State of the Desert Biome
Uniqueness, Biodiversity, Threats and the Adequacy of Protection in the Sonoran Bioreg ion

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The Wildlands Project

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The Wildlands Project

The Wildlands Project is a non-profit conservation organization whose mission is to protect and restore the native biodiversity and ecological integrity of North America through the establishment of a connected system of conservation reserves. The Project coordinates the activities of local, regional, national, and international groups that are developing regional proposals throughout the continent.

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Executive Summary

This report highlights (1) what is unique about the Sonoran Desert bioregion with respect to its organisms, ecological interactions and landscapes and (2), what threatens the future of this region's biological diversity. It is based on the compilation of surveys of 54 field scientists who average twenty years of field experience in this region of the southwestern United States and northwestern Mexico.

Regional Overview

The most tropical of the North American deserts, the Sonoran bioregion has distinctive biotas in each of its subregions due to the pervasive influence of geographic isolating factors. Most obvious is the Gulf of California, which has fostered high levels of endemism — unique sets of species -- on its 21 islands and on peninsular Baja California. Such extremely high levels of endemism can not only be found for plants, but for reptiles and small mammals as well. In general, these regional patterns of endemism should serve as one of the key guides to prioritizing the location of future protected areas.

With regard to indicators of terrestrial biodiversity among bioregions, the Sonoran Desert and adjacent biotic communities should rank higher than is commonly assumed. Current estimates of the plant species richness in the state of Sonora alone may be as high as 4,500 species, or 20% of Mexico's total flora in an area of less than 10% of the country. Reptile and riparian breeding bird diversity are notable. The overall pollinator diversity of the Sonoran region's bees, butterflies and bats is remarkably high compared to other areas of North America. The extant cultural diversity of indigenous communities is as high as any region north of the tropics.

Stressors: Threats to Biodiversity

Thirty-three of the field scientists responded to the portion of our written questionnaire which asked them to rank the ten most significant threats to the biodiversity of the Sonoran bioregion on the basis of their observations since 1975. The top ten threats, according to the tally of their responses, are as follows:

1. Urbanization's aggravation of habitat conversion and fragmentation;
2. The high rate of in-migration of newcomers to reside, work and recreate in the region, and their contribution to population growth and resource consumption;
3. Surface water impoundment and diversion from places where native vegetation and wildlife have access to it;
4. Inappropriate grazing of vegetation by livestock, especially when combined with conversion of plant cover to exotic pasture grasses;
5. Aquifer mining and salinization, the drop in water table, and their long-term effects on riparian vegetation and wildlife;
6. Lack of planning for growth;
7. Exotic grass planting;
8. Conversion to farmlands;
9. Recreational impacts;
10. Biological Invasions.

Since World War II, the Sunbelt of the U.S. Southwest and Northwest Mexico has been the setting for the largest in-migration in human history. A century and a half ago, indigenous communities still outnumbered European colonial communities, both in number and in the amount of land and water they managed. Today, the economic activities of the region are dominated by individuals who have lived in the region for less than a decade. The region's population nearly doubled (+98%) between 1970 and 1990 to a total population of 6.9 million. The greatest increases in population occurred in coastal resort areas, state capitals, and along the border. Currently, there is no sign that human population growth rates in the region will taper off during the next few decades.

Between 1940 and 1990, the populations of Arizona, Baja California Norte, and Sonora shifted from being one half to two-thirds rural, to over three-quarters urban. The present inhabitants' unfamiliarity with desert land and water management poses profound threats for most land, water, vegetation and wildlife resources within a half-hour's drive of the region's largest metropolitan areas. The actual effects of this urbanization on biodiversity are many and mutually reinforcing, including the aggravation of the "urban heat island effect"; the channelization or disruption of riparian corridors; the proliferation of exotic species; the killing of wildlife by automobiles, by toxics, and by pets; and the fragmentation of remaining patches of natural vegetation into smaller and smaller pieces that are unable to support viable populations of native plants or animals.

Hydrological engineers in the Sonoran Desert have impounded and diverted water flows from virtually all of the region's major rivers by constructing 41 major dams and associated irrigation canals. Among U.S. Federal Register notices listing plants and animals as endangered species, water impoundment and diversion are among the most frequently cited threats mentioned. Inundating vegetation in reservoirs behind dams and changes in river flow are among the most severe pressures on threatened plants and nesting birds in the U.S./Mexico borderlands. The regional decline of 36 of the 82 breeding bird species which formerly used riparian woodlands is a case in point. In combination with water diversion, groundwater pumping has affected nearly all river valleys in Arizona's portion of the Sonoran Desert. In the heart of agricultural areas, groundwater overuse has been most precipitous, leading to ground subsidence, salinization and the demise of riparian forests.

With regard to grazing, overstocking still continues on public and private lands in Arizona and Mexico's CODECOCA statistics confirm that 2 to 5 times the recommended stocking rates occur with regularity on the Sonoran side of the border. The cattle-related introduction and intentional sowing of African grasses in the Sonoran bioregion has not only affected the biotic composition of semidesert grasslands, but has profoundly changed vegetation structure, fire intensity and frequencies and migratory wildlife corridors within several subregions of the Sonoran Desert proper. The "grasslandification" of the Sonoran Desert, adjacent thornscrub and subtropical savanna by buffelgrass has already occurred on some 600,000 hectares of Sonora.

Adequacy of Current Measures to Protect Biodiversity

Although there are many stresses on the region's biodiversity, we have witnessed more areas decreed as protected (as international, national or state biosphere reserves) in the last decade than any other decade in the history of the Sonoran bioregion. In addition, there are now more resource managers working on both sides of the border than there were a decade ago, although many more need training to better manage their areas for biodiversity instead of for single species or for recreation. For each Sonoran Desert subregion, vulnerable species and areas, and areas that merit protection are listed.

When asked if protected area managers still allow activities which deplete biodiversity, twenty-five of the surveyed scientists answered yes, nine answered no, and seventeen answered that such harmful activities now occur less than before. However, it is a hopeful sign that over one quarter of the respondents see fewer harmful activities occurring within protected areas today than "before" -- meaning either before the decree of these areas, or for early-established parks and wildlife refuges, before 1975. A notable portion of the scientists felt that grazing was finally being addressed sufficiently in discussions between resource managers, ranchers and scientists. Others felt that the impacts of ecotourism (e.g. whale watching) and outdoor recreation were being sufficiently dealt with at the local level. However, a majority of the scientists felt that virtually no threat is truly being adequately addressed anywhere in the Sonoran biome where they have worked.

Emerging Conservation Needs and Priorities

When field experts conversant with the Sonoran bioregion were asked what they felt should be the number one priority for conservation, they responded in a variety of ways, noting policy issues, research and education needs, action strategies, as well as earmarking species, habitats or landscapes in critical need of conservation. The extensive list includes the need to shift away from social and economic systems that reward consumptive behaviors and short-term gain while damaging natural systems, manage irrigation tailwaters and sewage effluent to restore the wetlands of the Colorado River delta, and many other recommendations.

What's Next?

It is clear that there is much reported by the field scientists surveyed here that bears reflection, discussion, debate and action. It is also abundantly evident that scientists' attention is not spread evenly across the biotic communities of the bioregion -- some habitats such as mangrove swamps, riparian gallery forests and semidesert grasslands south of the U.S. - Mexico border are irregularly visited by biologists and poorly monitored relative to their significance.

There are four problems identified as the emerging issues which still require considerable discussion if they are to be resolved for the region:

1. The need for urban planning and agricultural lands restoration to allow for continuous corridors for wildlife passage through urban areas where their movements are currently blocked.
2. The need for guaranteeing river flow into coastal lagoons and estuaries of the Gulf of California (including the Colorado River delta) to ensure nutrient and fresh water flow essential to nursery grounds for invertebrates, fish, and waterfowl.
3. The need to redirect the management of critical habitats in state parks, wildlife refuges and national monuments away from recreation or protection of single species or features; focus needs to shift to overall biodiversity and the integrity of habitats, so that the interactions between species and natural communities persist.
4. The need for planning that reduces impacts of coastal and island development in the Gulf of California region where endemism is the highest.

Introduction

What is unique about the Sonoran Desert region? What kinds of organisms, ecological interactions and landscapes can be found here and nowhere else? Which of these have we safeguarded, and which are we letting slip away? What stresses and forces, both from within and from beyond the region, are threatening various elements of our region's biodiversity — the variety of distinctive populations, species, guilds, communities and habitats found here? How can we shift our ways of thinking, behaving and consuming to better protect what remains of our region's diversity? Where should our shared priorities lie?

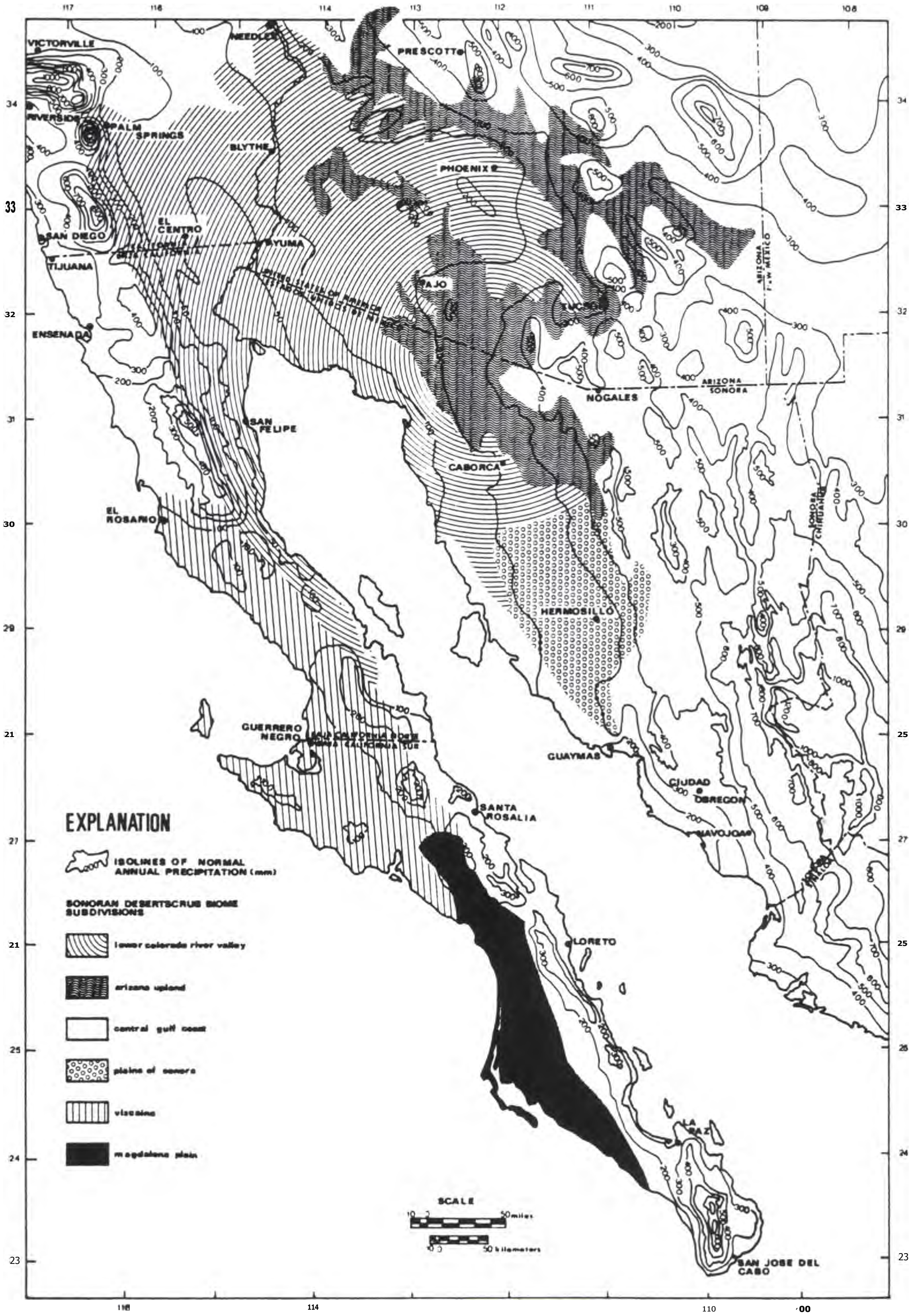
Although many communities across the American continent have been asking these and similar questions for some time, such inquiries have been spoken aloud only relatively recently in the Sonoran bioregion. Perhaps language barriers and an international boundary have prevented us from asking such questions as they relate to a realm of arid land, water and life found across two nation states. For most of this century, perhaps national conservation organizations have assumed that so few people lived in this "big empty" that the protection of natural areas remaining in more heavily-populated regions deserved higher priority.

And yet since World War II, the "Sunbelt' -- including the Sonoran Desert and adjacent biomes — has suffered from the greatest in-migration and most massive land conversion occurring within any fifty-year period in human history. Within the last half century, the number of human inhabitants in the region has increased sevenfold, but few of these residents are aware of how profoundly their collective presence is changing the desert. Unless we begin to understand how our own lives interact with those of other species in this desert biome, they are likely to "go away" before we know it. The Sonoran Desert biome extends beyond the boundaries of any single nation-state, tribe, or economy; a "state of the nation" will not tell us how it is faring. As defined here, the Sonoran bioregion or biotic province includes subtropical forest, thomscrub, semidesert grassland and other biotic communities within and adjacent to the Sonoran Desert proper, and aquatic habitats as well. Although its name is derived from the geopolitical state of Sonora, Mexico, this bioregion also covers parts of Arizona and California, USA, and Chihuahua, Baja California Norte, and Baja California Sur in the Republic of Mexico.

At least twenty indigenous nations have a long tenure within this region. Despite the widespread view that "deserts" are impoverished places for humans to live, the Sonoran bioregion retains as much biological and cultural diversity as any region on the North American continent.

As portrayed here (Figure 1), the Sonoran bioregion is delineated much the same way that Dice (1943) and Dasmann (1974) demarcated the Sonoran biotic province. Its terrestrial habitats cover between 310,000 and 330,000 square kilometers, depending on how one deals with intermittently flooded wetlands, playas, deltas and riverine corridors. Within this particular bioregional assessment, nine of the twenty-seven biotic communities displayed on the Brown and Lowe map of the Biotic Communities of the Southwest are considered (Brown 1982): Sinaloan Deciduous Forest at its northern limits; Foothills of Sonora and Coastal Thomscrub; Semidesert Grassland at its western limits and Sonoran Subtropical Grassland; "Cape" Thornscrub of Baja California; Sonoran Desert/Arizona Uplands; Sonoran Desert/Lower Colorado Lower River Valley; Sonoran Desert/Central Gulf Coast; Sonoran DesertNiscaino-Magdalena Plain; and Sonoran Desert/Plains of Sonora. In addition, we consider here a number of riparian, coastal, wetland and oceanic communities which are difficult to map but nevertheless critical to maintaining the region's biodiversity (Minckley and Brown 1982).

