Thirty-Three

Conservation and Landscape Transformation in Northwestern Mexico

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Mexico is the fourth richest area in the world in terms of biodiversity (Challenger 1998; Flores & Geréz 1988; Mittermeier & Goettsch Mittermeier 1992). Efforts to set up nature reserves in Mexico have had three major periods: the beginning of the twentieth century, the mid-1930s, and from the 1980s onward. The early attempts were oriented toward protecting dense, tall temperate forests; at the time, tropical lowlands and drylands were considered more abundant and less valuable ecosystems. Despite the great emphasis given to temperate and more recently to wet lowland tropical forests, the largest share of the richness of Mexican species is in the drylands, which cover about 70 percent of the country and have a high degree of endemism (Rzedowski 1991a). Yet drylands have received little recognition as areas of high biodiversity, and until recently, limited efforts were made to protect them (Flores & Geréz 1988; Janzen 1988).

Protection of the environment in Mexico began at about the same time as in the United States. In 1876 Desierto de los Leones was the first protected area decreed to safeguard a small portion of the extensive pine and fir forests of central Mexico. Afterward the Mexican government attempted to copy, without much success, the structure of the National Park Service of the United States. The main emphasis was on preserving small areas considered national monuments. These were set aside mainly for recreation rather than for management or protection of biological diversity. This first reserve system added only nine areas in the 18 years following the establishment of the Desierto de los Leones reserve (Anaya et al. 1992).

In the late 1930s the director of Flora and Fauna, Miguel Angel de Quevedo, single-handedly launched an intense lobbying effort to protect natural areas in Mexico. He was a visionary concerned with the conservation of natural resources of immediate use such as forests, the protection of upriver basins from erosion, and the establishment of large wildlife ranges. As a result, about 800,000 ha distributed over 17 Mexican states were protected (Colosio 1993). However, these reserves were not part of a national development strategy and never received funds for management. Many reserves had, and still have, land ownership problems, and they were repeatedly used as land banks for future development (Anaya et al. 1992; INE/CONABIO 1995). Despite the long history of reserve designation in Mexico, until 1936 there was not a single protected area in Sonora, and by 1994 there was still no area in the state attaining minimum international management standards of protection, a striking contrast with its neighbor across the international border, which has an extensive reserve system dating back many decades.

In this chapter we describe the present extent and history of the reserves in northwestern Mexico and discuss the major threats to the region. As the largest changes in the landscape have occurred in the continental rather than the peninsular environments, and most of the northwestern border of Mexico occurs in Sonora, we concentrate our attention on this Mexican state.

Extant Reserves in Northwestern Mexico

The landscape of northwestern Mexico encompasses a wide range of biomes, including most of the major Mexican vegetation types (Brown 1982; Brown and Lowe 1980; Búrquez et al. 1992; Gentry 1942; Marshall 1957; Rzedowski 1978; White 1948). Sonora by itself is a major reservoir of what Rzedowski (1991a, b) calls the "genuinely Mexican species," species that have differentiated mainly in the arid and semiarid zones of northern Mexico. The Sonoran vascular flora is estimated to include about 5,000 species (Felger et al. 2001; Rzedowski 1991a). This figure represents about 20 percent of

the Mexican flora in an area that is less than 10 percent of the country, which has an estimated national total of about 22,000 known species (Rzedowski 1991a). Even more striking figures are found for the fauna, which encompasses a rich, poorly known assemblage of species with Neotropical and Nearctic affinities for almost every major taxon (Felger & Wilson 1995). Baja California holds numerous endemic species and is the only area in Mexico with extensive chaparral communities (Challenger 1998).

The dominant feature of northwestern Mexico is the Sonoran Desert. As defined by Shreve (1951), it covers a wide range of environments, from extremely xeric to relatively mesic. The former are readily recognized by the scant plant cover and severe climatic constraints. However, much of the desert owes its diversity to diffuse transitions into varied thornscrub and tropical deciduous forests (Búrquez 1997; Búrquez et al. 1999; Martínez-Yrízar et al. 2000). The desert also has oases that arise from seeps and artesian springs in deep canyons, and forests that once flourished in the great desert river deltas (Felger 1999, 2000; Yetman & Búrquez 1996). Toward the east the great Sierra Madre Occidental harbors, at different elevations, tropical deciduous forests, oak woodlands, pine-oak forests, and conifer forests (Búrquez et al. 1992; Felger & Johnson 1995), and on the shores of the Gulf of California, wetlands add to Sonora's overall diversity, including the northernmost mangrove swamps on the continent (Felger & Moser 1985; Felger et al. 2001). The great biodiversity found in Sonora and the peninsula of Baja California is primarily caused by the uneven distribution of precipitation, surface water, and climate, along with marked variation in topography, geological substrates, and soils (Brown 1982; Búrquez et al. 1999; Wiggins 1980).

In spite of the biological and habitat richness of northwestern Mexico, nature reserves were not decreed until 1936–39 (Vargas et al. 2000). During this period five areas were set aside in Sonora: (1) Arroyo de Nogales, near Nogales, (2) Sierras Los Ajos, Buenos Aires y La Púrica, southeast of Cananea, (3) Cajón del Diablo, southwest of Hermosillo, (4) Zona Protectora Forestal de la Ciudad de Hermosillo, and (5) Bavispe, near the town of Bavispe (Figure 33.1). This last reserve added new areas to the already decreed Sierras Los Ajos, Buenos Aires y La Púrica. These actions protected about 282,000 ha, or approximately 1.5 percent of the state (Table 33.1), mainly pine and oak forests, although some portions of the Sonoran Desert were protected by Cajón del Diablo and Zona Protectora Forestal de la Ciudad de Hermosillo.

