dry season; life is seldom limited by either low temperature or scarcity of water. This biome is often called *tropical rainforest*. The upper tree canopy can attain 150 feet (45 m) in height. The epiphyte and vine life-forms are common, and annuals are almost absent. This biome does not occur in the Sonoran Desert Region, but a couple of canyons in southern Sonora support vegetation that is intermediate between dry and wet tropical forests.

RIPARIAN COMMUNITIES

Riparian communities are not biomes. Though they could be considered isolated ribbons of temperate broadleaf forest, they are better viewed as a unique habitat type. They occur within any biome wherever there is perennial water near the surface. The term *riparian* specifically refers to the zones along the banks of rivers; however, it is also applied to the shore-

line communities along slow or nonflowing waters such as marshes and lakes (see plates 24 and 25).

The drier the surrounding habitat, the more distinct is the riparian zone. In the desert or grassland, a flowing stream supports a conspicuous oasis with forests and wildlife that would not otherwise occur in the area. The available water also augments populations of more arid-adapted species in the adjacent habitat.

Riparian zones are so different at different latitudes and elevations that they should not be thought of as a single community type; they can be one of several communities with similar physical characteristics, primarily their dependence on perennial water. Montane streams support alders and aspens, while at lower elevations there are cottonwoods and sycamores. In tropical deciduous forest a riparian zone may be visually indistinguishable during the wet season because the overall appearance of streambank and hillside trees is similar, though the species may be different. But in the dry season most of the slope vegetation is deciduous, while tropical riparian species are typically evergreen.

Some ecologists broaden the concept of riparian communities to include dry washes in deserts. A wash in the Lower Colorado River Valley, with its woodland of palo verdes, ironwoods, and desert willows, is clearly distinct from the surrounding creosote flats. These dry washes occupy less than 5 percent of the area of the Arizona Upland subdivision of the Sonoran Desert, but they support 90 percent of its bird life. This concentration of life is the result of the greater availability of water, even though the wash may carry surface water for only a few hours a year. Desert drainageways should be labeled *dry riparian, desert riparian,* or *xeroriparian* to avoid confusion with wetter habitats that have surface water all or most of the year.

Dry riparian habitats share most of their defining characteristics with traditional "wet" riparian habitats. They are chronically disturbed, unstable sites where water and nutrients are harvested and concentrated from larger areas (watersheds). Finally, they are corridors for dispersal of plants (seeds) and animals (see plate 9).

COASTAL WETLAND COMMUNITIES

As with riparian communities, coastal wetlands are distinctive habitats that are not sufficiently extensive to be categorized as biomes. The vegetation consists of *halophytes* (plants that are adapted to highly saline water and soil). In temperate zones the halophytes are mostly low-growing species, such as pickleweed and saltgrass. In the tropics there are forests of several unrelated large shrubs and trees collectively called *mangroves*. Five species of mangroves occur in our region: red, black, white, sweet, and button.

WHAT IS A DESERT?

Although many people visualize deserts as dry, desolate wastelands, the term actually defines a wide spectrum of landscapes and plant and animal population densities. The Sonoran Desert does have seas of sand and expanses of desert pavement that are nearly devoid of visible life, but most of it is more reminiscent of a sparse woodland.

The common denominator of all deserts is extreme aridity—water is freely available only for short periods following rains. Desert is often defined as a place that receives less than 10 inches (250 mm) of annual average rainfall, but this definition is inadequate. For example, the Pacific coast of the state of Baja California and the north slope of Alaska both receive less, but those places are vegetated with chaparral and tundra, respectively. An accurate measure of aridity must compare rainfall (abbreviated P for precipitation) with potential water loss through evaporation and transpiration (the loss of water from leaves). Potential evapotranspiration (abbreviated PET, the water that would be lost from evaporation and transpiration if water were present to evaporate) is difficult to measure accurately, but it is crudely estimated to be 60 percent of pan evaporation (the water that