Figure 1:
Sonoran Desert Biotic Communities (from Brown 1982)



Map of the outline of the Sonoran Desert *biome* showing average annual rainfall amounts. Subdivision boundaries are from Shreve (1951) as modified by Brown and Łowe (1980).

This report aims to set conservation priorities for the establishment of a bioregional conservation plan sponsored by The Wildlands Project. To establish such priorities on a firm scientific basis, it has been necessary to first characterize the spatial patterns of biodiversity within the region, then to assess what protective measures already exist, and finally to determine where current conservation and management practices fall short of ensuring the long-term survival and health of the region's remaining biological riches.

To our knowledge, no one has ever assessed this entire region from the perspective of conservation biology. A region-by-region survey of Mexico (Villela and Gerez Fernandez 1989) included a preliminary biodiversity assessment of the Sonoran Desert in relation to other regions, but in it, statistics for the region as a whole were sometimes confused with those for the state of Sonora. Nevertheless, this report raised international concern regarding the rapidity of environmental change occurring within the region, reporting that at least 60 percent of its native vegetation had already been converted or destroyed.

As an initial phase in the development of a more comprehensive bioregional conservation strategy, we wish to draw attention to the threatened biota, disrupted ecological processes and diminished integrity of habitat mosaics in the region as they exist today. We also hope to acknowledge currently-effective conservation measures, but without naively assuming that they will continue to function well even if certain threats and pressures continue to increase in magnitude and severity. Finally, we wish to compile scientists' initial suggestions for better protecting certain species, landscapes and processes, topics which will be discussed more intensively during later phases of conservation planning.

Because the quality of published information on biodiversity and natural resource use is seldom collected on the same scale and with equal intensity on both side of the U.S. - Mexico border, we chose to supplement published literature with questionnaires directed to over 120 of the region's most active field biologists and protected area managers.

Fifty-four scientists responded to our surveys in whole or in part, an extremely high return for any survey tool. The average number of years that these scientists have been actively conducting field studies in this bioregion is twenty, perhaps making them the most seasoned body of experts ever asked to speak on behalf of the desert. Although they have collectively accomplished nearly 1,000 years-worth of field studies in this bioregion, this is but a crude indicator of their depth of understanding of the kinds of environmental change which is occurring. Some of them have literally worked at

"...the world drifts and our maps don't work anymore, our paradigms and stories fail, and we have to reinvent our understandings, our reasons for doing things...What we need most urgently, in both the West and all over America, is a fresh dream of who we are, [and stories] which can tell us how we should act... They will be stories in which our home is sacred, stories about making sense of a place without ruining it.. .Wreck it and we will have lost ourselves, and that is craziness."

-- William Kittredge
Who Owns the West? (1996)

hundreds of field sites on both sides of the border, and have been responsible for publishing the bulk of the ecological monographs and articles on the region's biodiversity over the last quarter century.

To more specifically address issues regarding the pace and extent of environmental change that they have personally witnessed, we asked these field experts to assess trends since 1975, in the nine (mappable) biotic communities mentioned above, as well as in aquatic and island habitats. Although their responses are not necessarily site-specific, they do offer a very tangible assessment of conservation issues at the level of specific biotic communities.

We are extremely grateful to the scientists who found time in their busy schedules to respond to our surveys; their contributions form the cornerstones of this report. We also thank the Arizona-Sonora Desert Museum for providing information that contributed to this assessment, Rob Marshall and Peter Warren of the Arizona Chapter of The Nature Conservancy for reviewing this report, Jennifer Dastrup for skillfully formatting the report and Anne Gondor for creating the color maps. Finally, we thank The Town Creek Foundation who supported The Wildlands Project in the compilation of this report.

Regional Overview

A. Uniqueness of the Sonoran Bioregion

Picture it as a hyperarid horseshoe surrounding a hypersaline sea, the Gulf of California. Imagine it as a relatively frost-free landscape -- the dream of any horticulturist -- with not one, but two shots at drought aimed at crop failure each year. Consider it as a place for tropical plants to grow in the worst of all soil media: infertile sands, alkaline talc, or burning volcanic cinder heaps. View it as place where vegetative cover is not so lush and monotonous that it interferes with seeing good geology and world-class sunsets.

As these rather whimsical scenarios suggest, the Sonoran Desert is physically and climatically distinctive in several ways. It is the most tropical of the North American deserts; that is, its southerly, low elevation vegetation subtly extends the ranges of certain freeze-intolerant tropical plants and animals northward, where they are ultimately limited by high temperatures and damaging solar radiation. Its gentle winter and spring rains foster a biota related to that of the Mohave Desert, whereas its more tempestuous thunderstorms and hurricane-fringe chubascos of late summer and fall foster a warm season biota related to that of the Chihuahuan Desert and the Neotropics. The classic view of biotic communities in deserts is that they are remarkably static unless perturbed by humans and their

> "The bimodal rainfall pattern of the Sonoran Desert allows for a greater structural diversity than in the Great Basin, Mohave, and Chihuahuan Deserts. The Sonoran Desert differs markedly from the other North American desert biomes, which are dominated by low shrubs, in its arboreal elements and its truly large cacti and succulent constituents. Even in its most arid parts, the Sonoran Desert exhibits tree, tall shrub and succulent life-forms along its drainages and other favored habitats. These provide for distinctive landscapes -- some of which can only be termed bizarre."
>
> -- Raymond M. Turner and David E. Brown
> "Sonoran Desertscrub", Biotic Communities of the American Southwest (1982)

livestock, whereupon they become fragile and/or irreversibly damaged. However, recent longitudinal studies of environmental fluctuations at sites fully protected from grazing and direct human manipulation demonstrate that the Sonoran desertscrub communities are dynamic, responsive entities with considerable resilience (Turner 1990).

The Sonoran bioregion has distinctive biotas in various subregions due to the pervasive influence of geographic isolating factors. Most obvious is the Gulf of California, which has fostered high levels of endemism -- unique sets of species -- on its 21 islands and on peninsular Baja California. In addition, extensive talc playas, sand dune fields and volcanic flows serve as edaphic seas isolating mountain ranges of limestone, granite or basalt from others of their ilk. This is true to varying degrees in all North American deserts, where basin and range physiography sets up an interplay between mountain islands and desert seas. Finally, aridity itself is an isolating factor, slowing the dispersal of colonizing species, most recently, the influx of certain Eurasian weeds.

Another important geographic factor of the Sonoran bioregion as it affects migratory species is the prevalence of easy-to-navigate north/south corridors. The Gulf of California and Lower Colorado River comprise the most extensive corridor. The Upper Rio Yaqui/Rio Bavispe form another corridor with the Rio San Simon. The Rio Sonora and the Rio San Pedro form another, and the Rio Magdalena/Rio Santa Cruz form a final corridor of more than 400 kilometers . These extensive corridors remain extremely important to migratory birds, but were even more remarkable before riparian gallery forests were dramatically reduced by agriculture and groundwater overdraft.

B. Biodiversity within the Sonoran Desert Bioregion

The Sonoran Desert and adjacent biotic communities do not necessarily rank high among bioregions with regard to the most commonly-cited indicators of terrestrial biodiversity: bird, butterfly or flowering plant species richness per hectare, or per square kilometer. Scientists have typically used these indicators because there are many more collection records of these taxa than there are of wild bees, moths, reptiles or lower plants. Some biogeographers have suggested that diversity of resident species per se is not the best criterion for evaluating the importance of desert habitats; use by migrants, or levels of endemism might be more revealing criteria.

This Sonoran region as a whole does indeed have remarkable levels of endemism found within certain of its subregions. For instance, 501 of 552 endemic plant species found on the Baja

> "First of all, we must point out that the distribution of endemics bears no relation to that of floristic richness: the largest number of endemic families and genera are found in xerophilous ecosystems. With regard to endemic species, it is the coniferous and oak forests that account for the largest proportion, followed by xerophilous scrub and grasslands and by deciduous forests. In contrast, the [highly diverse] evergreen forests come last with only 5% of Mexico's endemic species. In addition to the predominance of the areas of arid vegetation in regard to endemisms, the endemic species found in the following geographical regions are worthy of note: the Baja California peninsula, where 25% of all the species are endemic (explainable in part by its arid climate), some offshore islands such as Guadalupe (21% of the species)...and more locally, the peaks of the high mountains and areas with very selective soils such as gypseous or highly saline ones."
>
> Rodolfo Dirzo
> Mexican Diversity of Flora (1994)

California peninsula and its adjacent islands occur within its desertscrub and Cape thornscrub subregions, rather than in its Mediterranean chaparral, or in the uplands of the Sierra de San Pedro Martir and Sierra de Juarez (Villaseñor and Elias 1995). Over half of these are highly restricted or "microareal" endemics (Table 1), isolated to a single island or geographic zone of the peninsula. In addition to other species at risk (Appendix 4), they form the region's most unique biological legacy.

Table 1:
Distribution of endemic plant species of peninsula and islands

Geographic Zone	Microareal 1 zone only	Form of endemism Shared between adjacent zones	Regionally distributed
Northeast delta	2	2	4
Central desertscrub	42	44	65
Viscaino desertscrub	14	28	49
Mulege-Comondu	14	14	68
Sierra de la Giganta	14	40	59
Magdalena Plains	7	28	50
Sierra de la Laguna	27	24	42
Cape Thornscrub	74	78	64
Gulf Islands	12		
Pacific Coast Islands	51		

Adapted from Villaseñor and Elias (1995)

"Islands have always been fascinating places... We want very much to go back to [Angel de la Guardia] with time and supplies. We wish to go over the burned hills and snake-ridden valleys, exposed to heat and insects, venom and thirst, and we are willing to believe almost anything we hear about it. We believe...that unearthly animals make their homes there...And if we were told of a race of troglodytes in possession, we should think twice before disbelieving. It is one of the golden islands which will one day be toppled by a mining company or a prison camp."

-- John Steinbeck
The Log from the Sea of Cortez (1941)

Such extremely high levels of endemism can not only be found for plants, but for reptiles and small mammals as well. The islands of the Gulf are, of course, relatively rich in endemics: 12 plant species and 6 additional subspecies are restricted to the islands; 65 mammal subspecies, 15 species and one genus of fish-eating bats are restricted to them; and more than 30 species or subspecies of reptiles are endemic to one or more of the islands.

Although arid regions usually rank low relative to other biomes in overall species richness, this is not true across all taxonomic groups. Búrquez and Martinez-Yrízar (1988) report that current estimates of the plant species richness in the state of Sonora alone may be as high as 4,500 species, or 20% of Mexico's total flora in an area of less than 10% of the country. Rozenzweig and Winakur

(1969) claimed that the Upper Rio San Pedro watershed harbored a higher diversity of small mammals than any other area in North America known at that time. The species richness of mammals recorded in what is now the San Pedro Riparian National Conservation Area — some 86 species, including 12 at risk -- remains unsurpassed for any single landscape of comparable size in the U.S.. Overall, the region harbors perhaps 130 species of mammals, extrapolating from Hoffmeister's (1986)'s inventory of those found in Sonoran desertscrub and semi-desert grassland in Arizona, in addition to those found on the Gulf Islands. With at least 146 species found on the desert mainland, peninsula and adjacent islands. The region's reptile diversity is also high, with as many as 96 endemic taxa being found among the Gulf Islands, Sonora and Baja California (Flores-Villela and Navarro 1993). Certainly, with only 20 species, amphibian diversity is low: the islands and the peninsula have no endemics, and the mainland harbors only 11 endemic amphibians (Flores-Villela 1993). Freshwater native fish diversity is rather low for a region of this size -- perhaps 25 to 30 species (Minckley 1973; Minckley and Deacon 1968), but there are at least 250 marine species of rocky shore and reef fish in the northern and central Gulf of California (Thomson, Findley and Kerstitch 1979). The eleven endemic fishes of freshwater springs and creeks is perhaps a more revealing measure of the Sonoran Desert's biological value: desert pupfish, Yaqui suckers, Sonora chub, Colorado River squawfish, razorback suckers and other very narrowly-restricted species demonstrate that water in the desert is a limiting factor for evolution as it is for productivity.

Buchmann and Nabhan (1996) have projected that with an estimated 1200 species, there is greater species richness of native bees within an hour's drive of Tucson than anywhere else in the Americas, and perhaps anywhere else in the world. The overall pollinator diversity of the Sonoran region is remarkably high, with upwards of 150 butterfly species, perhaps as many as 1,200 moth species, 17 hummingbird species, and at least 5 nectar-feeding bats servicing the region's flowering plants.

Finally, we must consider bird diversity from a variety of perspectives. There have been at least 500 bird species reported in the Sonoran bioregion, roughly half the known number of birds present in the continental U.S. or in all of Mexico. Remarkably, north-south corridors such as the Rio San Pedro or the Rio Colorado may each harbor as many as 400 species for breeding, overwintering and migrating; that includes 75 percent of all the bird species which migrate between the U.S. and Mexico (Stevens et al. 1987; Anderson et al. 1987). There are roughly fifty species found in the Arizona portion of the Sonoran bioregion that are seen nowhere else in the

"Another attribute [of Mega-Mexico's flora] is their striking flowers. Many species in arid and semi-arid areas have highly colorful flowers which range in size from medium to large... These floral displays doubtlessly indicate a series of complex and intricate interactions between the plants and their pollinating agents. Although it could be assumed that an arid environment is not a suitable setting for biotic interactions, such an appreciation would be false, at least as far as pollination is concerned. Thus, there are hummingbirds, [stingless] bees, bumblebees, bats and butterflies with sensorial, digestive, and behavioral capabilities that provide an exquisite complement to the colors, aromas, and flavors of desert flowers."

Rodolfo Dirzo
Mexican Diversity of Flora (1994)

U.S., and 15 species endemic to Mexican portions of the region (Flores-Villela and Navarro 1993).

In desertscrub and semidesert grassland habitats, the per unit area diversity of breeding birds is not particularly remarkable -- 30 - 150 pairs per 40 hectares (Johnson et al. 1987). However, the deciduous riparian gallery forests of the Sonoran biome may have the highest breeding bird densities on the continent, harboring 304 to 847 breeding pairs per 40 hectares (MacArthur and MacArthur 1961; Carothers, Johnson and Aitchison 1974; Johnson et al. 1987). It is fair to say that in terms of breeding bird diversity and productivity, the Sonoran biome's riparian habitats are among the richest in all of North America.