The first reserve in Baja California was decreed in 1928; it was a faraway island in the Pacific, Isla Guadalupe, with a unique vegetation and fauna (e.g., Moran 1996). The national park Sierra de San Pedro Mártir was established in 1947, and in 1962 the Constitución de 1857 reserve brought protection to about 5,000 ha of pine-oak and chaparral communities. One year later the sixth reserve in Sonora was set aside: Isla Tiburón. On paper the protected areas of Sonora amounted to about 403,000 ha (2.2% of the state) and those in Baja California only 103,000 ha (1.4% of the state). No reserves were decreed in Baja California Sur until 1972, when Complejo Lagunar Ojo de Liebre was set aside for the protection of the gray whale (Vargas, Escobar, & del Angel 2000). In 1978 a new edict added the midriff islands (Islas del Golfo) to the Isla Tiburón reserve, increasing the protected area by nearly 150,000 ha. A year later, about 30,000 ha in the magnificent Sierra El Pinacate were protected as a wildlife refuge in Sonora (Table 33.1; Búrquez & Castillo 1994).

In 1980 a large expanse of Sonoran Desert ecosystems was protected by the wildlife refuge Valle de los Cirios in Baja California (2,521,776 ha). By then the edicts protecting the environs of Nogales and Hermosillo had been long ignored. These early-protected areas near major towns were being devoured by city growth and development. The rest were protected only by their isolation. However, they did not escape logging (the high sierras), cattle ranching (all reserves, excluding the gulf islands), the introduction of large, wild herbivores (African antelopes on the mainland; bighorns on Isla Tiburón), and the overexploitation of fisheries (gulf islands).

A new era of reserve designation was initiated in 1988 when a prominent desert area in Baja California Sur was established: Reserva de la Biosfera El Vizcaíno. Its implementation gave hopes of real protection to the largest tract of Sonoran Desert so far decreed—2,546,790 ha (Ortega & Arriaga 1991). Work by Instituto de Ecología, Universidad Nacional Autónoma de México (UNAM), and Centro Ecológico de Sonora led to the establishment of the Reserva de la Biosfera El Pinacate