evaporates from a wide pan of water exposed to the weather). Pan evaporation varies severalfold within a local area depending on slope and exposure to wind, so it is applicable only to the specific site where it is measured. Tucson receives an average of 12 inches (305 mm) of rain a year, while the pan evaporation is about 100 inches (254 cm). In other words, the climate of Tucson could evaporate eight times more water per year than is supplied by rain, a pan evaporation to precipitation ratio of 8:1. Using the 60 percent estimate for PET, Tucson's PET to P ratio is 5:1; climatologists classify areas with ratios higher than 3:1 as semiarid. This moisture deficit presents a significant challenge to the biota, but it is not large compared with that of hyperarid deserts such as that around Yuma, Arizona, which has an aridity index of 30:1, or the interior Sahara Desert's 600:1.

A concise, nontechnical definition of a *desert* is "a place where water is severely limiting to life most of the time." (Without the word *severely* the phrase defines semiarid habitats, such as grassland, chaparral, and tropical deciduous forest.) Though desert plants and animals must cope with scarce water, the common perception that they are struggling to survive is grossly inaccurate. The native biota is adapted to and usually thrives under these conditions and, in fact, most of the species require an arid environment for survival. Look at it this way: if a desert received much more rain, it wouldn't be a desert. A different, wetter biome would replace it. Thus an alternative and more positive definition might be: "A desert is a biological community in which most of the indigenous plants and animals are adapted to chronic aridity and periodic, extreme droughts, and in which these conditions are necessary to maintain the community's structure." (The desert biome requires chronic aridity, but not all of its component species do.)

WHY ARE DESERTS SO DRY?

The low rainfall typical of deserts is more easily understood if one knows a little about the basics of global climate. Atmospheric thermodynamics is an extremely complicated field, but the basic rules are simple. First, hot air rises and cool air sinks. Second, rising air expands and cools, while sinking air compresses and becomes warmer. Third, warmer air can hold more water vapor than cooler air. These three natural phenomena, plus the sun's heat, determine where rain falls on the planet.

The sun shines almost vertically on the equatorial belt year-round, but it shines on the polar regions at a shallow angle and only during each pole's summer. There are two consequences. A 1-square-meter beam of sunlight shines on about 1 square meter of the Earth's surface at the equator at noon, but it covers more than twice that area near the poles. The sun's light and heat are thus less concentrated at higher latitudes. In addition, at the equator the sunlight travels straight down through the atmosphere, but near the poles it travels through much more air, where more of the light is reflected, absorbed, or scattered, and less reaches the ground. This is why the equator is hot and the poles are cold.

Because of the great quantity of heat delivered to the equatorial belt, it is a zone of warm, rising air. It absorbs much water vapor from the oceans and land vegetation. As this air rises it cools. Eventually it reaches saturation (dewpoint temperature), and water vapor condenses into clouds and often falls as rain. So the equatorial region is both hot and wet.

The equatorial air rises, then spreads horizontally at high elevations to the north and south. Eventually, the now-cool air sinks and flows along the surface to replace the rising air at the equator, forming a circulation cell. It tends to sink at about 30° north and 30° south latitude. (These two zones were called the *horse latitudes* by mariners. Before motor power, sailing vessels could get becalmed in these latitudes for weeks at a time. According to one story, crews threw horses overboard to reserve precious water for themselves; other ships would encounter the floating carcasses.) As the air sinks it warms by compression, and

Deserts of the world (light areas). Horse latitude deserts are those on the western edges of all the continents near 30° north and 30° south latitude. The rest are rain shadow deserts. The difference between the two types of desert can be seen in South America, where the Andes Mountains stretch the entire length of the continent near the west coast. North of 30°, the trade winds blow from the northeast, causing a rain shadow desert on the west, or coastal, side of the Andes. South of 30°, the easterlies blow onshore and the rain shadow desert is on the eastern, inland side of the Andes. Near the 30th parallel there is no prevailing wind; the stable high pressure zone creates horse latitude deserts on both sides of the Andes.

because there is no source of evaporating water, it becomes drier with increasing temperature. Not only can sinking air not produce rain, but when it reaches the ground it absorbs water from the soil and vegetation, creating even more arid conditions.