The Sonoran biome is peculiar in another kind of diversity -- extant cultural diversity. Although indigenous cultures in Baja California were so devastated by European-introduced diseases that only the Paipai, Kiliwa, and Cucupa have persisted on the entire peninsula, the rest of the region has most of its native cultures still alive and thriving. The Guarijio, Yaqui, Mayo, Seri, Pima Bajo, Tohono O'odham, Hia c-ed O'odham, Gila River Pima, Cucupa, Maricopa, Mohave, Quechan, Cahuilla, Chemehuevi, Walapai, Havasupai, Western Yavapai, and Western Apache are among the indigenous cultures with long tenure in this bioregion. While the Yaqui reservation in Sonora is among the largest and most secure in all of Mexico, there are also five other reserves in Sonora and Baja California where indigenous people live today, as well as poorly-enforced Seri tribal rights to Islas Tiburon and San Esteban.

In the United States, a significant portion of all Arizona and California desert lands fall within the reservations of the Tohono O'odham, Ak-Chin, Gila and Salt River Indian Communities; of the Cahuilla and Chemehuevi; of the San Carlos, Camp Verde and Fort McDowell Apache and Yavapai; of the Cocopah, Ft. Yuma, Ft. Mohave and Colorado River Indian Tribal communities, and of the Walapai, Havasupai, Clarkdale and Prescott Yavapai. In the ten states running along both sides of the U.S./Mexico border from the Pacific to the Caribbean, indigenous communities manage as much as 17.8 million hectares -- which is more than all the private land reserves of The Nature Conservancy and other non-profit conservation groups in North America (Nabhan et al. 1991).

It has only been recently recognized that this diversity of human occupants historically fostered a mix of desert land and water management strategies, which no doubt kept habitats more heterogeneous than they are today (Rea 1997; Nabhan et al. 1982). Although the U.S. Bureau of Indian Affairs and Mexico's Instituto Nacional Indigenista have attempted to homogenize land use practices surrounding some indigenous communities, tribal

"[It was] the most famous roadside rest stop in the United States -- most famous among birders, anyway. It was only a small turnoff, with a few picnic tables, across the road from Sonoita Creek. But in the 1960s a birder from Nogales. ..had discovered that this rest area was a reliable place to find Rose-throated Becard, a rare bird north of the border. So he had begun visiting more often and had found more exciting birds, including the first United States colony of Five-striped Sparrows and the second colony of Thick-billed Kingbirds. Before long, birders from all over were flocking to the area and discovering state records like Yellow Grosbeak, Black-capped Gnatcatcher, and Yellow-green Vireo, plus a host of lesser rarities. This phenomenon -- of rare birds attracting more birders, who then find more rare birds, attracting more birders, and so on -- was soon given a name: 'The Patagonia Picnic Table Effect.'"

-- Kenn Kaufman
Kingbird Highway (1997)

responses to these pressures have varied, and the degree of habitat protection on tribal lands is not at all uniform.

In general, the very presence of the border has set up some "natural experiments" where it becomes easy to compare different land management "treatments" on either side of the boundary line. Juxtaposing ecosystem health in Anglo-, Hispanic- and Native-American communities adjacent to one another in the same habitat type has inadvertently allowed for ecologists to clearly see how different cultural management practices affect the same biota (Minnich 1981; Balling 1988; Nabhan and Suzan 1994). At another scale, the same principle holds true in habitat types where private, Forest Service, Park Service, Bureau of Land Management and state or reservation land managers all protect or manage wildlife and vegetation to different degrees.

We are only beginning to objectively compare the long-term effects of such a diversity of management strategies on the region's biodiversity. Nevertheless, conservation biologists working in the Sonoran Desert biome can at least be relieved that the entire landscape does not currently fall under the custody of a single management style, i.e., that of the Army Corps of Engineers, the Savory System, or shrubland chaining by range managers intent on "Ecosystem Improvement."

Stressors: Threats to Biodiversity

During autumn 1997, thirty-three of the field scientists responded to the portion of our written questionnaire which asked them to rank from assessments based on their own field experiences -- the ten most significant threats to the biodiversity of the Sonoran region. As Table 2 demonstrates, a total of 17 threats were pre-selected for evaluation, but the field scientists were welcome to propose others on their own. By far, the stresses which most concerned the scientists surveyed were the following:

1. Urbanization's aggravation of habitat conversion and fragmentation;
2. The high rate of in-migration of newcomers to reside, work and recreate in the region, and their contribution to population growth and resource consumption;
3. Surface water impoundment and diversion from places where native vegetation and wildlife have access to it;
4. Inappropriate grazing of vegetation by livestock, especially when combined with conversion of plant cover to exotic pasture grasses; and
5. Aquifer mining and salinization, the drop in water table, and their long-term effects on riparian vegetation and wildlife.

The kind of ranking summarized in Table 2 is a subjective means of assessing the severity of various stresses which work at different scales and for different durations. We argue that this "subjectivity" is of positive value in this case; the average duration of fieldwork by the scientists surveyed is far longer than most individual published studies of most federally-employed land managers' tenure in one landscape . Their views are essential to this overview because there are few statistical summaries which document with equal precision on both sides of the international border the stresses, pressures and threats affecting all habitats found within the region.

While Table 2 highlights these scientists' ranking of a pre-categorized set of stresses or threats, the following discussions are more broadly defined, covering additional statistical data and commentary on regional trends. Whenever possible, we have included demographic or resource use data from both sides of the border at the most comparable scale we could find. The following texts address each stressor in a sequence different from the ranking in Table 2. However, we will remind readers of other rankings of threats from various reports pertinent to the region, for example, Nabhan et al. (1991)'s ranking of threats to native plants in the U.S./Mexico borderlands, and Rick Knight's (pers. comm.) assessment of endangered species notices in the Federal Register. We will also include any relevant commentaries which the field scientists offered in regard to how these threats are actually affecting the region's biodiversity.

Table 2:
Stresses Negatively Affecting Biodiversity in the Sonoran Bioregion Listed In Order of Perceived Severity by 33 Field Scientists

	Number of scientists who ranked it:	
Stress or Threat	**Most Significant**	**In the Top Three**
1. Urbanization/fragmentation	6	15
2. In-migration	6	14
3. Water impoundment/diversion	4	10
4. Livestock grazing	1	13
5. Aquifer mining	2	5
6. No planning for growth	1	7
7. Exotic Grass planting	1	7
8. Conversion to farmlands	2	4
9. Recreational impacts	1	5
10. Biological invasions	1	5
Secondary Stresses		
11. Population growth of residents	2	5
12. Elite's resource consumption	2	5
13. Wild plant overharvesting	1	5
14. Animal overharvesting	1	1
15. Mining and its water use	0	1
16. Pesticide exposure	0	0
17. Predator control	0	0
Other Stresses (Added to pre-categorized list by scientists surveyed)		
18. Lack of public understanding	1	1
19. Inappropriate management	1	1
20. Aquaculture	0	1
21. Climate change	0	1

In-Migration

Since World War II, the Sunbelt of the U.S. Southwest and Northwest Mexico has been the setting for the largest in-migration in human history. A century and a half ago, indigenous communities still outnumbered European colonial communities, both in number and in the amount of land and water they managed. Then, families of European descent were still a minority in most parts of the region; today, the economic activities of the region are dominated by individuals who have lived in the region for less than a decade, if they "reside" here at all. The average resident of the Phoenix metropolitan area has lived there for less than five years, and has moved around within the area two or three times since arrival. Such trends are serious impediments to the development of a "sense of place," or to the will and wherewithal to protect unique features of a place. No wonder the scientists surveyed placed in-migration and rapid population change as the paramount threat to the region's uniqueness and biodiversity.

It is unlikely that most newcomers will glean much of the traditional community-based knowledge of the desert's limiting factors and diversity. The majority of immigrants from other regions in the U.S. and Canada are from more humid areas where water is less of a limiting factor; the same is true of those emigrating from central and southern Mexico, or from other areas of Latin America. Thus is it not merely the sheer numbers of recent immigrants that is of concern; it is also that their expectations of desert ecosystems are skewed by their movement from better-watered areas. They have seldom had sufficient contact with those land-based community members who have had to learn how to live within the desert's constraints.

Population Increase

Let's look in detail at trends in human population increases, first on a regional basis, then by state and area, and later in terms of the changing balance between rural and urban areas.

In the Sonoran Desert Bioregion, population nearly doubled (+98%) between 1970 and 1990 to a total population of 6.9 million (Table 3). The greatest increases in population occurred mostly in coastal resort areas, state capitals, and along the U.S. - Mexico border (Figure 2). The municipio of the popular Gulf of California resort area, Puerto Peñasco, ballooned a walloping 188%. Maricopa County, home of Phoenix, grew 118% and the Sonoran capital, Hermosillo, grew by 116%. Within individual biotic communities, population more than doubled in three of the seven major communities (Arizona Upland/Lower Colorado River Valley, Plains of Sonora, and Magdalena Plain). Population in all of the other subregions grew by half or more, to population densities of up to 25 people/km^2 except for Viscaino, which witnessed growth of 16% to a population density of only 2 people/km^2 (Table 3, Figures 2 and 3).

However, striking population increases are not the rule for all areas, and population densities remain relatively low in some subregions. In forty-two percent of the counties and municipios, population increased by less than 30% or even decreased in some Sonora municipios. However, these counties and municipios represent only 14% of the land area while 68% of the land area is occupied by counties whose population increased by over 60% (Figure 2). Even though population increased by over 85% in Central Gulf Coast and Magdalena Plain, 1990 population densities were only 1 and 5 people/km^2 (Table 3, Figure 3).

Currently, there is no sign that human population growth rates in the region will taper off during the next few decades. The Arizona Department of Economic Security estimates that Maricopa County will have nearly 2.5 times its 1995 population in 2045. While Maricopa County's current population is already well beyond carrying-capacity, other so-called underpopulated counties and municipios are also expected to grow well beyond their current resource base and infrastructure in the next few decades. By 2045, Yuma County is projected to harbor nearly 2.7 times its 1995 population. By 2010, the municipios of Mexicali and Ensenada in Baja California Norte are projected to be 40 and 124% more populous than they were in 1990 (Baja California 1992).

Table 3:
1970 to 1990 Population Increase in the Sonoran Desert

Biotic Community*	1970 Population	1970 Population Density (#/km^2)	1990 Population	1990 Population Density (#/km^2)	% Change
AZ Upland / Lower Colorado	2,505,211	9.7	5,149,766	18.7	106
Semidesert Grassland	17,589	2.6	32,778	4.9	86
Plains of Sonora	253,628	12.7	508,914	25.6	101
Central Gulf Coast	4,134	0.4	7,683	0.6	86
Foothills and Coastal Thomscrub	472,648	13.4	743,761	21.1	57
Viscaino	33,092	1.7	38,528	2.0	16
Magdalena Plain	32,260	1.9	65,969	3.9	104
Mixed	188,815	3.1	392,432	6.4	108
Total	3,507,377	9.8	6,939,831	19.5	98

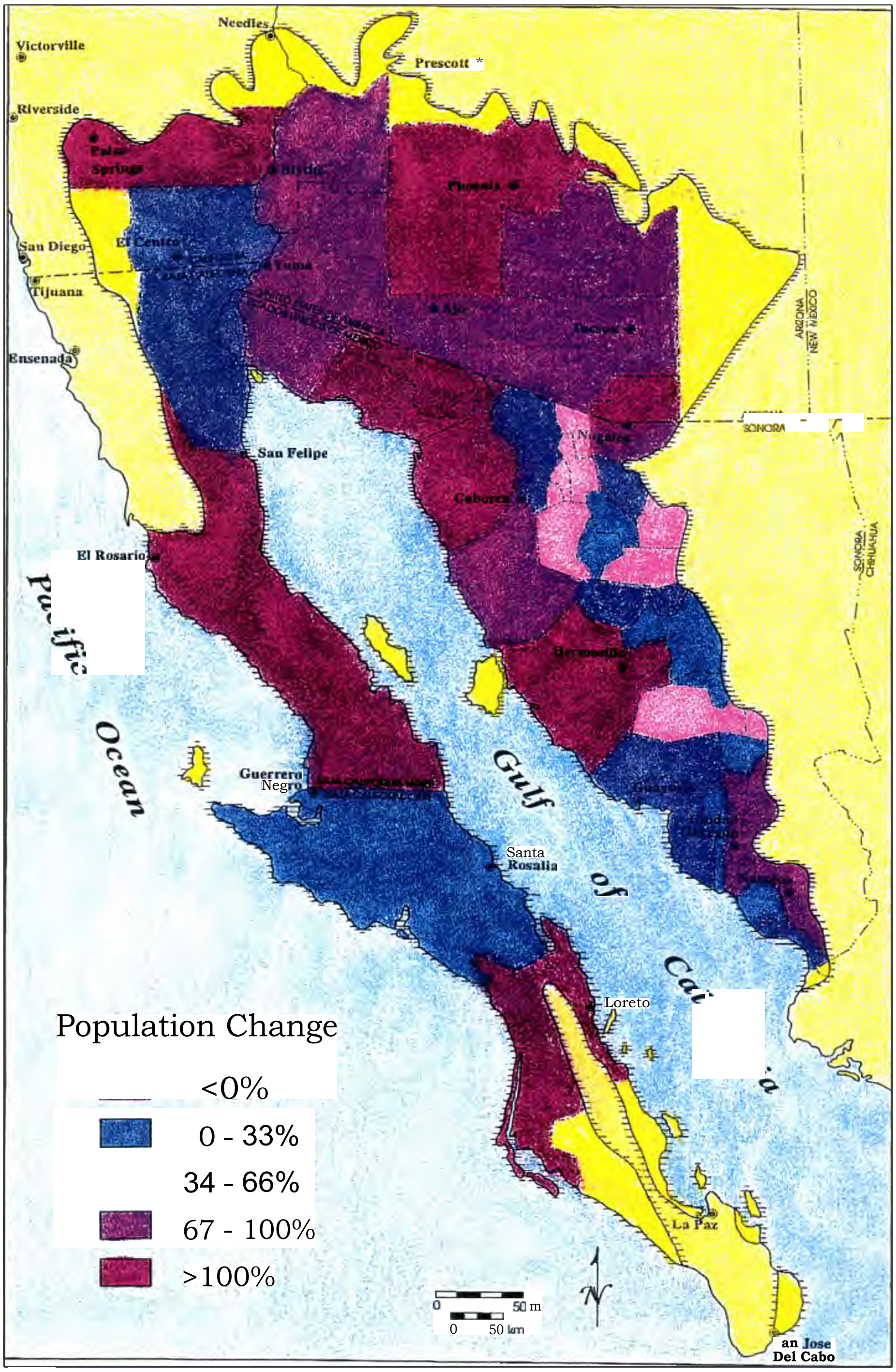
Counties were grouped by Brown and Lowe 1980 biotic communities when the particular biotic community occupied greater than 60% of each county or municipio's area. The Central Gulf Coast, Viscaino, and Magdalena Plain are represented largely by one municipio each, while other communities are represented by 3-13 counties or municipios. The mixed category includes counties that include multiple biotic communities, sometimes mixed with higher elevation oak woodland. However, the bulk of population growth has occurred below the oak woodland communities.