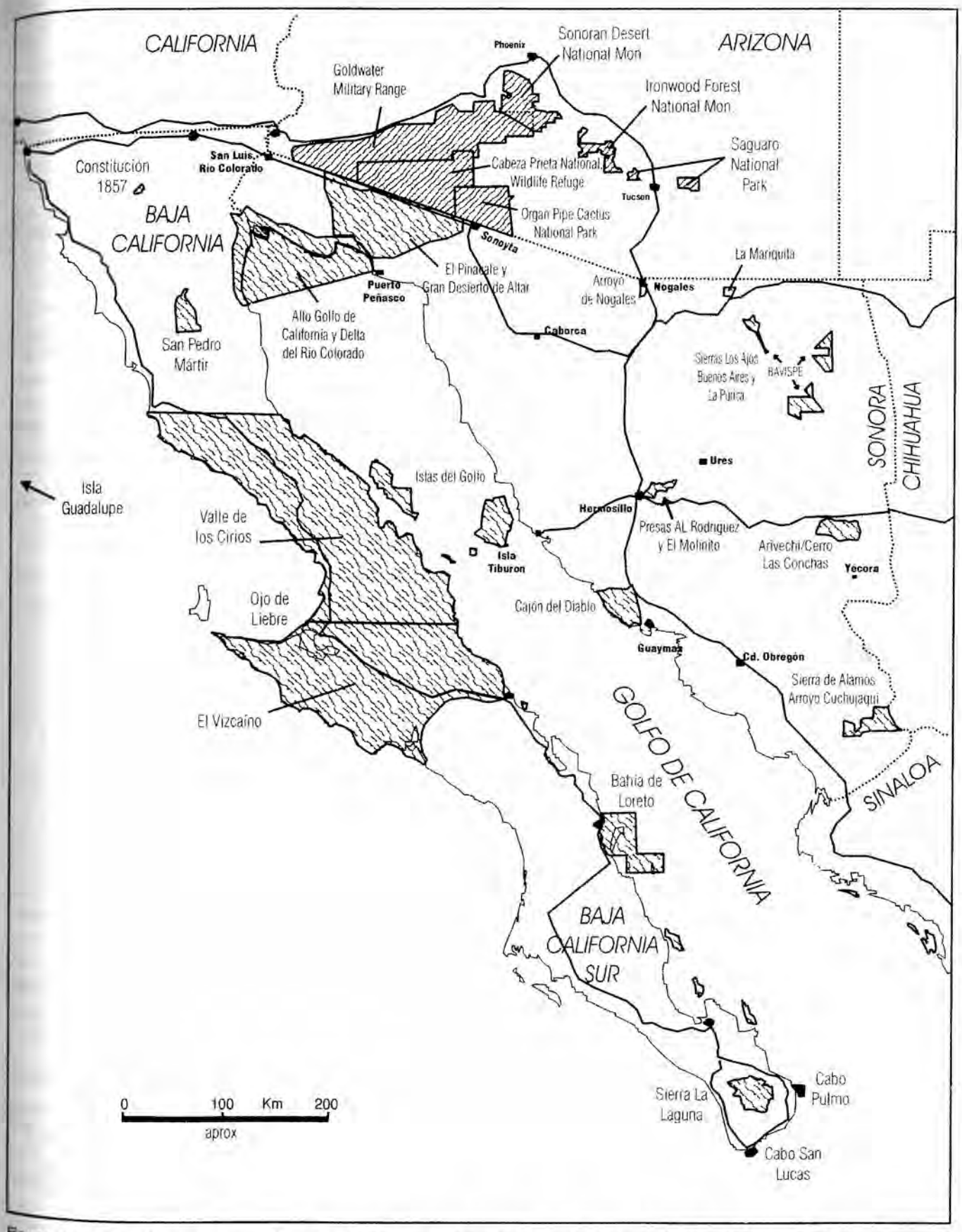

Figure 33.1. *Locations of nature reserves in Sonora and the Península of Baja California. Bavispe includes the following ranges: El Tigre, Iturriquipa/Pilares, Las Iglesitas, Los Ajos, Buenos Aires y La Púrica, and La Madera. The Barry M. Goldwater Range, Cabeza Prieta National Wildlife Refuge, and the Sonoran Desert, Ironwood Forest, and Organ Pipe Cactus national monuments are indicated to show the possible extent of a United States–Mexico international Sonoran Desert reserve. Data from official decrees in* Diario Oficial de la Nación, *Benítez & Loa 1996, and unpublished reports from Centro Ecológico de Sonora; data for reserves in the U.S. from World Wide Web (www) sites of the National Park Service, U.S. Fish and Wildlife Service, and Bureau of Land Management.*

TABLE 33.1. *Extant nature reserves in northwestern Mexico, by order of creation.*

RESERVE	STATUS	LOCATION	YEAR CREATED	MAIN ECOSYSTEM	AREA (HA)
Isla Guadalupe	Reserva Especial de la Biosfera	Pacific BC	1928	Desertscrub, pine-oak forest, and numerous endemic spp.	25,000
Arroyo de Nogales	Zona Protectora Forestal[a]	Northern S	1936	Oak woodlands/desert grassland/riparian	8,650
Sierras Los Ajos, Buenos Aires y La Purica	Reserva Forestal Nacional[b]	NES	1936	Oak-pine forest	21,494
Cajón del Diablo	Reserva de Caza[c,d]	Central coast S	1937	Sonoran Desert	50,000
Ciudad de Hermosillo	Zona Protectora Forestal[a,e]	Central S	1938	Sonoran Desert/riparian	17,250
Bavispe	Reserva Forestal Nacional y Refugio de la Fauna Silvestre[c]	NES	1939	Oak-pine forest	184,770
Sierra de San Pedro Mártir	Parque Nacional	Northern BC	1947	Pine forest, fir forest, chaparral	72,911
Constitución de 1857	Parque Nacional	BC	1962	Oak-pine, chaparral	5,009
Isla Tiburón	Zona de Reserva Natural y Refugio de la Fauna Silvestre[d,e]	Gulf of California	1963	Sonoran Desert	120,756
Complejo Lagunar Ojo de Liebre	Reserva de la Biosfera	BCS	1972	Insular and marine	60,343
Islas del Golfo de California	Zona de Reserva y Refugio de Aves Migratorias	Gulf of California	1978	Sonoran Desert/marine	150,000
Sierra El Pinacate	Reserva Forestal y Refugio de la Fauna Silvestre[f]	NW S	1979	Sonoran Desert	28,660
Valle de los Cirios	Area de protección de flora y fauna	Central BC	1980	Sonoran Desert	2,521,776
El Vizcaíno	Reserva de la Biosfera	BC	1988	Sonoran Desert	2,546,790
Reserva del Centro Ecológico de Sonora	Endowment to the state park[a,g]	Central S	1988	Sonoran Desert	CA. 1,000
El Pinacate y Gran Desierto de Altar	Reserva de la Biosfera	NW S	1993	Sonoran Desert	714,557
Alto Golfo de California y Delta del Río Colorado	Reserva de la Biosfera	NW S and NE BC	1993	Sonoran Desert/marine	934,756
Presas Abelardo L. Rodríguez/El Molinito	Zona sujeta a conservación ecológica[g]	Central S	1994	Sonoran Desert/wetlands	28,000
Sierra La Laguna	Reserva de la Biosfera	Southern BCS	1994	Desertscrub, pine forest, tropical deciduous forest	112,437
Sierra de Alamos–Río Cuchujaqui	Area de Protección de Flora y Fauna Silvestre y Acuatica	Southern S	1996	Tropical deciduous forest/ pine-oak forest	92,889
Cabo Pulmo	Parque Nacional	Southern BCS	1995	Coral reef	7,111
Bahía de Loreto	Parque Nacional	BCS	1996	Mangrove, dunes, desert	206,581
Cabo San Lucas	Area de Protección de Flora y Fauna	Southern BCS	2000	marine	3,996
Arivechi–Cerro Las Conchas	Zona sujeta a conservación ecologica[g]	Eastern S	2000	Sonoran Desert	72,300