The horse latitude zones of sinking air are not continuous belts. The combination of the Earth's rotation and the interaction between landmasses and oceans creates stable high-pressure zones (sinking air) over the oceans west of the continents. The resulting aridity is reinforced by the cold ocean currents that also occur on western coasts at this latitude; the cold water further inhibits the potential for rising air currents that are necessary to make rain. Thus on the west edge of every large landmass there is a hyperarid area near 30° latitude called a *horse latitude desert*. Despite the proximity of the oceans, the high-pressure zone is so strong over the Atacama and Sahara Deserts that decades may pass without rain.

Deserts are also caused by rain shadow effects wherever mountains block prevailing winds. Wind is forced up and over the mountain. As it rises, it cools and drops most of its moisture on the windward slope. On the leeward side it descends, warms, and dries. At latitudes that have a prevailing wind direction, rain shadow deserts are created on the lee sides of the mountains.

Aridity is the primary attribute of deserts, but it also generates several other characteristics of deserts. In addition to being meager, desert precipitation is also highly variable and unpredictable. The more arid the desert, the more variable is its rainfall. The average annual precipitation is a poor predictor of the rainfall in a given year. For example, Yuma, Arizona, has an average annual rainfall of 3½ inches (90 mm), but in most years it receives less, sometimes none at all. When the stable weather pattern that enforces aridity breaks down occasionally, Yuma may receive two or three times its annual average, sometimes in a single storm.

Desert temperatures vary widely both daily and seasonally. The dry, transparent air and cloudless skies transmit maximal solar energy to the ground, where much of it is absorbed and converted to heat; the temperature rises

dramatically. At night the same conditions permit most of this heat to be radiated to the sky, and the temperature plummets. (Water vapor, either as humidity or cloud cover, reflects infrared radiation and slows heat loss.) Daily temperature variation can be more than 50°F (28°C). The same conditions create great seasonal fluctuation. High-elevation deserts that have 100°F (38°C) days in summer can experience nights below 0°F (–18°C) in winter.

Besides the heat it creates, the intense sunlight in arid lands is itself a challenge. The ultraviolet radiation can damage animals' retinas, cause skin cancer, and destroy vital plant molecules, such as chlorophyll. Desert organisms have evolved a variety of adaptations to avoid getting too much sun.

THE NORTH AMERICAN DESERTS

North America has four major deserts: the Great Basin, Mojave, Chihuahuan, and Sonoran Deserts. All but the Sonoran Desert have cold winters. Freezing temperatures are even more limiting to plant life than is aridity, so colder deserts are poorer in both species and life-forms, especially succulents.

The GREAT BASIN DESERT (see plate 10) is both the highest-elevation and northernmost of the four North American deserts and has very cold winters. The seasonal distribution of precipitation varies with latitude, but temperatures limit the growing season to summer. Vegetation is dominated by a few species of low, small-leafed shrubs; there are almost no trees or succulents and few annuals. The *indicator plant* (the most common or conspicuous one used to identify an area) is big sagebrush, which often grows in nearly pure stands over huge vistas. (Such cold shrub-deserts in the Old World are called *steppes*.)