Sources: Direccion General de Estatistica. 1971a; Direccion General de Estatistica 1971b; Direccion General de Estatistica 1971c; INEGI 1991b; Baja California 1992; Lorey, D.E. 1993; U.S. Government Printing Office 1971; U.S. Dept. of Commerce 1992.

Urbanization, Uncontrolled Growth and Habitat Fragmentation

Urbanization ranks among the five most-frequently cited pressures on threatened plants of the U.S./Mexico borderlands (Nabhan et al. 1991). Between 1940 and 1990 the populations of Arizona, Baja California Norte, and Sonora shifted from being one half to two-thirds rural, to over three-quarters urban (Table 4). This obviously changes the degree to which the majority of the inhabitants are "in touch" with natural resource conservation issues, but it also poses profound threats for most land, water, vegetation and wildlife resources within a half-hour's drive of the largest metropolitan areas.

Figure 2:
Population Change between 1970 and 1990 in the Sonoran Desert Bioregion

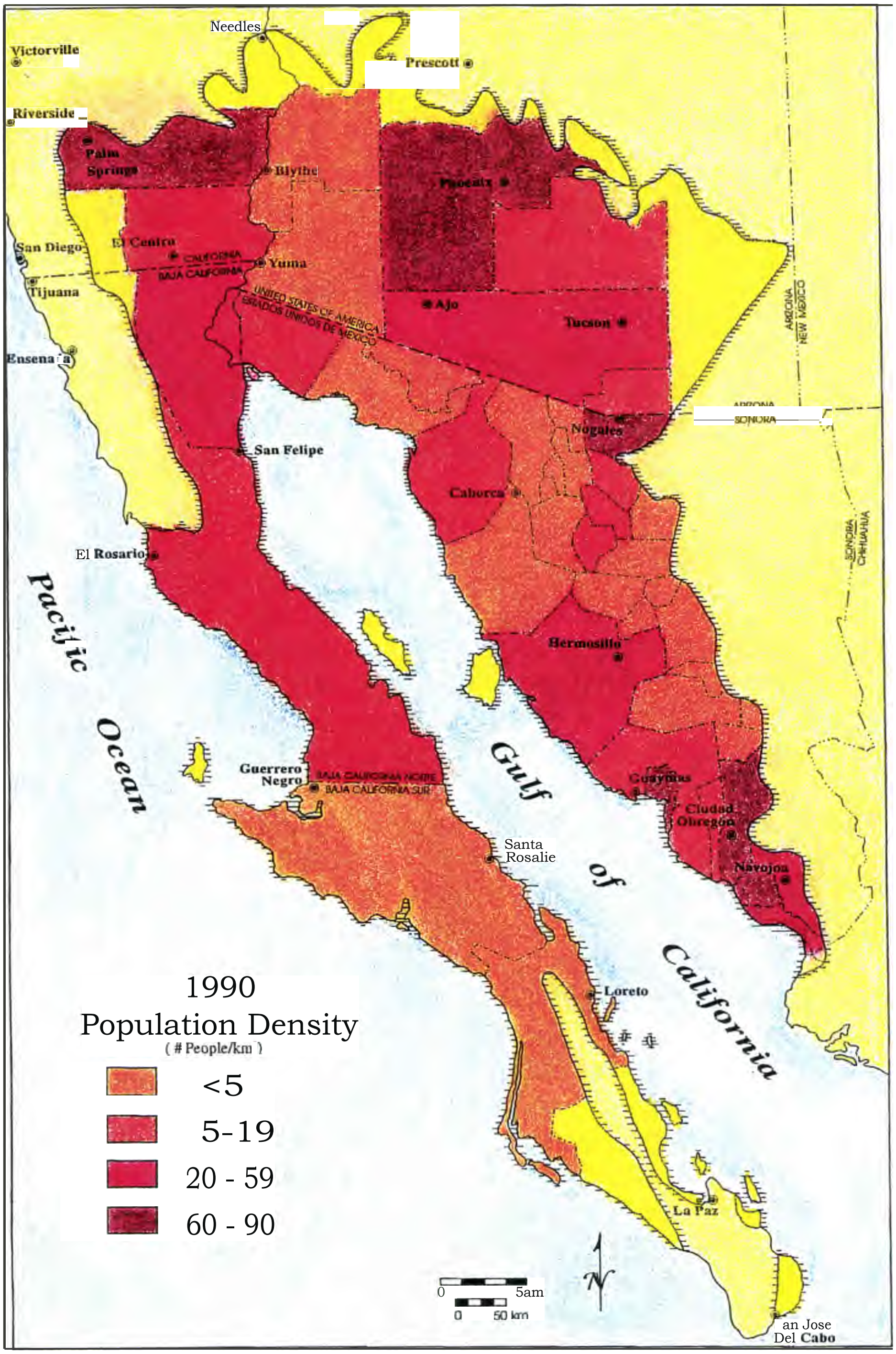


County/Municipio Boundary ,EBioregional Boundary for Report

Sources: See Table 3

Note: [redacted]0- 1990 population change is shown for La Paz and Yuma Arizona counties combined because La Paz county was the northern part of Yuma county in 1970. The same is true for the municipios of Puerto Peñasco and General Plutarco

Figure 3:
1990 Population Density in the Sonoran Desert Bioregion



—·— County/Municipio Boundary ꞏꞏ Bioregional Boundary for Report

Sources: See Table 3

Table 4:
Urban and Rural Populations in three Sonoran Desert States

State	1940	1990
Arizona		
Urban	34.8	87.5
Rural	65.8	13.5
Baja California Norte		
Urban	50.5	90.9
Rural	49.5	9.1
Sonora		
Urban	32.7	79.1
Rural	67.3	20.9

Source: Lorey, D.E. 1993.

"City development has also taken its toll on nature reserves. The decrees for the Arroyo Los Nogales and the Zona Protectora Forestal de Hermosillo were obliterated and the land sold to developers.... This case mirrors the ultimate fate of many nature reserves in Mexico."

– Alberto Búrquez and
Angela Martínez-Yrízar
Conservation and Landscape Transformation in Sonora, Mexico (1997)

The actual effects of this urbanization on biodiversity are many and mutually reinforcing, including the aggravation of the "urban heat island effect" (Balling 1988; Nabhan 1990); the channelization or disruption of riverine corridors; the proliferation of exotic species; the killing of wildlife by automobiles, by toxics, and by pets; and the fragmentation of remaining patches of natural vegetation into smaller and smaller pieces that are unable to support viable populations of native plants or animals.

One of the best-studied cases of the effects of urbanization on natural habitat remnants within the metropolitan grid has been summarized by Nabhan (1990) for Papago Park inside Phoenix, Arizona. Known as Papago Cactus National Monument until 1929, less than a thousand hectares of depauperate natural vegetation remains, surrounded by golf courses, baseball fields, irrigation canals, highways, and tract housing. Most of the park's native carnivores have been killed by traffic, and in the absence of predators other than humans, jackrabbits, cottontails, gophers and ground squirrels have proliferated, particularly as a result of out-migration from artificially-watered golf courses and parklands. In sample plots below Papago Buttes, 95% of the palo verde trees one meter tall or more have rabbit droppings under them, and more than half of these "nurse plants" have either rabbit holes or bedding areas cleared beneath them, free of herbs or cacti. Sign of small mammals have become ubiquitous, including gnawing marks on paloverde shoots and cactus stems (McAuliffe 1990).

"Juanita [an elderly Tohono O'odham woman] has seen rapidly accelerating changes in the Tucson setting, some of them natural events like the flood of 1983, as well as many other man-made improvements'... She watches both the constructive and the destructive, both the water-wise gardener who has replanted desert vegetation around his house, and the insatiable developer who plants new housing on acknowledged floodplains, then runs smiling to his out-of-state bank before the next big rains threaten unsuspecting clients."

– Tony L. Burgess and
Martha Ames Burgess
"Clouds, Spires and Spines," in Tucson: A Short History (1986)

These unchecked herbivores have devastating effects on the regeneration of the cactus-legume associations in the remnant desertscrub vegetation below Papago Buttes. Jackrabbits and cottontails quickly ravaged a cohort of 150 palo verde seedlings which germinated with summer rains one year, and by the end of the year, the last twelve surviving seedlings were all scarred or clipped by herbivorous jackrabbits and cottontails. Palo verdes are typically the most frequently-used nurse plants by saguaro cacti, but there was no evidence of saguaro recruitment in these plots since 1941. Of the saguaros aged 150 years or younger, 60% had been gnawed at the base by small mammals. Not only saguaro populations, but those of yuccas, chollas and certain herbs have declined precipitously over the last four decades as Papago Park has become a desert island in an urban sea (Nabhan 1990).

During the last forty-five years, the urban heat island effect has caused an increase of 3.9 degrees Centigrade in minimum temperatures, as well as higher wind velocties and greater local evaporation rates (Balling and Brazel 1987). Desert bighorn, badgers and bobcats are no longer seen in the park as they were earlier in the century. Mountain bike trails have proliferated to the degree that not only vegetative cover but topsoil has largely been stripped from the rocky flanks of the Papago Buttes.

Recreation

Although once considered a non-consumptive use of the desert relative to mining, grazing and logging, recreation-related damage is now considered the second most pervasive impact upon threatened and endangered species in the Western United States (Rick Knight, pers. comm.) Off-road vehicle damage of vegetation, vandalism and illicit collecting of endangered plants -- all incidentally associated with outdoor recreation -- are collectively cited more frequently than any other pressures on threatened plants in the U.S./Mexico borderlands (Nabhan et al. 1991).

Ironically, in the Sonoran Desert, the most intensive poaching of endangered cacti occurs on the public lands where the "conservation message" of land management agency is supposedly the strongest -- in National Parks and National Wildlife Refuges, then less dramatically so, on BLM lands, Indian reservations and private lands (Bennett et al. 1987). For example, Park Service biologists recorded a 44% loss of Thomber's fishhook cactus individuals due to "recreational cactus-poaching" and trampling by tourists at an intensively-visited site in Organ Pipe Cactus National Monument.

"We recognize that many [outdoor] activities -- for example, camping, hiking, fishing, and hunting -- are popular forms of recreation and important ways for humans to keep in touch with nature. However, if they become too intensive or are poorly controlled, they can damage biodiversity... The problem is that people, be they back-country hikers or weekend car campers, are attracted to precisely the same spots that are rare within our arid Southwest deserts: areas with trees, areas around water, and of course areas with both trees and water. These are typically the places with the richest array of species. These spots are most susceptible to human activities such as burning wood, polluting water, and disturbing animals."

-- Allen Cooperrider et al.
Defending the Desert (1995)

Similarly, studies in recreational campgrounds in Oak Creek Canyon at the northern limits of the Sonoran Desert have conclusively demonstrated that breeding bird density and diversity decline precipitously once campgrounds are opened for seasonal use (Aitchison 1987).

We surveyed managers of Sonoran Desert protected areas about visitation, growth of visitation, types of recreational use, the detrimental effects of this use on the natural values of the area, sensitive species, and management of recreational use. The numbers of recreationalists, trends in these numbers, and the extent of certain detrimental visitation effects are often little known and difficult to quantify, but we did receive some valuable information (Table 5).

Recorded visitation per year (1996 or 1997) ranged from about 500 to 2000 in several BLM Arizona Upland/Lower Colorado River Valley Wilderness areas and reached 200,000 to 400,000 in Organ Pipe National Monument and Saguaro National Park (Arizona Upland/Lower Colorado River Valley). Tourists visited these areas for a variety of activities, from hiking to off-road recreational use.

Not surprisingly, total visitation remains unknown for most protected areas in Mexico, and unknown for 3 out of 10 protected areas in the U.S.. The growth in visitation over the last quarter century was known in only 30% of the protected areas.

With regard to detrimental effects of recreational use, soil erosion was the most frequently cited negative impact, occurring at 8 of the 10 protected areas surveyed. It was followed in frequency of reports by disturbance of archeological sites (in 40% of the areas), disturbance of understory vegetation (40%), fuelwood harvesting (30%), disruption of nesting birds (20%), and disturbance of other landscape features, including riparian vegetation and dunes.

Almost all areas are attempting to mitigate recreational impacts by employing various intervention strategies. These include: heightened emphasis on pre-visitation educational orientations, public advertizing of visitation rules, stricter law enforcement, and even complete closure of sensitive areas. The BLM is completing an inventory of vehicle routes in the Barry M. Goldwater Air Force Range in order to close "redundant" ones. Despite these efforts, only 30% of the surveyed managers thought that recreational impact management strategies would be adequate for the protection of the areas in the next 10 years.

"We sailed in the morning on a short trip to Guaymas. It was the first stop in a town that had anything like communication since we had left San Diego. The world and the war had become too remote to us; all the immediacies of our usual lives slowed up... We could understand, because we could feel, how the Indians of the Gulf, hearing about the great ant-doings of the north, might shake their heads sadly and say, 'But it is crazy. It would be nice to have new Ford cars and running water, but not at the cost of insanity.' "

-- John Steinbeck
The Log from the Sea of Cortez (1941)

High Per Capita Consumption

Laney (1997) reminds us of the differences between various socioeconomic classes and cultures in consumption levels of limited desert resources. The wealthy elite in Phoenix -- and perhaps in Puerto Peñasco and Hermosillo neighborhoods with lush lawns, swimming pools and extravagant household cooling systems as well -- consume about 1500 liters (370 gallons) of water per person per day. Middle-class residents in Tucson -- and Tubac or La Paz -- who have adopted desert landscaping or water-conserving practices in their dooryard gardens use about 450 liters (114 gallons) of water per person per day. A Tohono O'odham rancheria with adobe houses and ramadas, a few mesquite trees and cacti on the carefully-tended desert floor, and small patches of herbs or vegetables fed with runoff from thunderstorms, consumes only 80 liters (20 gallons) per person per day (Laney 1997). The same magnitude of consumption characterizes fossil fuel use by multi-car families living in the metropolitan areas of Arizona and California versus the horsebacked herders of the Sierras of Sonora, Chihuahua and Baja California. Interestingly, only Mexican scientists noted "resource consumption by the elite" as a major regional stress.