Notes: Total area of Sonora is 18,543,100 ha; Baja California, 7,160,200 ha; and Baja California Sur, 7,142,900 ha. S = Sonora; BC = Baja California, BCS = Baja California Sur. Locations are shown in Figure 33.1. [a]*Unofficially appropriated for urban and rural development.* [b]*In 1939 included within Reserva Forestal Nacional y Refugio de Fauna Silvestre Bavispe.* [c]*Not formally delimited. The area is approximate.* [d]*Reserva Especial de la Biosfera from 1989.* [e]*In 1978 included within the Islas del Golfo de California designation.* [f]*In 1994 included within Reserva de la Biosfera El Pinacate y Gran Desierto de Altar.* [g]*State of Sonora decree.*

y Gran Desierto de Altar in 1993 (Table 33.1). This reserve, together with El Vizcaíno and Valle de los Cirios, included the most pristine areas of the Sonoran Desert. At the same time, another biosphere reserve, proposed by a consortium of Mexican institutions, was decreed: Reserva de la Biosfera Alto Golfo de California y Delta del Río Colorado. It is mainly marine, with approximately 70 percent of its area in the sea, but includes critical land areas in the delta and along the coast.

Recent additions of protected land are the Presas Abelardo L. Rodríguez y El Molinito (Del Castillo 1994) and the Sierra de Alamos–Río Cuchujaqui. The former includes two artificial impoundments and the highly disturbed riverside of the Río Sonora near Hermosillo, and the latter provides a measure of protection for diverse tropical deciduous and oak forests in southern Sonora. The state government designated Arivechi–Cerro Las Conchas a wildlife refuge in 2000, the latest official addition to the nature reserve system of Sonora. In Baja California Sur several reserves were also proclaimed in the 1990s: Bahía de Loreto, Cabo Pulmo, and Cabo San Lucas to protect mainly marine environments, and Sierra La Laguna, an isolated sierra at the tip of the peninsula, to safeguard thornscrub, tropical deciduous forests, and pine-oak forests (Table 33.1).

Today about 1,500,000 ha, or 8 percent, of land in the state of Sonora has some form of protection; in both Baja California (the northern state) and Baja California Sur nearly 37 percent of the area is protected (ca. 2,700,000 ha each). These figures do not include reserves lost to city development or marine areas. Through the Comisión Nacional de Áreas Naturales Protegidas (CONANP) the federal government is increasing its efforts to operate the reserves formally. Nevertheless, the allocation of funds is still precarious and some reserves have no protection other than that given by the edicts and their natural isolation.

Planned Reserves in Sonora

In addition to the Secretaría del Medio Ambiente y Recursos Naturales (SEMARNAT, the federal environmental agency), institutions such as UNAM, state universities, the Comisión Nacional para el Conocimiento y Uso de la Biodiversidad (CONABIO), several state-level agencies, and many nongovernmental organizations (NGOs) are working on selecting and studying high-priority areas for protection in Mexico. For Sonora, the Centro Ecológico de Sonora and CONABIO (Arriaga et al. 2000; Benítez & Loa 1996), with the aid of NGOs and academic institutions, have proposed areas of high priority for conservation in various parts of the state (Table 33.2). If decreed, important portions of the Sonoran Desert, Gulf of California marine environment, and sky islands in the Sierra Madre Occidental will receive protection and more adequate management.

Proposed reserves such as Sierra San Luis, Sierra La Mariquita, Sierra El Tigre, Mesa El Campanero, and Sierra Mazatán are sky islands with oak, pine-oak, and pine forests. They also include portions of desert grasslands and small areas of foothills thornscrub. During 1997–98 an area of 2,196 ha in Sierra La Mariquita, northeastern Sonora, was endowed to the Instituto Nacional de Astrofísica, Optica y Electrónica (INAOE) to guarantee optimal conditions for scientific research at the Observatorio Astrofísico Guillermo Haro (Estévez 1999). This area has been included in the projected Reserva Mavavi, an extension of the Ajos-Bavispe reserve, proposed by the Instituto Nacional de Ecología (INE) and SEMARNAT. The proposal calls for an increase in area from the present 185,000 ha to 780,000 ha. It would include the basin of the Río San Pedro, a tributary of the Gila River, as well as Sierra Los Ajos, Buenos Aires, La Púrica, and La Mariquita mountains. The area collects about 50 percent of the Río Sonora basin precipitation and provides the main water supply for Hermosillo, the state capital (J. L. Guerra Limón, Los Ajos reserve director, personal communication 2003). It is also renowned for its biodiversity, connectivity with southern tropical ecosystems, and mineral reserves. If decreed, it will encourage the protection of the Sonoran sky islands, a complement to the protected areas in the mountains of Arizona. However, the proposal has not yet been approved, and it is strongly resisted by the mining lobby, which has steered the opinion of peasants *(ejidatarios)* and small landowners.