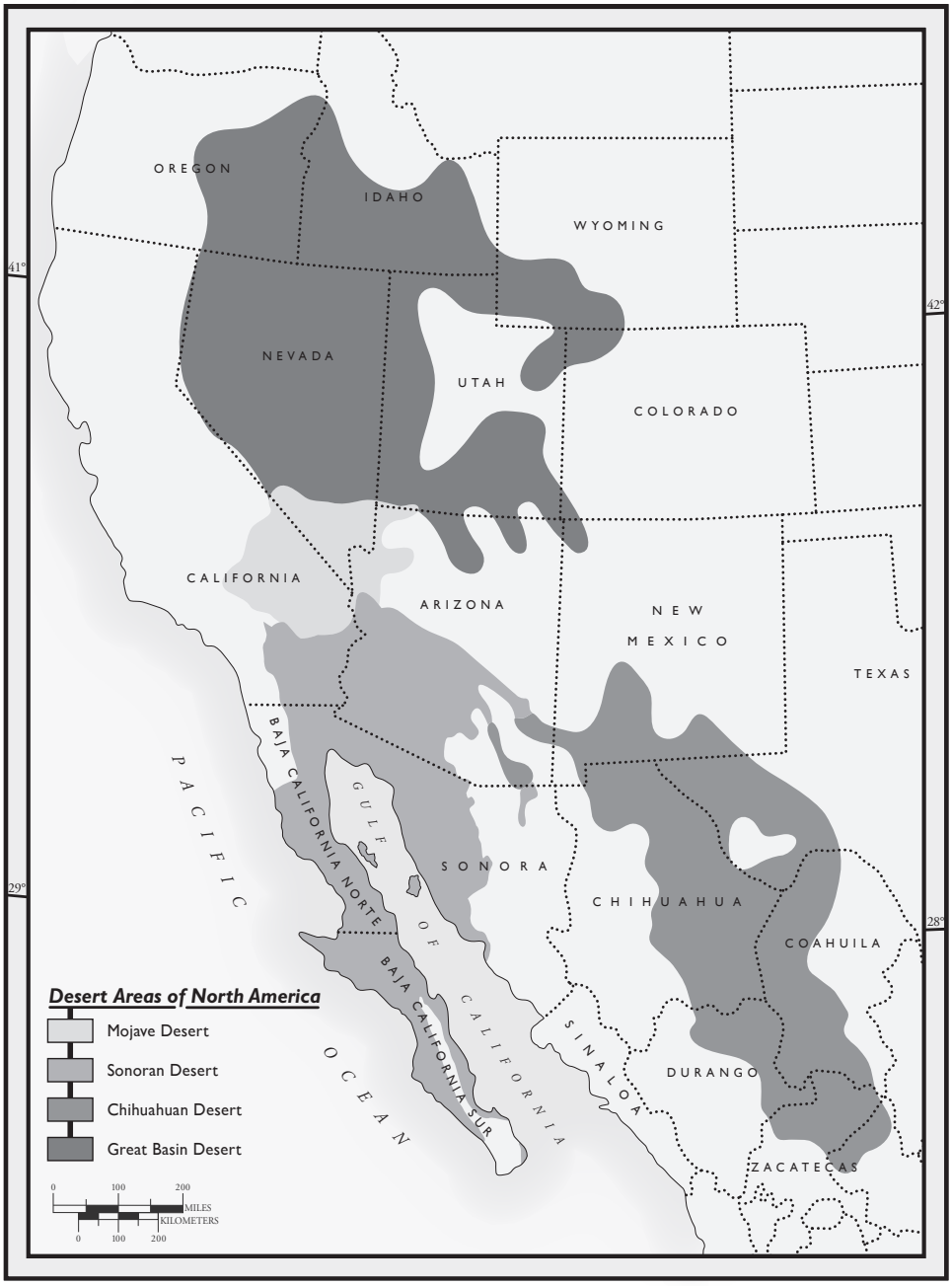
The MOJAVE DESERT (see plate 11) is characterized largely by its winter rainy season. Hard freezes are common but not as severe as in the Great Basin Desert. The perennial vegetation is composed mostly of low shrubs; annuals carpet the ground in wet years. Few succulents and trees grow there. The only common tree species is the characteristic Joshua tree, an *arborescent* (tree-like) yucca that forms extensive woodlands above 3000 feet (900 m) elevation.