Water Diversion and Impoundment

Since 1908, hydrological engineers in the Sonoran Desert have impounded and diverted water flows from virtually all of the region's major rivers by constructing 41 major dams, with 17 in Arizona, 21 in Sonora, 1 in Baja California, and 2 in Baja California Sur (Figure 4). The dams in Arizona have impacted the entire Sonoran Desert portions of the Salt, Gila, Bill Williams and Colorado Rivers. These impacts include stream conversion to lakes above the dams and the creation of dry stretches below them; the loss of natural flooding processes, and related changes in riparian dependent biotic communities. Below the Salt River's Granite Reef Dam, for example, all water is diverted and there is no riparian vegetation until the outpouring of treated sewage effluent from Phoenix wastewater treatment plants. Where there is riparian vegetation below dams, it is now most frequently dominated by exotic salt cedar.

The damming of the Colorado River and the Ríos Yaqui and Mayo in Sonora has dramatically reduced the annual floods that carried the nutrient-rich sediments to once highly-productive, biodiversity-rich delta and marine ecosystems. Given that the total diversion capacity of the Colorado River for municipal and agriculture projects is more than the average flow of the river at Lee's Ferry, it is now a rare event when the Colorado's flow reaches the Gulf of California. When it does reach the Gulf, it is

> "In the arid West, water diversion -- primarily for agriculture — has been going on for thousands of years, albeit on a small scale until the late nineteenth century. Native Americans sometimes diverted water to grow crops, but they generally grew crops where the water was, rather than moving water to the crops.. In the twentieth century, this urge to capture and store water reached its culmination with the building of the gigantic Hoover and Glen Canyon Dams on the Colorado River. These large dams and diversions cause much biological impoverishment due to habitat fragmentation, alteration in water flow patterns, increases in exotic species, and other changes."
>
> -- Allen Cooperrider et al.,
> Defending the Desert (1995)

Table 5:
Recreational use, its negative effects, and its management in selected Sonoran Desert protected areas.

Protected Area	Bill Williams River National Wildlife Refuge	Cibola National Wildlife Refuge	Kofa National Wildlife Refuge	Yuma District BLM Wilderness Areas (4)[2] and ACECs[3]	Imperial National Wildlife Refuge	Organ Pipe Cactus National Monument	Phoenix Parks	Catalina State Park	San Pedro Riparian National Conservation Area	Colorado River and Alto Golfo de California
# of Visitors in the Last Year	18,000	39,000	50,000	—2,050	132,200	200,000 - 400,000		145,000	100,000	unknown
Has # Increased by Half Since 1990 ?	no	no	unknown	Yes, in Eagletail Wilderness only. Unknown for others	unknown	unknown	unknown	yes	yes	unknown
Recreation Types[1] (ranked)	FI, ORV, BO, BW, HI, HU, PH	BO, BW, FI, HU	HI, HU, RC, RV, PI, BW, BP	Viewing cultural sites, HI, HU, RC, BP	BO, HI, EE, ORV, PI, HU, BW	HI, RV, PI, PH, BW, MB, BP	HI, BW, PI, MB, HR (not ranked)	HI, RV, PI, BW, MB, BP, HU	BW, HI, PI, HU, BP, MB, RV, RC, BO	RV, ORV, BO, PI, BW, BP, HI, HU
Elements Negatively Effected and/or Negative Effects	nesting birds, migratory birds, soil erosion	riparian habitat	fuelwood, understory vegetation, soil erosion, archeological sites, noise	archeological sites, "natural values", desert pavement disturbance by off-road vehicles	surface disturbance and creation of off-road vehicle routes	fuelwood, understory vegetation, endangered plants, archeological sites, soil erosion on trails, off-road vehicle damage	no data	archeological sites, soil erosion	nesting birds, understory vegetation, endangered plants, soil erosion, archeological sites	small mammals, fuelwood, understory vegetation, water quality, soil erosion, traffic, noise, dune disturbance, solid waste, endangered plants, endangered animals
Is Recreation Management Adequate for the Next 10 Years ?	no	?	yes	yes	yes	no		no	no	no

1. BW: birdwatching; BO: boating; BP: backpacking; FI: fishing; HI: hiking; HR: horseback riding HU: hunting; MB: mountain biking ORV off-road vehicle use; PH: photography PI: picnicking RC: rock collector RV: recreational vehicle camping; EE: environmental education
2. Eagletail Mountains, Muggins Mountains, New Water Mountains, Trigo Mountains
3. Including Areas of Critical Environmental Concern: Gran Desierto Dunes, Mohawk Mountains and Sand Dunes, Tinajas Altas Mountains
4. Visitation is estimated to have increased by more than half (50%) between 1970-1980 and 1980-1990.

In general, the very presence of the border has set up some "natural experiments" where it becomes easy to compare different fertilizer and pesticide residue. In combination with fisheries overharvesting, the reduction of water flow, sediment loads, and water quality from the Colorado River, Río Yaqui and Rio Mayo has resulted in the endangerment of the totoaba *(Totoaba macdonaldi),* the "vaquita" porpoise *(Phocoena sinus)* and sea turtles, and produced substantial reductions in the Gulfs shrimp harvest (Búrquez and Martínez-Yrízar 1997).

Among U.S. Federal Register notices of listing plants and animals as endangered species, water impoundment and diversion are among the most frequently cited threats mentioned (Rick Knight, pers. comm.). Inundating vegetation in reservoirs behind dams, and changes in river flow are collectively among the top seven cited pressures on threatened plants in the U.S./Mexico borderlands (Nabhan et al. 1991).

Because so many native species in this arid region critically depend upon the limited surface water which is episodically available, water impoundment and diversion away from riparian habitats has radically changed the distribution and abundance of many organisms. As a case in point, Johnson, Bennett and Haight (unpubl.) have documented the regional demise of 36 of the 82 breeding bird species which formerly used riparian woodlands. These "bosques" — dominated by closed mesquite canopies -- have decreased in abundance since 1900 in the Sonoran Desert lowlands to the point that 12 of their historic breeding bird species are now more frequently found in desertscrub than in water-starved floodplain habitats.

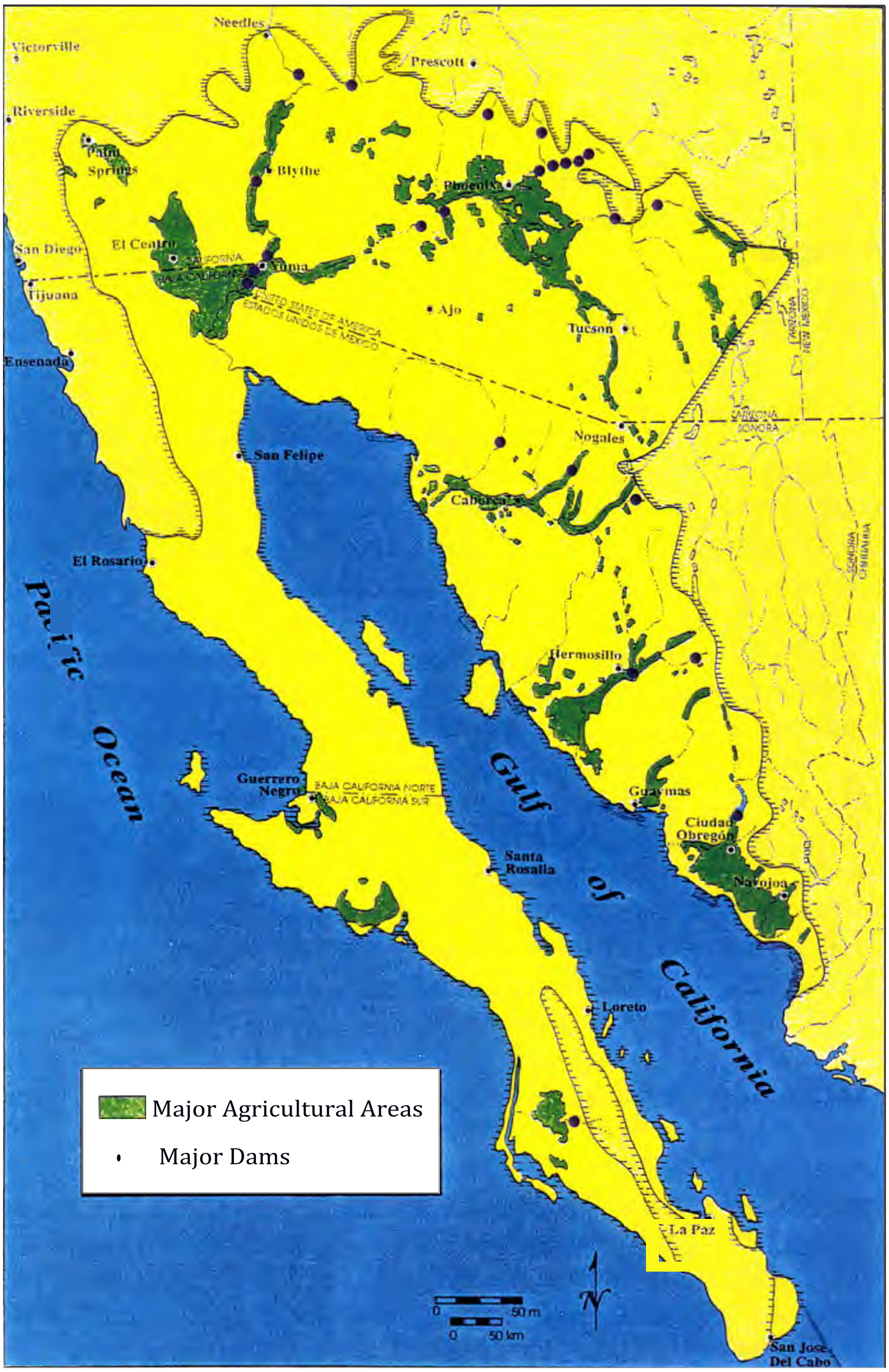
Even small water impoundments and developments can unintentionally serve to disrupt wildlife populations, and change relationships between large ungulates, their predators, parasites and diseases. Broyles (1995) has recently reviewed the ecological impacts of desert wildlife water developments such as artificially-impounded sheep tanks and bubblers, and calls to question whether these “habitat improvements” cause more harm than good.

On a much larger scale, the heavily altered wetlands of the Colorado River delta provide the greatest testimony for the tragic effects of water diversion and impoundment. However, there remains the possibility of restoring the continent's grandest river delta ecosystem. Extensive agricultural production and related river diversion and channelization have converted cottonwood-willow gallery forest to low stature, salt tolerant vegetation and once vegetated areas into salt and mud flats. Salt cedar now dominates much of the delta, denying such birds as the yellow-billed cuckoo and southwestern willow flycatcher the nesting and feeding sites they prefer. The Sonoran Desert's single endemic grass species, Palmer's Saltgrass (*Distichlis palmeri*), occurs only in the northern Gulf of California, but has not been observed regenerating under current more saline conditions there.

Nevertheless, the Colorado River delta is still the largest wetland in the Sonoran Desert. Since 1973, its areal extent has fluctuated between 5,800 and 63,000 hectares. Relatively wet periods (such as 1980-1993) have breathed life into the delta wetlands, allowing floodwaters to once again reach the delta in near-record volumes. Saline agricultural drainage supports Cienega de Santa Clara's habitat for 22 wetland plant species, an important migratory waterfowl stopover site, and the world's largest populations of Yuma clapper rails and desert pupfish (Glenn et al. 1996). Additionally, the delta provides an important nursery grounds for marine crustaceans and fish.

Glenn et al. (1996) claim that "delta wetlands are not directly in danger due to lack of water," for it is the management of water that is pivotal. The Cienega de Santa Clara would be dramatically altered if the Yuma Desalting Plant started operating and utilized the agricultural drain water that flows to it. Even though it is part of a biosphere reserve, the delta's water requirements are not taken into account in water management and land use planning. However, sustaining the current delta wetlands could be accomplished without undermining irrigation needs nor municipal demands (Glenn et al. 1996). There are now efforts underway to define management criteria that will further protect wetland values in this delta and region.

Figure 4:
Major Dams and Agricultural Areas in the Sonoran Desert Bioregion.



Bioregional Boundary *for* Report

Groundwater Overdraft

Within the first quarter of the twentieth century, many of the Sonoran Desert's Pleistocene aquifers moved from a state of hydrologic balance to one of severe depletion, or overdraft. By 1923, groundwater pumpage surpassed water recharge in Arizona. With the continued development of relatively inexpensive and more powerful mechanized pumps, groundwater overdraft increased exponentially in agricultural areas of the Sonoran Desert. In combination with water diversion, groundwater pumping has affected nearly all river valleys in Arizona's portion of the Sonoran Desert (Figure 5). Large expanses of riparian forest and mesquite woodlands have died as groundwater levels declined. While other biotic communities are also affected by water table declines, the relationship between their vegetation changes and lowering groundwater levels is still largely unexplored (Bahre 1991). Nevertheless, it is clear that groundwater pumping immediately outside protected areas can devastate the vegetation within them (Nabhan and Klett 1994), and ultimately effect faunas.

In the heart of agricultural areas groundwater declines have been precipitous. In 18% of 56 groundwater basins in all Sonoran Desert states (excluding California) there have been groundwater declines of over 1 meter per year (Figure 6)[1]. In another 16% of the basins, groundwater declines have ranged from 0.3 - 1 meter per year. In the Carefree sub-basin northeast of Phoenix water levels in one area have dropped over 3 meters per year, largely due to golf course development (ADWR 1994b). In the area around Casa Grande, Arizona groundwater levels have dropped up to 150 meters since 1920 (ADWR 1994a). In the 1940s this agriculture-induced drawdown became the principal cause of the death of the once extensive mesquite bosque at Casa Grande National Monument (Judd 1971). The creation of the Costa de Hermosillo irrigation district was the direct cause of the loss of the extensive mesquite bosques in the delta of the Rio Sonora. In the Río Yaqui and Rio Mayo deltas, over a million hectares of coastal thornscrub, riparian

> "When alfalfa and ryegrass are planted to raise feedlot beef, they use twenty tons of irrigation water to produce one pound of hamburger. The groundwater around [Casa Grande] has already dropped from twelve feet below ground level to more than two hundred since the 1920s. A century ago, one manmade object as tall as the center pivot irrigation pipes and water towers stood out on the desert plains: Ge ki, a prehistoric multistory ceremonial center, rose up from the mesquite forest. Today, the Indian ruin sits in Casa Grande National Monument right in the middle of hundreds of acres of rotting trees killed by the drawdown of groundwater below their root level. What we have now is a National Park of dead stumps."
>
> --Gary Paul Nabhan and Mark Klett
> Desert Legends(1994)

[1] Descriptions of basin-wide groundwater level changes are as representative as the number of wells that are monitored, the conditions under which they are monitored and the period of time over which they are monitored. Figure 6 shows levels measured over a wide variety of time periods and some only until the late 1970s and early 1980s. Also, groundwater level declines are not just a factor of the volume and rate at which the water is pumped but also the geohydrological factors surrounding the well and the rate of recharge. However, the available information does provide the means for an initial region-wide assessment of where groundwater overdraft has been a more severe problem.

forests, and mesquite woodlands have been lost (Búrquez and Martínez-Yrízar 1997). In the upper San Pedro basin of southeastern Arizona, water levels have declined an average of 0.4 meters per year in the vicinity of a large cone of depression in Sierra Vista, Arizona (Lacher 1994). While some efforts are being made to prevent the growth of this cone of depression and its lessening of surface water flows, negative impacts on the life sustaining flows of the riparian area are likely (Lacher 1994). Stromberg et al. (1996) suggests that just a 0.3 meter decline in riparian zone water levels could reduce key species such as rushes, and a 1 meter drop would eliminate them, reducing willow coverage by 51 percent, and allowing mesquite and tamarisk to expand, creating "desertification" of riparian areas.