Coastal environments are considered in the proposed reserves of Las Bocas, Bahía de Lobos, Estero El Soldado, Cajón del Diablo y Cañón El Nacapule, and Sierra Bacha. These reserves also include considerable portions of Sonoran Desert or, as in the cases of Bahía de Lobos and Las Bocas, coastal thornscrub (Búrquez et al. 1999; Friedman

TABLE 33.2. *Proposed nature reserves in Sonora, Mexico.*

RESERVE	LOCATION	MAIN ECOSYSTEM
Reserves Not Yet Decreed		
Las Bocas	Huatabampo	Coastal thornscrub, coastal wetlands
Bahía de Lobos	Guaymas	Coastal thornscrub, coastal wetlands
Estero El Soldado	Guaymas	Sonoran Desert, coastal wetlands
Sierra Bacha	Pitiquito	Sonoran Desert
Bahía San Jorge	Caborca	Sonoran Desert, coastal wetlands
Sierra El Viejo	Caborca	Sonoran Desert, foothills thornscrub
Trincheras	Trincheras	Sonoran Desert
Sierra Libre	La Colorada/Hermosillo/ Guaymas	Sonoran Desert, foothills thornscrub, tropical deciduous forest
Sierra Bacatete	Guaymas/Cajeme	Sonoran Desert, foothills thornscrub, tropical deciduous forest
San Javier/Tepoca	San Javier/Yécora/Onavas	Riparian, foothills thornscrub, tropical deciduous forest
Soyopa/Sahuaripa	Soyopa/Sahuaripa	Riparian, foothills thornscrub, tropical deciduous forest
Mazocahui/Puerta del Sol	Ures/Baviácora	Riparian, foothills thornscrub, tropical deciduous forest
Sierra San Luis	Agua Prieta	Desert grassland, oak-pine forest
Mesa El Campanero/Arroyo El Reparo	Yécora	Pine-oak forest, tropical deciduous forest, highland wetlands
El Carrizo	Benjamin Hill/Trincheras/ Opodepe/Carbó	Sonoran Desert, desert grassland
Sierra de Mazatán	Mazatán/Ures	Sonoran Desert, foothills thornscrub, oak woodland
Cerro Agualurca/Centro Ecológico de Sonora	Hermosillo	Sonoran Desert, foothills thornscrub
Santuario del Aguila Calva	Sahuaripa/Soyopa	Foothills thornscrub, tropical deciduous forest
Reserves Already Decreed but with a New Proposal in Progress		
Cajón del Diablo, Cañón El Nacapule	Hermosillo and Guaymas	Sonoran Desert, foothills thornscrub, tropical deciduous forest, marine
Islas Tiburón y San Esteban	Gulf of California	Sonoran Desert, foothills thornscrub, marine
Mavavi: Sierras Los Ajos, Buenos Aires y La Púrica, including El Tigre, Huachineras, and La Mariquita	NE Sonora	Oak-pine forest, desert grassland, highland wetlands

Notes: Location is the municipality where most of each reserve is found. Locations are illustrated in Figure 33.1.

2006). Mesa El Campanero y Arroyo El Reparo, the area between San Javier and Tepoca, and Soyopa and Sahuaripa are proposed reserves protecting riparian habitats, foothills thornscrub, and the most northern tropical deciduous forests on the continent (Table 33.2). Until recently, tropical deciduous forests have been one of the least protected biomes of Mexico (Trejo & Dirzo 2000), and they are among the most endangered major tropical ecosystems (Janzen 1988). Soyopa and Sahuaripa have also been recognized as important breeding areas for the endangered bald eagle (Guadalupe Morales, personal communication 2002).

Other planned reserves that include substantial portions of Sonoran Desert are located at Sierra Libre, Sierra Bacatete, Sierra El Viejo, Rancho El Carrizo, Sierra Mazatán, Trincheras, and Cerro Agualurca. The already mentioned area of Cajón del Diablo y Cañón El Nacapule, located in Gentry's Guaymas Monadnock (Gentry 1949), has a wealth of endemics and disjunct tropical taxa shared with Baja California and the Sierra Madre foothills along Mexico's Pacific coast (Búrquez et al. 1999; Felger 1999; Turner et al. 1995). Sierra Libre, Puerta del Sol/Mazocahui, and Sierra Bacatete are similar cases, virtually unexplored biologically but known to have a rich disjunct tropical flora as well as remains of Seri, Opata, and Yaqui cultures (see Yetman & Búrquez 1996). Trincheras is famous for its prehistoric agricultural terraces and other features. Sierra El Viejo, near Caborca, has remarkable transitions of several Sonoran Desert subdivisions and probably the northwesternmost extension of foothills thornscrub (Brown & Lowe 1980). Here substantial numbers of desert bighorn sheep *(Ovis canadensis mexicana)* are still found (Medellín et al. 2005). The only population of boojum tree *(Fouquieria columnaris)* on the mainland is located in Sierra Bacha, along the coast south of Puerto Libertad (Felger & Moser 1985; Hastings & Turner 1965). In this pristine area of the Central Gulf Coast subdivision of the Sonoran Desert there are also populations of desert bighorn and archaeological features and artifacts of the Seri culture. South of Benjamin Hill in the northern desert grasslands is Rancho El Carrizo, where the only remaining natural populations of masked bobwhite *(Colinus virginianus ridgwayi)* are found (Garza-Salazar et al. 1992). It also supports fine examples of the desert grassland–shrubland continuum of the Plains of Sonora subdivision (Búrquez et al. 1998). These reserves would protect a gradient harboring notable transitions in vegetation, from marine environments to coastal wetlands and from Sonoran Desert to coniferous forests. They would also add distinct units of the Sonoran Desert to the already existing reserves of El Pinacate y Gran Desierto de Altar and Alto Golfo de California y Delta del Río Colorado, as well as to the special microcosms of the protected Islas del Golfo de California and Cajon del Diablo.