Though the CHIHUAHUAN DESERT (see plate 12) is the southernmost North American desert, it lies at a fairly high elevation and is not protected from Arctic air masses by any barrier, so hard winter freezes are common. Its vegetation consists of many species of low shrubs, leaf succulents, and small cacti. Trees are rare. Rainfall is predominantly in the summer, but in its northern reaches there is occasionally enough winter rain to support massive blooms of spring annuals. Despite the winter cold, the Chihuahuan Desert is rich in species.

THE SONORAN DESERT

The Sonoran Desert as currently defined covers approximately 100,000 square miles (25,900 ha) and includes much of the state of Sonora (Mexico), most of the southern half of Arizona, southeastern California, most of the Baja California Peninsula, and the islands of the Gulf of California. Its southern third straddles 30° north latitude and is a horse latitude desert; the rest is rain shadow desert. It is lush in comparison to most other deserts. The visually dominant elements of the landscape are two life-forms that distinguish the Sonoran Desert from the other North American deserts: legume trees and large columnar cacti. This desert also supports many other life-forms, encompassing a rich spectrum of more than 2000 species of plants, about 550 species of vertebrates, and unknown thousands of invertebrate species.

The amount and seasonality of rainfall are defining characteristics of the Sonoran Desert. Much of the area has a bi-seasonal rainfall pattern. From December to March frontal storms originating in the North Pacific bring occasional widespread, gentle rain to the northwestern two-thirds. From July to mid-September, the summer monsoon brings surges of wet tropical air and localized deluges in the form of violent thunderstorms to the southeastern



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two-thirds. So distinct are the characteristics of the two types of rainfall that Sonoran residents have different Spanish terms for them—the winter rains are *equipatas* (derived from the Yaqui-Mayo word for rain, *quepa*), and the summer rains are *las aguas* ("the waters").

The Sonoran Desert prominently differs from the other three North American deserts in having mild winters. Most of the area rarely experiences frost, and the biota are partly tropical in origin. Many of the perennial plants and animals are derived from ancestors in the tropical thornscrub to the south, their life cycles attuned to the brief summer rainy season. The winter rains, when ample, support great populations of annuals (which make up nearly half of the species of our plants). Some of the plants and animals are opportunistic, growing or reproducing after significant rainfall in any season. (See chapter 9 for details on the evolution of the Sonoran Desert.)

SUBDIVISIONS OF THE SONORAN DESERT

Forrest Shreve, an American botanist who worked at the Carnegie Institution's Desert Laboratory in Tucson, Arizona, first defined the Sonoran Desert in 1953. He divided it into seven subdivisions based on the diverse and distinctive vegetation found here. One of these (the Foothills of Sonora) has since been reclassified as foothills thornscrub, a non-desert biocommunity.