In the Sonoran Desert, areas with the highest levels of groundwater extraction, soil compaction, land subsidence and associated fissuring are secondary effects of groundwater overdraft. These effects are of most concern in intensive agricultural areas. Around Picacho Peak between Tucson and Phoenix, land has subsided by one meter causing fissures which extend for more than a kilometer. In the municipio of Caborca, Sonora subsidence and fissuring are so extensive that roads have been closed for fear that vehicles would disappear into subsurface crevices (SARH, pers. Comm.) Fissuring can cause the abandonment of agricultural fields (Anderson 1989) but then further delays the recovery of these lands. In areas with natural vegetation, fissuring changes runoff patterns which consequently could alter the vegetation community.

For many areas of Arizona, the greatest damage from groundwater overdraft has already occurred. Arizona groundwater pumping peaked in 1974 at 5.7 million acre-feet but dropped to 3.2 million acre-feet in 1990. This reduction is due principally to the statewide decline in irrigated cropland, but also to above average precipitation and the use of Central Arizona Project (CAP) water (de Kok 1997). As a result, groundwater levels have leveled off and even rebounded in many Sonoran Desert basins; 23% of basins have areas where groundwater levels have increased (Figure 6). Metropolitan sprawl has converted irrigated croplands to housing subdivisions, but it remains unclear whether this necessarily means that we are "saving water" over the long run. The peak water withdrawal of 2.2 million acre-feet in the late 1950s fell to less than one million acre-feet in the late 1980s (de Kok 1997). However, the degree to which the transfer of water from agriculture to urban use reduces long term groundwater overdraft deserves careful analysis, taking into account projections of population growth, per capita water demand, and water pricing subsidies.

Reliance on the waters of the already over allocated Colorado River is the lynch pin of most plans to reduce or cease Arizona's overdraft of its Pleistocene aquifers. After such plans were formulated, it became obvious that they will be difficult to implement; further demands on surface water supplies and prolonged aquifer overdraft seem likely. In the Phoenix Active Management Area projected water demands are expected to be 17% higher in 2040 than in 1990 (ADWR 1994). The AMA's goal is the attainment of safe yield (balance between groundwater withdrawals and natural and artificial recharge) by 2025. While safe-yield in the face of increased demand is expected to be accomplished largely with CAP water, the means for achieving this goal are still very uncertain. The Tucson AMA is also projected to attain safe yield by 2025, but demand is anticipated to be 30% higher, with overdraft expected to be 90,000 acre-feet (67% of 1990 overdraft). This shortfall is due to the lack of economic and management incentives to use renewable supplies (ADWR 1994a). The goal for the

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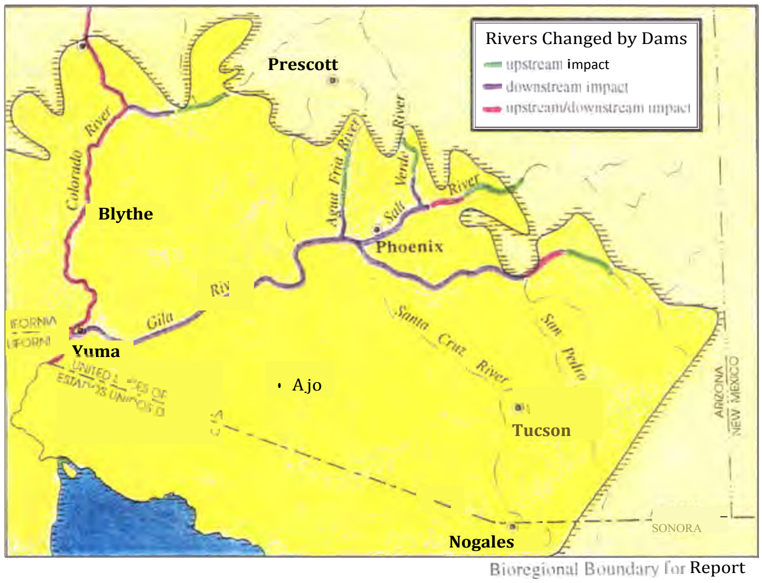
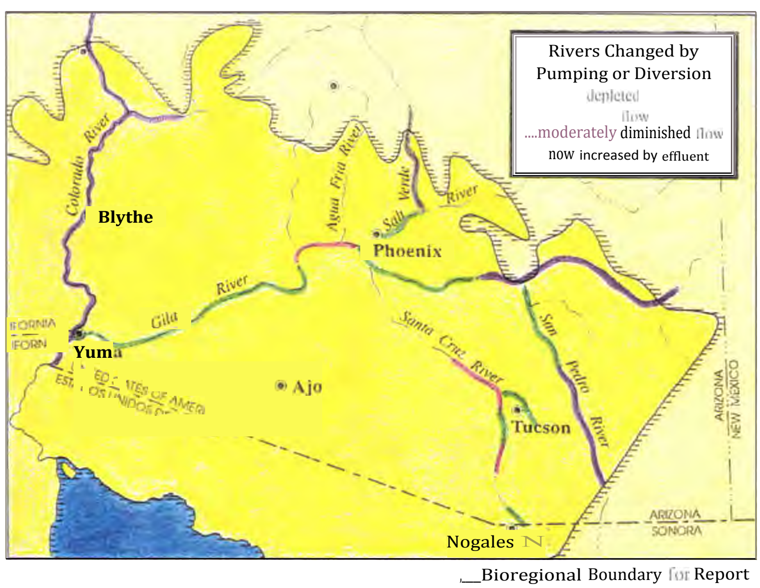
[2] Active Management Areas (AMAs) were established by the 1980 Arizona Groundwater Act in severely water depleted areas. While the area of the Santa Cruz AMA was separated from the Tucson AMA in 1994, the two are combined for the purposes of this report.

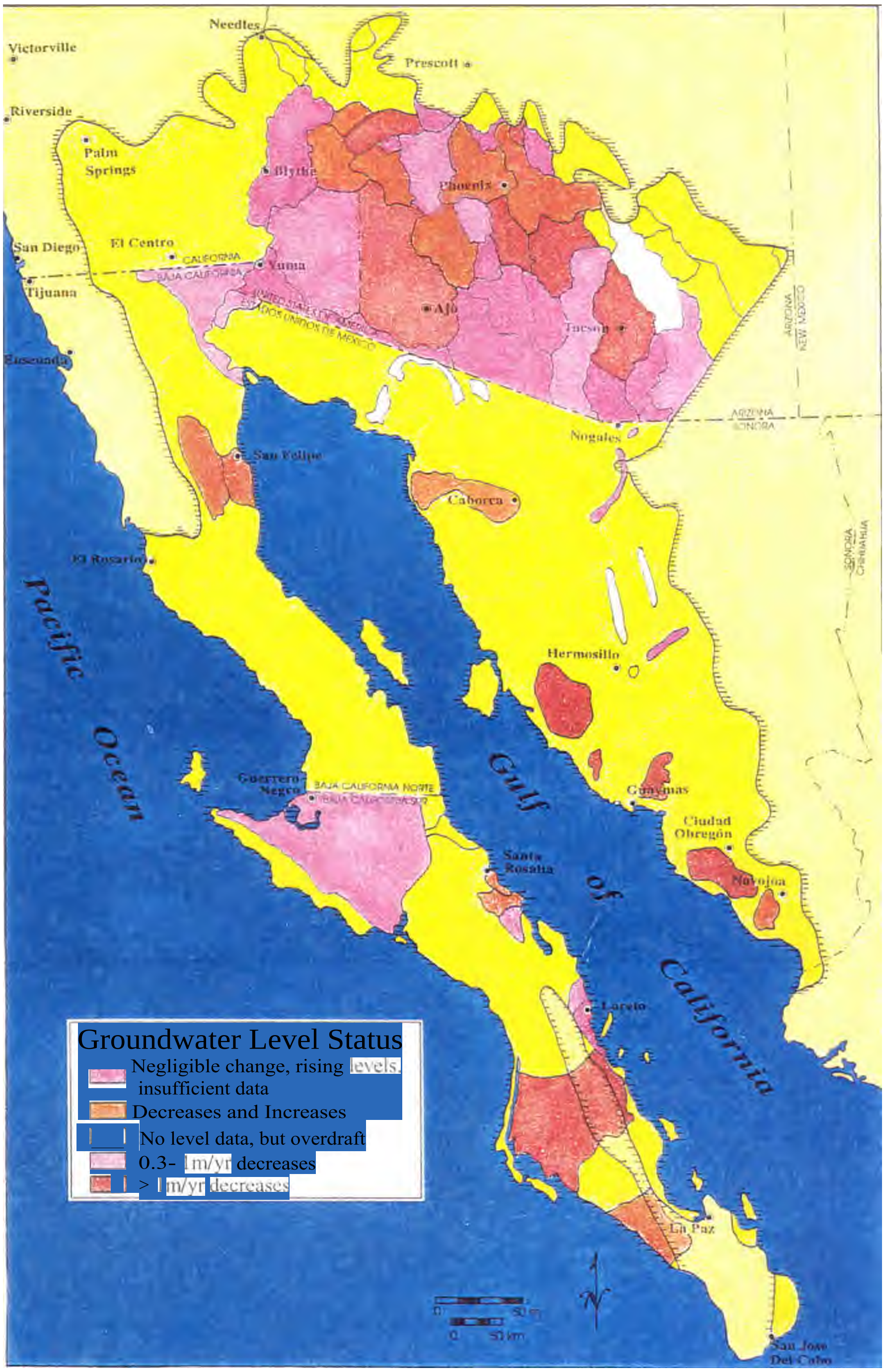
Figure 5:
The Impact of Dams, Water Diversion and Groundwater Pumping on Rivers in Arizona's Sonoran Desert





Source: Tellman et al. 1997

Figure 6:
Groundwater Level Changes in Selected Basins of the Sonoran Desert Bioregion



— Groundwater Area Boundary   Bioregional Boundary for Report

Source ADWR 1994b; INEGI 1993; 1995a, 1996
Note Data for California is not included

Pinal AMA is planned phase-out of crop irrigation; agricultural use will be extended as long as possible while still allowing for municipal non-irrigation development. Water demands in Pinal county are expected to grow 8% between 1990 and 2040. However the lack of a municipal CAP allocation to one subbasin where severe groundwater overdraft continues could imperil the long-term economy of the Pinal AMA (ADWR 1994a), and hasten land subsidence and fissuring.

Agriculture

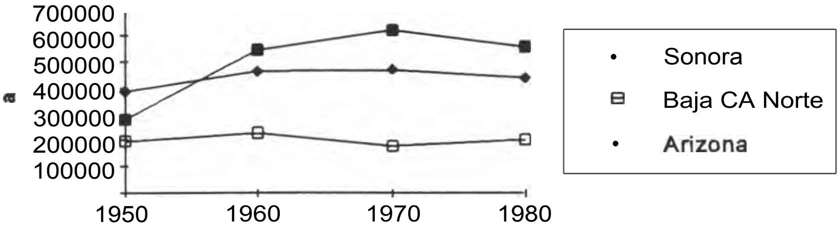
Associated with agriculture are a number of land management problems which can degrade local biotic communities: vegetation clearing, followed by later field abandonment, leaving barren lands; wind erosion and air contamination with particulates coming from fallow fields; disruption of watercourses and fragmentation of floodplains; build-up of saline and alkaline soil crusts; pesticide and herbicide use, affecting numerous non-target organisms; chemical fertilizer (especially nitrate) contamination of streamflows and aquifers, as well as nitrogen enrichment of adjacent wildlands; introduction and spread of exotic weeds, plant diseases and insects; and proliferation of certain wildlife (jackrabbit, cottonrat and passerine birds) beyond what can be supported year-round. On the other hand, agriculture can sometimes have a positive effect on wildlife and fieldside wild plant populations. That typically occurs when farming is practiced on a modest scale, without pesticide and herbicide use (Reichhardt et al. 1994; Rea 1997). A brief trip through the history of Sonoran Desert agriculture illustrates the transition from small-scale to large-scale agriculture.

From the top of "A" Mountain, C.E. Watkins took a photograph overlooking the Tucson basin that illustrates the nature of late 19th century Sonoran Desert agriculture. One can clearly see fields dissected by an elaborate network of canals that diverted surface water from the perennially flowing Santa Cruz river. Save for some dryland agriculture, agriculture was largely absent where the groundwater level was deep, where artesian wells could not be found, and where water could not be diverted from a river. As a result, floodplains had already been highly modified for centuries, but other habitats were largely intact (Bahre 1991). The establishment of such dam and diversion canal projects such as Punta de Agua near San Xavier and the Silver Lake in Tucson in the late 19th century expanded agriculture's conversion of adjacent habitats. However, the effect of such projects was minor compared to the advent of inexpensive, efficient groundwater pumps following World War I (Bahre 1991). This technical advance greatly facilitated the spread of agriculture into virtually all of the non-riparian lowland biotic

> "The Gila River Indian Reservation has experienced a widespread loss of wildlife. Twenty-eight species that once frequented the reservation are no longer found there, including the Grizzly, wolf and numerous birds. Almost all these losses are directly related to loss of riparian woodlands and marshes."
>
> --Barbara Tellman, Richard Yarde and Mary G. Wallace
> Arizona's Changing Rivers (1997)

communities, in the valleys of Arizona and the coastal plains of Sonora.

Figure 7:
Irrigated Cropland in Three Sonoran Desert States



Source: D.E. Lorey (ed.). 1990. United States-Mexico Border Statistics since 1900. University of California, Los Angeles.