Human Impacts on the Sonoran Desert Region

The growth and decline of large-scale agriculture, extensive and intensive cattle ranching, the damming and silting of rivers, indiscriminate logging, and fisheries overexploitation are some of the human activities that have affected the landscape and resources of the region (Stoleson et al. 2005).

Agriculture

Historically, most of the settlements in Sonora were on the western edge of the Sierra Madre Occidental and in the Madrean foothills. Precolumbian agriculture was common along the river margins, sometimes with sophisticated irrigation systems (Camou 1991; Moreno 1992). In historical times agricultural development in the desert was confined to small areas with a shallow water table, but nonetheless by the end of the nineteenth century it had seriously affected riparian habitats (Bahre 1991; Camou 1991).

After many years of low rates of population increase, growth in Sonora accelerated rapidly in the twentieth century, mainly because of the development of large-scale agriculture in the coastal plains (Stoleson et al. 2005). In the late 1940s the vast aquifers of the Río Concepción, Río Sonora, and Río Mátape basins began to be appropriated. The Río Mayo and Río Yaqui deltas were not extensively altered until the construction of dams upriver between the 1940s and 1960s. The resulting reservoirs stimulated further population growth through the generation of electricity and the rapid expansion of agriculture. By the late 1970s the delta regions and their associated alluvial plains were almost entirely converted to field crops. Thus within a few years huge expanses of natural vegetation had been cleared. The vast mesquite forests of the Llanos de San Juan Bautista,

in the deltaic plains of the Río Sonora, disappeared with the colonization of the Costa de Hermosillo irrigation district (Felger & Lowe 1976). The progressive salinization of the aquifer and the increasing cost of water extraction have caused a decrease in the land devoted to crop production. From the original 150,000 ha cleared for agriculture, only about 70,000 ha remain operative, and the rest is derelict land. The nonsustainable operation of this district, the ever-lowering water table (dropping up to 1 m yr^{-1}), and the faltering local economy are documented by Moreno (1994, 2000).

In the Río Yaqui and Río Mayo deltas' coastal plains, nearly one million ha of mesquite, cottonwood, and willow riparian forests and coastal thornscrub disappeared after dams upriver started to operate. These rivers followed the same path of vegetation eradication as that of the Colorado after the construction of Hoover Dam (Felger 2000; Glenn et al. 1992). Today both irrigation districts face serious environmental problems because of poor drainage, salinization, and toxic levels of pesticides and fertilizers (Celis 1992).

Cattle Ranching

Compared with agriculture, cattle raising has a relatively brief history in the drylands of North America. By the sixteenth century, Precolumbian agricultural towns along the fertile foothills of the Sierra Madre and major desert rivers, as well as hunter-gatherer societies in the desert, had attained a precarious equilibrium with their use of resources. This equilibrium was broken when cattle were introduced by the Europeans as a new form of land use. Cattle created a major source of conflict between the new pastoralists and the indigenous agriculturists—cattle did not respect boundaries, particularly those of unfenced crops (Camou 1991; Doode & Pérez 1994; Moreno 1992). It also affected hunter-gatherer societies, whose members considered cattle a rich source of animal protein roaming the common land, ready and easy to harvest (Felger & Moser 1985; Thompson 1989). Until the last century only localized areas of desertscrub were used for cattle raising. Because of constant raids by Native Americans, cattle were confined to small areas, which often were overgrazed. By the end of the nineteenth century the organization of the large "haciendas" allowed extensive exploitation of the arid lands. Large cattle herds transformed the natural balance between desert grasslands and desertscrub, contributing to the so-called invasion of mesquite and thornscrub (Archer 1989, 1994; Bahre 1991; Búrquez et al. 1998; Hastings & Turner 1965; Johnston 1963). During the Mexican Revolution cattle stocks diminished drastically (Machado 1981), allowing some recovery of the rangelands. However, the cattle industry regained momentum, mainly in northern Mexico, transforming large expanses of semiarid and arid lands (Barral 1988; Búrquez et al. 1998; Ezcurra & Montaña 1988).

The introduction of Indo-African buffelgrass *(Pennisetum ciliare)* in the 1960s, promoted by the USDA Soil Conservation Service (Cox et al. 1988; Johnson & Navarro 1992), altered large expanses of the Sonoran drylands beyond recognition. Buffelgrass, which increases the range productivity of cattle forage by about three times (Hanselka & Johnson 1991), is planted after the desertscrub and thornscrub are stripped away. Unfortunately, this process eradicates desert perennials that provide winter and spring forage when buffelgrass is dormant. The replacement of native perennials coupled with overstocking of cattle led to a perceived higher occurrence of drought, despite the fact that rainfall patterns have not changed appreciably in this century. It is paradoxical that the desert has historically been devoted to cattle raising, the most water-demanding land use. To produce 1 kg of beef in the desert requires 100,000–200,000 kg of water, whereas most other crops can yield the same amount of energy with only 500–2,000 kg water. Broiler chickens, a source of high-quality protein, need only about 4 percent of the water used by beef per kilogram of protein produced (Pimentel et al. 1997).