Lower Colorado River Valley

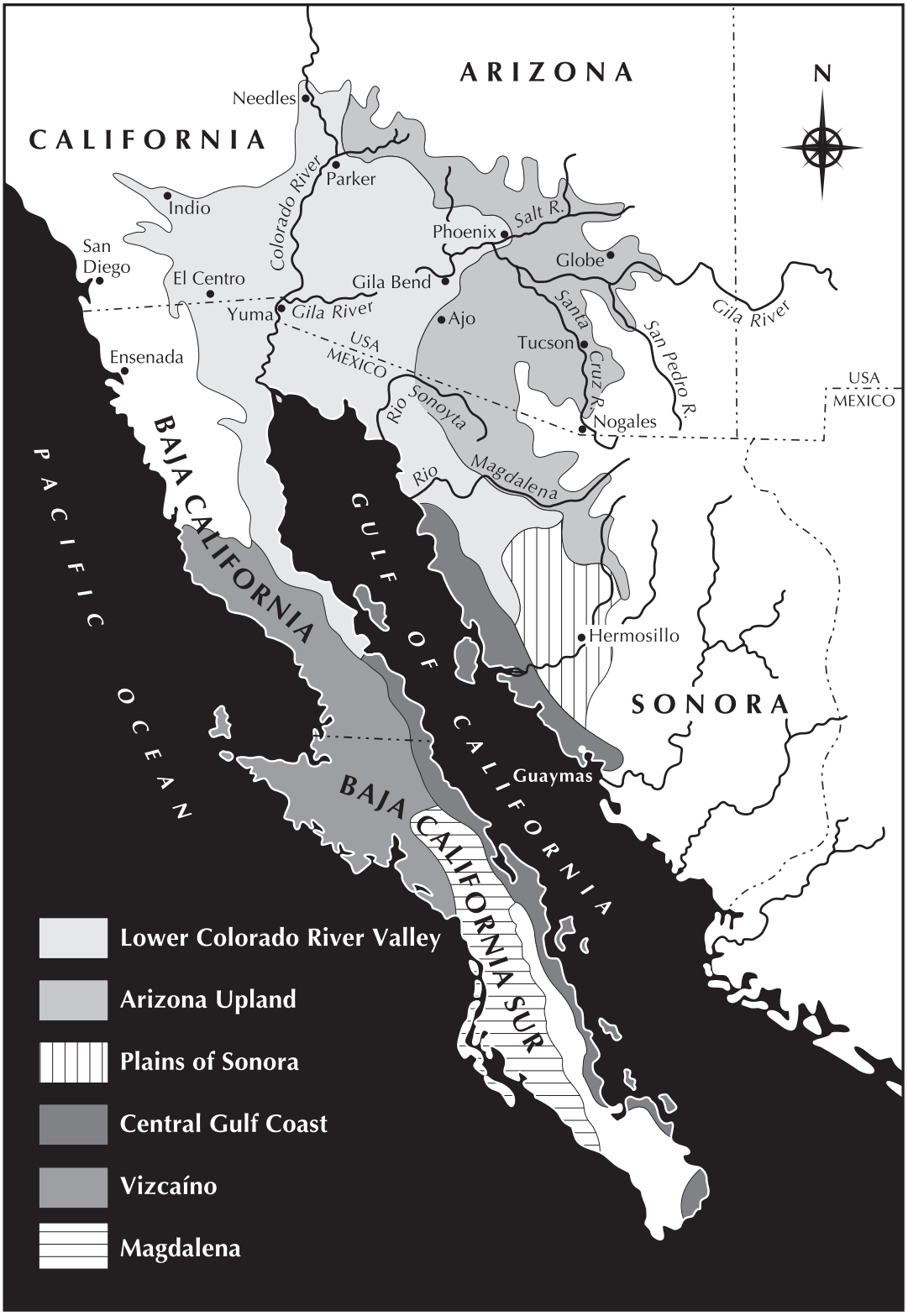
Named for its location surrounding the lower Colorado River in parts of four states, this is the largest, hottest, and driest subdivision. It challenges the Mojave Desert's Death Valley as the hottest and driest place in North America. Summer highs may exceed 120°F (49°C), with surface temperatures approaching 160°F (71°C). The intense solar radiation from cloudless skies on most days and the very low humidity suck the life-sustaining water from plants, water that cannot be replaced from the parched mineral soil. Annual rainfall in the driest sites averages less than 3 inches (76 mm), and some localities have gone 36 months with no rain. Even so, life exists here, abundantly in the rare wet years.