By the 1940's in Sonora, agricultural water development provided the catalyst for rapid growth rates and extensive vegetation change in the coastal plain. This process began with the appropriation of water from the large aquifers of the Rio Concepción, Rio Sonora and Rio Mátape. Later, the development of dams along the Rio Yaqui and Rio Mayo boosted growth by producing electricity and furthering agricultural development (Búrquez and Martinez-Yrizar 1997). Overall irrigated land area in Sonora nearly doubled between 1950 and 1960 and peaked in 1970 at 3% of the land surface. In Arizona, irrigated land peaked in 1970 at 16% of the state's land surface. In Baja California it peaked in 1960 at 3% of its land surface (Figure 7).

However, it can be argued that the post World War II boom in Sonoran Desert irrigated agriculture has been ecologically and economically unsustainable. Between 1970 and 1980, a 10% decline occurred in the extent of Sonora irrigated land (Figure 7). A host of problems including salinization, increased water pumping costs, and groundwater and soil contamination have dramatically decreased agricultural productivity and left many abandoned, nearly denuded fields. Only 70,000 hectares of the original 150,000 hectares in the Costa de Hermosillo irrigation district remain in production (Búrquez and Martinez-Yrizar 1997). In Arizona, the reduction in irrigated lands statewide was slight between 1970 and 1980 but more marked in most of the Sonoran Desert counties; between 1982 and 1992 cropland declined by 6, 19 and 32% in Pinal, Pima, Maricopa and Yuma Counties, respectively. Between 1987 and 1992, cropland

"Even with good irrigation practices, many of the fields in the Imperial Valley that I see from both the ground and from the air have empty moth-eaten spots shaved out of the green. Salt is not only present in the soil but is carried in solution by the Colorado River, and desalinization is becoming a major concern in the valley. The gloomiest estimates are for only twenty years more life before the valley is no longer fit for crops and the desert takes back its own. Once there was desert here, and here there may be desert again."

--Ann Haymond Zwinger
These Mysterious Lands (1989)

dropped by 8% in Pima County (U.S. Dept. of Commerce 1996). This decrease is due to declining groundwater, increasing pumping costs, decreasing economic subsidies to irrigated agriculture, and the increased value of land for urban development. For example, Tucson and Scottsdale, Arizona are purchasing the agricultural water rights in many adjacent lands to transfer agricultural water use to urban water consumption (Bahre 1991). Since the construction of the Central Arizona Project and the 1980 Arizona Groundwater Management Act, roughly 40,000 hectares of agricultural land has been bought by municipalities, mines, and other industries.

While at a regional scale agriculture has been declining, in certain localities it has remained the same and even increased over the past few decades. Between 1982 and 1992 cropland in the semidesert grassland of Santa Cruz County increased by 12%. It increased by 30% in the La Paz County (Lower Colorado River Valley) between 1987 and 1992 (U.S. Dept. of Commerce 1996). Likewise, in the Sonoyta Valley of Sonora flanking Organ Pipe Cactus National Monument across the U.S.-Mexico border, cropland quadrupled in extent between 1977 and 1987 due in part to government supported agricultural development. Proximity to U.S. fruit and vegetable markets, inexpensive labor, good quality water, and government agency interest in increased fruit and vegetable acreage in the area mean that agricultural production and the associated descent of groundwater levels could continue in the future (Brown 1991). Some scientists surveyed noted that clearing for agriculture was becoming more severe in portions of the Lower Colorado River Valley, Central Gulf Coast, and Viscaino.

Current Sonoran Desert cropland is most extensive in the border county of Mexicali and the extreme southern end of the Sonoran Desert where most counties have from one-quarter to three quarters of their land surface as cropland. The central section around Hermosillo, Sonora is 15-25% cropland and the rest of the area is less than 15%. However, these figures do not include the millions of hectares of abandoned agricultural land. In Arizona's Casa Grande and Santa Cruz valleys alone there are approximately 325,000 ha of abandoned farmland. Some fields are barren even though they were abandoned 35 years ago, and others support mostly burroweed (*Isocoma tenuisecta),* and all generally provide very poor wildlife habitat (Jackson 1991). There are some efforts to reseed these areas with exotic grasses (Bahre 1991) which may reduce soil erosion but further threaten the integrity of surrounding native vegetation communities. However, large-scale restoration of abandoned farm lands to native vegetation is possible, depending on prior field management, proximity to native vegetation, soil characteristics, and other factors (Jackson 1991).

Livestock Grazing

Views of the entire earth from space highlight the overall climatological and ecological irrelevance of political boundaries. The usual message is "everything is connected." However, recent satellite images of the Arizona-Sonora border graphically show a different story. Especially in the grasslands along the eastern edge of the Sonoran Desert, the U.S. side of the border is darker from greater vegetation densities while the Mexican side is brighter due to lower vegetation densities. This large-scale ecological experiment shows that such natural factors as climate change cannot be causal but that differing land-tenure and land-use systems are (Bahre and Bradbury 1978 in Bahre 1991). More specifically, different livestock and fuelwood cutting intensities have been implicated (C. Huthchinson pers. comm.) We discuss the former in this section.

Livestock grazing in the Sonoran Desert has fluctuated greatly in the last several centuries from being relatively confined and intensive to being extensive and intensive. In the 19th century repeated Apache raids on ranchers and the paucity of water limited cattle production to relatively small areas (Bahre 1991). However, since the late 19th century's largest stocking rates in history, extensive cattle production has played a major role in the transformation of grasslands to scrublands, down-cutting of arroyos, the spread of exotic plants, and degradation of riparian areas. Stocking rates are now much lower than in the 1890s because such regulations as the Taylor Grazing Act of 1934 helped improve range land quality. However, overstocking still continues on public and private lands in Arizona (Bahre 1991), and Mexico's CODECOCA statistics confirm that 2 to 5 times the recommended stocking rates occur with regularity on the Sonoran side of the border (R. Aguirre, pers. comm.) Sonora's higher stocking rate is likely due to its greater amounts of private and ejidal (communal) land, less regulation, and the greater dependence on ranching and farming in Mexico (C. Hutchinson pers. comm.).

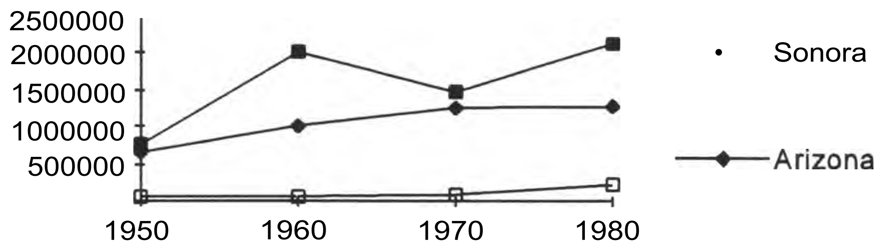
The comments above are particularly relevant to the semidesert grassland along the eastern edge of the Sonoran Desert. Robert Humphrey rephotographed the "two grazing treatment" transect provided by the 1890 boundary markers between the Rio Grande and the Colorado River. Ninety years later, after the initial photos were taken, he found significant vegetation degradation in the semidesert grassland sections in eastern Sonora. However, there were no significant changes in the species composition or lifeform dominance in the desertscrub along the U.S.-Mexico border west of Tucson (Humphrey 1987). Nevertheless, desertscrub vegetation structure can be dramatically altered. Blydenstein et al. (1957) found that in Sonoran desertscrub perennial grasses and the palatable shrub, range ratany, declined precipitously under grazing. Fleischner (1994) has provided a thorough analysis of the ecological costs of livestock grazing in many regions, including Sonoran desertscrub, semidesert grassland and riparian areas.

Figure 8 charts the dramatic fluctuations in Sonora cattle numbers and the relatively modest increase in livestock in Arizona and Baja California Norte. Búrquez and Martínez-Yrízar (1997) consider the cumulative impacts of cattle grazing in Sonora to be irreversible. Livestock grazing was ranked among the five most serious stressors by the surveyed scientists. However, 20% of the scientists surveyed thought that livestock grazing practices have diversified and in some places improved. Between 1982 and 1992, cattle numbers in Pinal, Santa Cruz and Maricopa counties dropped by 11%, 18% and 45%, respectively (U.S. Dept. of Commerce 1996). However, some scientists reported that over-grazing has become more severe in the Lower Colorado River Valley, Central Gulf Coast,

"During the Mexican Revolution cattle stocks (in Sonora) diminished drastically, allowing some recovery of the rangelands. However, the cattle industry regained momentum mainly in the arid and semi-arid areas of northern Mexico, creating the present almost irreversible degradation of large expanses of semi-arid and aridlands.

— Alberto Búrquez and Angela Martínez-Yrízar
Conservation and Landscape Transformation in Sonora, Mexico (1997)

Figure 8:
Cattle Numbers in Three Sonoran Desert States



Source: D.E. Lorey (ed.). 1990. United States-Mexico Border Statistics since 1900. University of California, Los Angeles.

> "Under the moon around the campfire that night, with tongues loosened by locally distilled moonshine (bacanora) made from native agaves, opinions clashed. Supporters of livestock production argued that the cattle were reasonable proxies for the extinct ice age megafauna and that the mountains were too tough and too dry to support many cows anyway. It might even be better for the plants to coexist with cows than without them, especially those plants, like the aguarita, that rely on large mammals for seed dispersal. The antibovine faction objected to stepping in cow pies, to local terracing and erosion on steep slopes caused by many hooves, and to the threat of buffel grass invasion or other touted 'range improvements,' another manifestation of 'bovine imperialism.' Easy for us to say, we tourists from the north, the land of many imperialisms. The debate, I noticed, seemed to separate the plant transect people from the fossil hunters."
>
> -- Paul S. Martin
> The Secret Forest (1993)

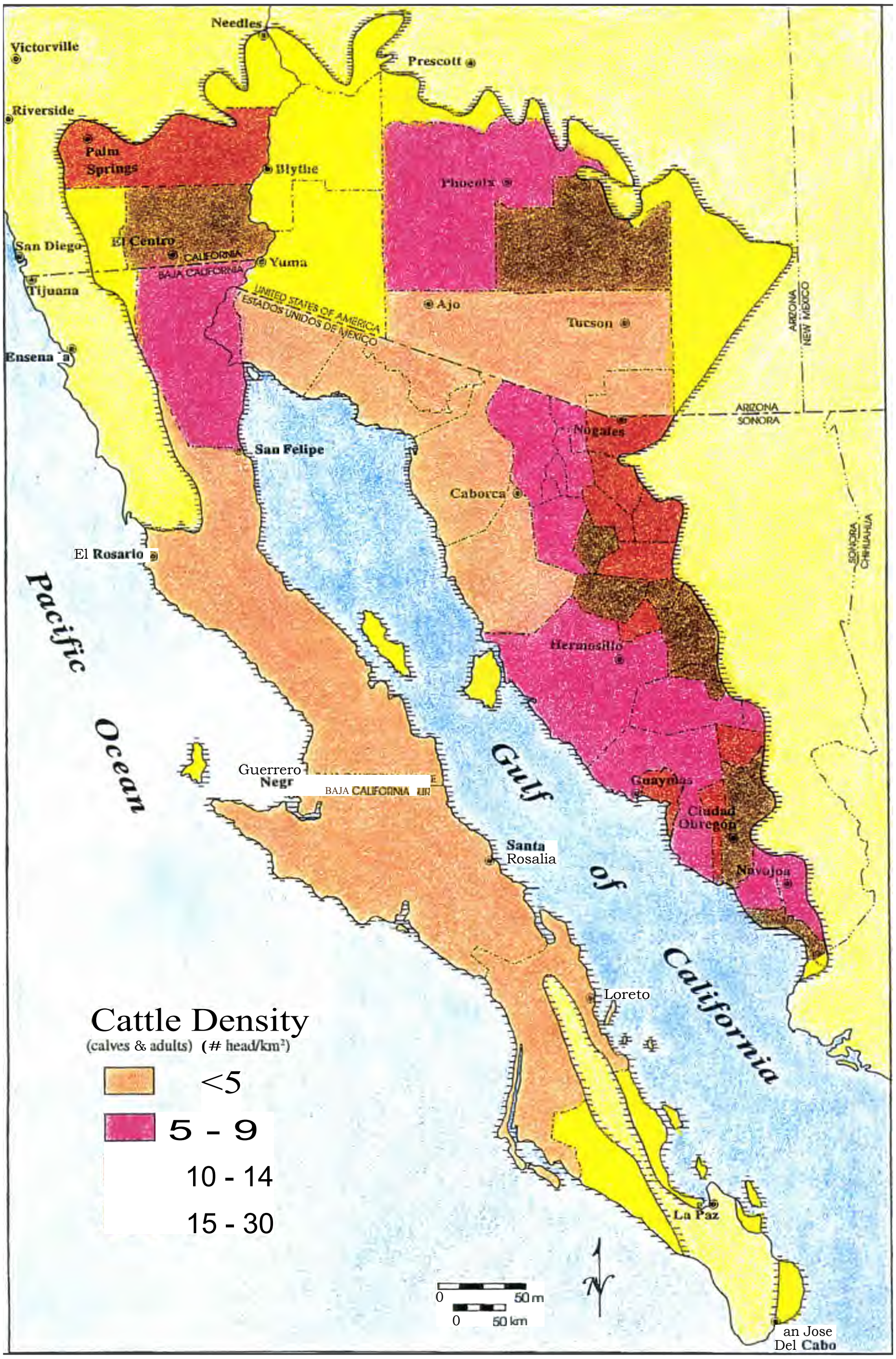
Foothills of Sonora Thornscrub/Coastal Thornscrub, Semidesert Grassland, and Riparian Deciduous Forests. It is most severe west of Hermosillo where cattle densities are as high as 22 head/km^2 in areas with low productivity. Overall, cattle densities are highest (>5 head/km^2)towards the more mesic eastern and southern portions of the Sonoran Desert (Figure 9).

Many scientists consider that the most drastic cattle-related land transformation in Sonora has been the introduction of the extremely invasive African buffelgrass *(Pennisetum ciliare)*. This phenomenon is described below in the section on exotic species.