After a few years buffelgrass productivity decreases, and prescribed fires are needed to increase soil fertility and stop the return of some desert and thornscrub species. In addition, there is enough fuel accumulation in the form of indigestible stubble to allow extensive natural burning. Since Sonoran Desert plant species are not fire-adapted, a cycle of decreasing biodiversity begins, converting the rich desert into a species-poor grassland (Búrquez et al. 1998, 2002). Paired samples with and without buffelgrass show an order of magnitude decrease in species numbers and a fourfold decrease in standing crop biomass

maximum of 5 tons per ha above-ground standing crop in buffelgrass vs. 20 tons per ha in natural desertscrub; Búrquez et al. 2002). Central Sonora, particularly the Plains of Sonora desert subdivision, has been the most severely affected area, with about one million ha already cleared for pasture (Búrquez et al. 2002; Johnson & Navarro 1992) and a government call for as much as 6 million additional ha. Adventive buffelgrass is now expanding its range through repeated natural burning of the desertscrub and is present throughout Sonora at elevations below 1,000 m (Búrquez et al. 2002; Cox et al. 1988; Yetman & Búrquez 1994).

Given the government subsidies to establish exotic grasslands, to maintain large cattle herds, and to support marginal cattle ranching, the desert and thornscrub in Sonora will probably be replaced in the near term by ecosystems with significantly lower species diversity and reduced structural complexity, unless control measures are implemented.

Mesquite Logging, Charcoal Production, and Clearings

The largest production of legal hardwood legumes for charcoal is in the districts of Hermosillo, Guaymas, Puerto Peñasco, Sonoyta, and San Luis Río Colorado. These areas have historically accounted for more than half the mesquite extraction in Sonora (in 1985, for example, 74,700 out of a total of 135,300 m^3; INEGI 1990). Former mesquite forests have disappeared at an alarming rate because of demand for charcoal in Sonoran and North American markets. The establishment of clearings for buffelgrass is closely related to charcoal production. The woody remains from clearings are piled in long *chorizos* (sausages), forming strips of dead vegetation that are later sorted for fuelwood and charcoal. Populations of ironwood (*Olneya tesota*), among the oldest plants in the Sonoran Desert, have shifted toward smaller sizes because of illegal logging for charcoal, *desmontes* (clearings), and the gathering of wood for sculpture or carvings (Búrquez & Quintana 1994; Nabhan & Plotkin 1994). Old-growth ironwood is a major community structuring element of the southern Sonoran Desert, allowing the persistence of many species and forming true islands of diversity under its canopy (Búrquez & Quintana 1994; Tewksbury & Petrovich 1994). Any reduction in this particular habitat can threaten populations with low numbers, such as queen of the night cactus (*Peniocereus striatus;* Nabhan & Suzán 1994), or species with low rates of recruitment, such as columnar cacti and ironwood itself (Búrquez & Quintana 1994).

Mining and Urban Development

Mining and cement works generate extensive landscape alteration, depriving the land of its natural vegetation cover, accelerating erosion, polluting rivers with toxic wastes, and producing large clouds of airborne particles. Traditionally, the environmental impacts of digging, leaching, and smelting operations have not been acknowledged. Vegetation rehabilitation and restoration with native species at the end of operation is negligible. The economic importance of mining is increasing exponentially in Sonora, now Mexico's leading mineral producer, so such alteration of the environment is likely to continue.

Urban centers in the desert also have grown exponentially, placing stress on scant water supplies. Deep-well water extraction and water diversion from rivers, coupled with effluent discharges from city sewage, are rapidly affecting water distribution and quality. The reduction of the natural cover of phreatophytes that depended on the underground aquifer has promoted erosion and increased the quantity of aerosols. Industry has grown in both the borderlands and the interior of the state with the installation of numerous maquiladora assembly lines for the United States market (Lara 1992). Maquiladoras have overtaxed the water resources available for development in the major cities, exacerbating environmental damage. Toxic wastes generated by the maquiladoras and mining industry are often mishandled or casually discharged, causing not only severe damage to natural ecosystems but also serious human health problems (Denman 1992; INEGI 1993; Moreno-Vázquez 1991).

Hermosillo is following the development model of Phoenix, its counterpart in Arizona. Chronically short of water, it is home to about one-fourth the Sonoran population. Government initiatives have called for large-scale water projects, ranging from the plan to connect the Río Yaqui to the Río Sonora basin to supply water for population and industrial growth to the building of massive desalination projects (Búrquez &

Martinez-Yrizar 2000). Apart from the enormous construction costs, these projects may decrease energy generation by diminishing water availability for the dams upriver or require large investments in energy to desalinate. Alternative actions such as increasing city water-use efficiency have been only superficially analyzed, reflecting the current pattern of government development projects that consistently omit environmental concerns (Joseph 1993; Ortiz 1993).

Urban development has also taken its toll on Sonora's nature reserves. Three of the reserves have already disappeared through the ignorance and complacency of local authorities. The edicts protecting the Arroyo de Nogales and Zona Protectora Forestal de Hermosillo were ignored, and these areas were appropriated for urban growth. In 1996 the reserve by which the Centro Ecológico de Sonora had been endowed by a former governor was cleared to promote urban development. Ironically, the impact assessment to effect this land-use change was furnished by the same Centro Ecológico de Sonora (now Instituto del Medio Ambiente y Desarrollo Sustentable del Estado de Sonora, or IMADES), a Sonoran government agency. This case reflects the tenuous status of many nature reserves in Mexico during the 1990s (see, e.g., Otero & Consejo 1992 and Jardel et al. 1992 regarding the problems faced by other Mexican reserves).