The terrain consists mostly of broad, flat valleys with widely scattered, small mountain ranges of almost barren rock (see plate 13). (There are also seas of loose sand and the spectacular Pinacate volcanic field [see plates 14 and 29]). The valleys are dominated by low shrubs, primarily creosotebush and white bursage. These are the two most drought-tolerant perennial plants in North America, but in the driest areas of this subdivision even they are restricted to drainageways. Trees grow only in the larger washes. The mountains support a wider variety of shrubs and cacti, but the density is still very sparse. Columnar cacti, one of the indicators of the Sonoran Desert, are rare (virtually absent in California) and are restricted to valley floors. Annual species make up over half the flora, up to 90 percent at the driest sites; they are mostly winter-growing species and appear in large numbers only in wet years.

This is the only part of the Sonoran Desert that extends into California, where most residents call it the Colorado Desert. North of a sagging line between the Coachella Valley (Palm Springs) and Needles, California, it merges almost imperceptibly into the lower Mojave Desert.

Arizona Upland

This northeastern subdivision is the highest and coldest part of the Sonoran Desert. Located in south-central Arizona and northern Sonora, the terrain contains numerous mountain ranges and valleys narrower than those of the Lower Colorado River Valley subdivision. Trees are common on rocky slopes as well as drainageways, and saguaros grow on slopes above the cold valley floors. This community is also called the *saguaro–palo verde forest* (see plate 15). It is the only subdivision that experiences



Subdivisions of the Sonoran Desert. The six subdivisions reflect the biological diversity of this large desert and the fact that it has been intensively studied. Each subdivision has a different climate, topography, and vegetation.

Five Seasons

The following descriptions apply clearly to the Tucson area, but they are fairly applicable to all the Arizona Upland subdivision and to the eastern half of the Lower Colorado River Valley subdivision.

Summer monsoon or summer rainy season (*early July to mid-September*). In Tohono O'odham tradition, the year begins with the most dramatic weather event of the region—the often abrupt arrival of the summer rains (see photo on page 22). *Monsoon* is derived from an Arabic word for "season," and it was applied to a wind that changes directions seasonally. The North American monsoon wind shift, in our case typically a southerly wind in July, brings tropical moist air that moderates the temperatures from June's extremes and can generate frequent thunderstorms. This is the main growing season for many of the larger shrubs and trees. (A sixth season, late summer, lasting from mid-August through September, is sometimes recognized. This is a hot and dry period in years when the monsoon ends early.)

Autumn (*October and November*). Warm temperatures; low humidity; little rain; few species in flower, but the growing season for winter annuals begins if there is enough rain. Late summer and autumn occasionally receive heavy rains from the remains of Pacific hurricanes (tropical storms).

Winter (*December and January, sometimes February*). Mostly sunny, mild days, with intermittent storms that bring wind, rain, and cool-to-cold temperatures; February is often warm and dry, more spring-like (see plate 17).

Spring (*early to late February through April*). Mild temperatures; little rain; often windy; one of two flowering seasons; winter annuals may start blooming in February in warm, wet years (see plates 18 and 27).

Foresummer (*May and June*). High temperatures; very low humidity; no rain in most years; May is very warm and often windy; June is hot and usually calm. The only common plants in flower are saguaro, prickly pear, foothill palo verde, and desert ironwood; usually only saguaro continues into June. Most plants and many animals are dormant until the rains arrive (see plate 19).

frequent hard winter frosts, so many species of the lower-elevation and more southerly subdivisions cannot survive here. Nevertheless, it is a rich area. The small range that is the Desert Museum's home, the Tucson Mountains, has about 630 *taxa* (species and subspecies) of plants. This richness is partly explained by the two equal rainy seasons, which total 12 inches (305 mm) per year on average. The hilly terrain provides a multitude of microhabitats on north and south slopes and deep, shaded canyons. The proximity to chaparral, woodland, and grassland communities contributes still more species to the flora (see plate 16).

Arizona Upland's climate, vegetation density, and biodiversity resemble thornscrub at least as much as desert. It may join the former Foothills of Sonora subdivision and be reclassified as non-desert in the future.