Desert Coastal Wetlands, Rivers, and Fisheries

The Sonoran Desert has an intimate relationship with the Gulf of California and the Pacific Ocean. Humidity from the ocean streams into the desert during the monsoon thunderstorms. Cold currents in the Pacific create unique communities based on dew deposition in the west side of the peninsula, and within the gulf a narrow strip of desertscrub and the coastal thornscrub in southern Sonora are directly influenced by dew deposition, salt spray, and sand movement. In turn, the coastal wetlands and continental platform are enriched by the load of sediments and organic matter carried by arroyos and rivers (see Felger & Lowe 1976).

Fisheries in the Gulf of California have decreased markedly in recent decades. Steinbeck and Ricketts (1951) wrote passionately about the ongoing destruction of the Gulf of California by trawler fishing boats. Little has transpired since that time to address these prescient concerns. Recently, some attempts have been made to preserve the productivity of the gulf, without a great deal of success: the Alto Golfo reserve is now fully operating and the site of substantial research, but fishermen have curtailed most efforts to bring about a sustainable use of upper gulf resources (see Brusca, Turk Boyer, and Hastings & Findley, this volume; Bergman 2002). Upriver dams have stopped the annual floods rich in nutrients and have blocked, by virtue of the lack of water in the estuaries, the entrance of many marine species that used river deltas as spawning areas. The effects of such changes are evident today. The totoaba (*Totoaba macdonaldi*), once so abundant that it supported a large fishery, now is listed as endangered, along with the small vaquita porpoise (*Phocoena sinus*), also endemic to the upper gulf (Hastings & Findley, and Navarro, this volume). Sea turtles, formerly abundant (Clifton et al. 1982; Felger et al. 1976; Felger & Moser 1985), are also listed as endangered and legally protected (Felger et al. 2005; Navarro, Seminoff & Nichols, and Turk Boyer, this volume). The shrimp fishery has suffered serious decline, and the sardine fishery is following suit (Doode et al. 1992). Along with overexploitation, a major role has been played by the damming of the large rivers that feed the gulf: the Colorado, the Mayo, and the Yaqui. Before construction of Hoover Dam, the Colorado alone carried an annual average of 180 million tons of sediments past Yuma, Arizona (Fradkin 1981). Today only during periods of extraordinary runoff does fresh water from the Colorado reach the sea, and when these rare waters enter the gulf, they are laced with pesticides and fertilizers (Bergman 2002). This case is repeated on a smaller scale with the Río Yaqui and Río Mayo (Celis 1992). There is little hope that fresh water will flow again into the gulf unless high-level agreements are reached between governments. In the Río Fuerte, in northern Sinaloa, another huge dam—Luis Donaldo Colosio—was completed at Huites. It provides water for development of the relatively pristine coastal thornscrub of southern Sonora and northern Sinaloa.

The transformation of coastal wetlands for aquaculture and tourism has affected the growth of fisheries by diminishing precious habitat used by many fish species for breeding. This is the case at Estero Puerto Peñasco, in the upper gulf; Estero

La Cruz, near Bahía Kino; Estero Bacochibampo, Estero El Soldado, Estero El Rancho, Bahía San Carlos, and Bahía Empalme in the Guaymas region; and many others farther south, including the large inlet of Agiabampo. Most of these estuaries have been buried or drowned by land reclamation, destruction of the mangrove vegetation, and the construction of ponds for shrimp and oyster production.

Conclusions

The development of Sonora, and most of northern Mexico, has relied on extensive rather than intensive use of the land. Widespread cattle ranching has extirpated large areas of the natural vegetation cover, promoted erosion, and introduced exotic species that are now fully naturalized. These changes compromise the tenuous ecological balance by creating new competitors and new ecosystem dynamics, mainly the fire-grass cycle. For its part, large-scale agriculture in the desert relies on the nonsustainable use of groundwater and fossil fuels and on ever-silting dams, pesticides, and fertilizers.

The exploitation of minerals and industrial development have not been matched by strong measures to protect the environment. Especially lacking is the establishment of large nature reserves. The need for preserving natural areas has clashed with the desires of government and investors to develop large-scale mining, water-use projects, coastal tourism, fisheries, cattle ranching, and agriculture. The importance of nature reserves in preserving biodiversity, protecting upriver basins from erosion, providing recreation, keeping hydrological systems in balance, and reducing health risks have been only cursorily taken into account in government programs (Búrquez & Martínez-Yrízar 2000).

The lack of coordination between government agencies creates conflicts that directly affect the value of resources within a given community. For example, the development of marinas in desert coastal wetlands eradicates mangrove swamps, affecting in turn their recreational value and the population dynamics of marine species that use them as recruitment grounds. These wetlands are also silted and polluted by upstream erosion caused by agricultural drainage, mining, and cattle ranching. Efforts to preserve the Sonoran Desert are feeble and underfunded when compared with investments promoting the development of industry, mining, agriculture, cattle ranching, and tourism. Protected natural areas are a major component in the resolution of these conflicting interests because they provide sites where natural processes ameliorate the human use of areas nearby. Natural areas are no longer protected by their isolation, simply because there are no longer isolated places anywhere.

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