Tucson is the only major city entirely within Arizona Upland, while in metropolitan Phoenix, the Lower Colorado River Valley subdivision intergrades with Arizona Upland. Residents who have moved to this area from temperate climates often complain about the lack of seasons. Actually, Arizona Upland has *five* seasons, which, though more subtle than the traditional temperate four, are distinct if one learns what to look for. The "Five Seasons" sidebar above applies to the Tucson area, but it is fairly applicable to the rest of Arizona Upland and to the eastern half of the Lower Colorado River Valley subdivision as well. The seasons are a little later at higher latitudes and elevations, earlier at lower ones. The monsoon is later and more sporadic farther west; in some years it fails to reach the Colorado River.

Plains of Sonora

This small region of central Sonora is a series of very broad valleys between widely separated

ranges. It supports denser vegetation than does Arizona Upland because there is more rain (with summer rain dominant) and the soils are generally deeper and finer. It contains most of the same species as Arizona Upland, plus some tropical elements, because frost is less frequent and less severe. There are abundant legume trees, especially mesquite, and relatively few columnar cacti. The few hills in this region support islands of thornscrub. Most of this subdivision has been converted to agriculture in the last few decades. If Arizona Upland is reclassified as thornscrub, the wetter Plains of Sonora subdivision would also have to be reclassified from desert to thornscrub.

Central Gulf Coast

The Central Gulf Coast occupies a strip along both sides of the Gulf of California. Extreme aridity dictates the distinctive appearance of this subdivision. It straddles the horse latitude belt, and desert vegetation grows right to the seashore. Small shrubs are nearly absent; their shallow root systems and lack of water storage cannot sustain them through the droughts, which commonly last for several years. Large-stem succulents, particularly the massive cardón (a giant relative of the saguaro), and trees such as palo verde, tree ocotillo, ironwood, elephant tree (*Bursera* spp.), and limberbush dominate the vegetation; the trees are leafless most of the time. The average annual rainfall of less than 5 inches (125 mm) occurs mostly in summer, though not dependably enough to call it a rainy season. A year with no rain is not rare (see plate 20).

Vizcaíno

The Vizcaíno subdivision is on the Pacific side of the Baja California Peninsula. Though rainfall is very low, cool, humid sea breezes with frequent fog mitigate the aridity. Winter rain predominates and averages less than 5 inches (125 mm). This subdivision contains some of the most bizarre plants and eerily beautiful landscapes in the world. There are fields of huge, sculpted, white granite boulders or black lava cliffs that shelter botanical apparitions such as boojums, twisted and swollen Baja elephant trees, 60-foot-tall (18-m) cardóns, rock figs, and blue palm trees. In stark contrast to the hilly interior of this subdivision, the coastal Vizcaíno Plain is a flat, cool, fog desert of shrubs barely a foot tall, with occasional mass blooms of annual species (see plates 21 and 26).

Magdalena

Located in coastal Baja California Sur, south of the Vizcaíno, Magdalena is similar in appearance to the Vizcaíno but the species are somewhat different. Most of its meager rainfall comes in summer, and the aridity is modified by Pacific breezes. The bleak coastal Magdalena Plain's only conspicuous endemic plant is the weird creeping devil cactus (see plate 22), but inland the rocky slopes are rich and dense with trees, succulent shrubs, and cacti.

Foothills of Sonora

This was Shreve's seventh subdivision of the Sonoran Desert. It has since been reclassified as foothills thornscrub community and is no longer considered part of the desert biome because of its greater rainfall, taller trees and cacti, and denser vegetation.

Shreve's delineation of the Sonoran Desert's boundary and subdivisions are the most widely accepted. There are at least five other major attempts to define this area, with dramatically differing boundaries. One version excludes most of the Baja California Peninsula from the Sonoran Desert. Another includes the Mojave as part of the Sonoran Desert. (Indeed, it is difficult to distinguish the two along the currently accepted boundary.) These differences of interpretation reflect the great diversity of geography and biota found here.

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