Intentionally Planted Exotic Species

The introduction and intentional sowing of African grasses in the Sonoran bioregion has not only affected the biotic composition of semidesert grasslands, but has profoundly changed vegetation structure, fire intensity and frequencies, and migratory wildlife corridors within several subregions of the Sonoran Desert proper. Of particular concern to ecologists are the extensive plantings of lovegrasses *(Eragrostis spp.),* buffelgrass *(Pennisetum ciliare*) and fountaingrass *(Pennisetum sp.)* into desert areas where they are capable of dispersing to adjacent areas and outcompeting natives. The "grasslandification" of the Sonoran Desert, adjacent thomscrub and subtropical savanna by buffelgrass (Miller et al. in review) has already occurred on some 600,000 hectares of Sonora, and is becoming notably dominant at lower elevations of Baja California. Cox (1991) recently claimed that buffelgrass is now the dominant herbaceous perennial on eight to ten thousand hectares in the Southwestern USA and Northern Mexico. Mexican agricultural

Figure 9:
Cattle Density in the Sonoran Desert Bioregion



—·— County/Municipio Boundary ,SBioregional Boundary for Report

Sources: INEGI 1995b,c; INEGI 1996a; U.S. Department of Commerce 1996.
Note: U.S. densities are for 1992 and Mexico densities are for 1995.

officials claim that they would like to see the area in Sonora planted with buffelgrass grow from 600,000 to more than 2.0 million hectares in the coming decade. The ecological consequences of buffelgrass and higher elevation lovegrass plantings and invasion affect native biota in several ways (Bock and Bock 1992). First, buffelgrass typically invades native desertscrub communities by establishing under the canopies of the dominant legumes there, usually ironwood and mesquite (Miller et al. in review). Because 165 other natives use the canopy of ironwood and mesquite as nurseries (Nabhan and Carr 1994), this disrupts the regeneration of many herbs, cacti and shrubs. Paired sampling of neighboring plots in buffelgrass and in desertscrub have shown that plant richness decreases fourfold, and diversity decreases tenfold (Miller et al. in review). Changes in fire regimes then occur, and in the summer of 1996 alone, there were hundreds buffelgrass-spread wildfires in Sonora below 1000 meters in elevation where historically, fires seldom occurred. Fire-intolerant cacti, woody legumes, small mammals, butterfly larvae and ground- and twig-nesting bees are negatively impacted. With lovegrasses numerous native birds decline while only a few thrive (Bock and Bock 1992).

There are also profound changes in standing biomass, nutrient cycling and availability, and in surface water flows. Búrquez and Martinez-Yrízar (unpublished) have found that conversion of arboreal desertscrub vegetation to buffelgrass pasture causes a three- to fourfold reduction in aboveground standing crop biomass. Nitrogen is more easily volatilized in buffelgrass pastures, while phosphorous and potassium are quickly lost after fires. Buffel pastures can choke out or lead to the burning-away of xeroriparian vegetation, including chuparosa bushes which serve as critically important seasonal floral resources for migrant hummingbirds. Calder (pers. comm.) has recently recorded dramatic decreases in Rufous Hummingbirds migrating through desertscrub, which may potentially be attributable to reduced springtime floral resources along their "nectar corridor" through Sonora. Such potential consequences of buffelgrass dominance need to be evaluated for a variety of ecological interactions and consequences.

> "...the new buffelgrass pastures do not give the trees a chance to recover. The dense grass prevents germination or seedling establishment. While ranchers often leave "keeper trees"...to provide shade, edible fruit, or fence posts, these trees are doomed. If not cut down first, the keeper trees will die of old age or be blown down in storms, leaving the field exclusively to buffel grass. For the buffel to remain thrifty, it must be grazed heavily or burned. Meanwhile more and more dry tropical forest and thornscrub is being destroyed for buffel grass."
>
> --Paul S. Martin
> The Secret Forest (1993)

Invasive Species

Felger (1992) estimated that there are at least 146 non-native plant species naturalized in the Sonoran bioregion, which he believed to be no more than 6% of the total desertscrub and thornscrub flora of the biome. (This compares to Nabhan's (1982) estimate that 9%, or 328 species, of Arizona's flora of 3666 plants are exotics). If we add 5 to 10 naturalized mammals, 5 to 10 birds, 1 reptile, 2 amphibians, 45 to 50 fish, and an unknown number of invertebrates, the total number of exotics naturalized and competing with natives in the Sonoran bioregion is well over 200 species. Table 6 gives a short list of naturalized animals, while Table 7 highlights the most extensive or problematic plant invasions.

Table 6: Exotic Animals Naturalized in the Sonoran Desert Bioregion

Invertebrates
Tobacco Whitefly
Poinsettia Whitefly
German Cockroach
Turkestan Cockroach
American Cockroach
Brown-banded cockroach
Big-jawed Ant
Fireant
Ensign Wasp
Africanized and European Honey Bees
Housefly
Varroa Mite
Tracheal Mite
Egyptian Yellow Fever
Crawfish

Vertebrates			
Threadfin Shad	Black Crappie	Walking Catfish	Cattle Egret
Tilapia (3 spp)	Fathead Crappie	Variable Platyfish	Starling
Black Bullhead	Flathead Minnow	Sailfin Molly	House Finch
Yellow Bullhead	Northern Pike	Mexican Molly	House Sparrow
Flathead Catfish	Walleye Pike	Guppy	Rock Dove
Channel Catfish	Mosquitofish	Banded Tetra	Inca Dove
Grass Carp	Largemouth Bass	Golden Shiner	Turtle Dove
Carp	Smallmouth Bass	Red Shiner	House Mouse
Rainbow Trout	Striped Bass	Bigmouth Buffalo	Norway Rat
Brook Trout	White Bass	Smallmouth Buffalo	Nutria
Brown Trout	Warmouth Bass	Black Buffalofish	Dog
Coho Salmon	Sargo Grunt	Goldfish	House Cat
Green Sunfish	Croaker	Bullfrog	Feral Burro
Pumpkinseed	Convict Cichfid	Tiger Salamander	Feral Horse
Redear Sunfish	Blue Catfish	Indian House Gecko	Feral Cattle
Bluegill	Green Swordtail	Mediterranean Gecko	

These tables suggest the astonishing range of exotic species introduced to the Sonoran bioregion, intentionally or unintentionally, which have invaded other habitats and changed biotic interactions there. Microbes such as Giardia and scabies should also be considered for their effects on native wildlife such as desert bighorn, particularly where they are transmitted at artificial water developments (Broyles 1996).

Constant reminders of the magnitude of change caused by these exotics are in order, since Burgess et al. (1991) claim that once begun, most of the invasions are irreversible, and that several exotics formerly considered minor are showing signs of becoming increasingly invasive. For example, the salt cedar or tamarisk, after its introduction to North America for erosion control in the 1850s, spread to over 4,000 hectares of riparian habitat. Naturalized in the Colorado River watershed by the 1920s, it arrived in the Phoenix area of the Gila and Salt Rivers by the 1930's, where it became named and dreaded by the Gila River Indians. A mature tamarisk consumes as much as 800 liters of water per day -- 10 to 20 times the amount used by native species which it tends to replace, such as mesquite (Cooperrider et al. 1995). In one study of winter bird populations along the Lower Colorado River, biologists found 154 birds per 40 hectares of native vegetation compared to 4 birds per 40 hectares in comparable tamarisk-doinated areas (Anderson et al. 1987; Johnson 1986). While stands of tamarisk may have considerable insect diversity and high productivity of White-winged doves, they often choke out native vegetation to the extent that animals which specialize in natives are displaced from the scene. Whereas invasions of tamarisk and many other species are irreversible for biological or geographical reasons, the most destructive / invasive ungulate, the Feral Burro, is legally unmanagable due to the Wild Horse Act.

Extractive Harvests

Despite the commonly-held perceptions that deserts are either economically-worthless wastelands or untouched wildemesses, there is an astonishingly high diversity of plants within the bioregion which are the subject of extractive harvests for commercial purposes. A recently-initiated biodiversity inventory of native plants used for indigenous crafts marketed from the region has already identified more than 80 species currently in use by basketmakers and other artisans (Turok and Nabhan, eds. in prep.) Of the 350 or more edible wild plants in the Sonoran Desert proper, only a few such as saguaro, organpipe, prickly pear, chiltepines, acorns and mesquite have entered the marketplace within the last twenty-five years. The same is true for medicinal plants: perhaps only creosotebush, ratany, yerba mansa, jojoba, and damiana have been commercially marketed on any scale.

The major commercial non-timber harvests occurring in the region are for mesquite and ironwood (treated together in statistics for charcoal and fuelwood), jojoba, croton ("vara blanca") tomato stakes, cottonwood, bacanora and lechuguilla agaves, beargrass, damiana, oregano, candelilla, and chiltepines. Other forestry products include resins and barbasco. Table 8 provides a comparison of Baja California Norte and Sonora in terms of the number of "rural production units" for non-timber forest products in 1990.

Table 8:
Non-Timber Forest Harvests in Rural Production Units*, 1990

Harvestable Item	Sonora Total	Baja California Norte Total
Fuelwood	8,173	432
Candelilla Wax	43	8
Barbasco	52	9
Resins	109	**14**
Agaves	147	11
Other	106	52
Total Units of Harvest**	8,292	481

Source: INEGI 1995 b,c.
* Rural production units are groups of active or inactive land parcels for agriculture, ranching or forestry in the same municipio and managed under the same administrative body.
**State totals do not add up because multiple items can be harvested in any one Rural Production Unit.

Table 7: The most problematic or extensive exotic plants invading the Sonoran bioregion

Grasses
Giant carrizo reed *(Arundo donax)*
Red brome *(Bromus rubens)*
Bermuda grass *(Cynodon dactylon)*
Lehmann's lovegrass *(Eragrostis lehmanniana)*
Wild barley *(Hordeum murinum)*
Johnsongrass *(Sorghum helapenses)*
Buffelgrass *(Pennisetum ciliare)*
Fountaingrass *(Pennisetum setaceum)*
Mediterranean grass *(Schismus barbatus)*

Herbs
Russian thistle *(Saisola australis)*
Yellow star-thistle *(Centaurea melitensis)*
Sahara mustard *(Brassica tournefortii)*
Filaree *(Erodium cicutarium)*

Trees and Shrubs
Tree tobacco *(Nicotiana glauca)*
Salt cedar *(Tamarix ramosissima)*
Chilean mesquite *(Prosopis chilensis)*
Jerusalem thorn *(Parkinsonia aculeata)*

Table 9:
Commercial Wild Plant "Forestry" Extraction in Sonora in cubic meter rolls, except for jojoba (in metric tons)

Year	Cottonwood	Croton	Jojoba	Fuelwood	Charcoal
1983	3,869	5,370	100	3,642	79,074
1986	566	4,600	42	9,331	91,057
1989	2,256	8,554	35	3,640	76,740
1992	0	4,419	23	2,525	77,473

Source: Forestry Program, SARH, in Solis and Espericueleta (1997)

While it is difficult to gain from these statistics anything more than a sense of the magnitude of area where harvesting occurs, Table 9 highlights recently-available yield data for selected wild harvests for native plants being commercially harvested in Sonora.

The increase in exploitation of ironwood and mesquite in Sonora and Baja California since 1975 illustrates how quickly the slow-growing vegetative cover of the Sonoran Desert can be depleted, thereby depleting attendant biodiversity as well. More than 165 plant species use these two desert legumes as nurse plants, while numerous birds and mammals use these trees for nesting and roosting (Nabhan and Car 1994). However, since "mesquite charcoal" became a craze in United States restaurants in the early 1980's, both mesquite and ironwood have been harvested off the same lands, with as much as 15-40% of each mesquite charcoal bag consisting of ironwood prior to 1991. As a result, both trees were locally overexploited in Sonora and Baja California Sur, to the extent that ironwood received special federal protection status, and is now a priority species for sustainable use.

Despite recent closings of charcoal pits operated without permits, Solis and Espericueleta (1997) report that there is virtually no regeneration of mesquite or ironwood by seedlings in areas where they have been commercially exploited on permit. Ironwood, too, has failed to resprout from the base of its trunks wherever chainsaws have cut its wood close to the ground. Of the 1830 individual trees which they evaluated in areas where "mesquite cutting permits" were given, 19.7% of all trunks of ironwood and mesquite were cut, and roughly double that percentage were cut from the large size classes of trunk diameters. Tree height, basal area, and canopy cover were significantly reduced for both legume species, reducing their value as wildlife habitat. While not endangered species, ironwood and mesquite have been so significantly reduced as habitat that two of the field scientists surveyed felt that their overharvesting was the greatest threat to the region's biodiversity.

Mining

Mining not only affects the land surface where minerals are extracted; it has historically caused more pervasive air and water pollution, degrading entire watersheds. Even a 2-3 decade mining boom's use of water, and historically, of massive quantities of fuelwood, can dramatically change the composition of neighboring biotic communities for more than a century (Bahre 1991).

Sizeable mines have dramatically changed the ecology of land around Globe, Bisbee, San Xavier, Nacozari, Casa Grande, Ajo, San Manual/Mammoth, Cananea, Alamos, La Colorado, Quitovac, Bagdad, San Pelipe (B.C.), and Jerome. For a while it looked as though copper mining would become less and less lucrative in the region so that few new mines would ever open. However, claims have recently begun to be reactivated in the Santa Ritas, in the Grand Canyon area, and throughout much of northern Sonora.

The spread of mining in Sonora has become much more likely in the last 5 years. Under the influence of the World Bank, Mexico revised its mining law in 1992. The new law allows the National Institute of Ecology only 90 days to review applications for claims, does not require public participation, and eliminates restrictions on the size of explorations. The law even goes as far to say that mining "being of public utility, has preference over all other uses of land". A new foreign investment law permits 100 percent foreign investment in mines. Within the three years following the passage of the new mining law, over 70 foreign companies, mostly U.S. and Canadian established offices in Hermosillo, Sonora (Border Ecology Project 1995). As in the past, it is unlikely that Mexican environmental laws will be strictly enforced. For example, only 0.15% of the 200 million dollar World Bank loan that catalyzed Mexican mining reform was budgeted for environmental impact studies, standards preparation, and standards enforcement training for staff (McCafferty 1993). Given these policy changes and new technologies that allow mining of low-grade ore but cause considerable environmental harm, it is very probable that damage to vegetation, wildlife and local aquifers may be aggravated by these new mining developments. There are already indications of this in some of the largest new mines in Sonora (Border Ecology Project 1995).

"Much of the management of bighorn sheep populations has been at the local (i.e. mountain range) scale and not at the landscape (i.e. metapopulation) scale. Habitat within mountain ranges has been enhanced, but the projects should be conducted'... with the awareness that all areas used by mountain sheep may be essential for their long-term survival. For viable populations of mountain sheep to persist, more than 'mountain islands within desert seas' must be protected.'"

--Paul Krausman with quote by V.C. Bleich et al. 1990
The Influence of Scale on the Management of Desert Bighorn Sheep (1997)

Habitat Fragmentation and Desert Ungulates

Desert bighorn sheep and Sonoran pronghorn antelope once inhabited most of the Sonoran Desert bioregion. The pronghorn and bighorn of the Pinacate area of northwestern Sonora were once so plentiful as to seem limitless. However, the decades following the publication of William T. Hornaday's *Campfires on Desert and Lava* (1908) brought more and more hunting expeditions to the Pinecate area in search of desert trophies. Now the Sonoran pronghorn antelope *(Antilocapra americana sonoriensis)* population is extremely small with only 350 counted in 1993 (Arizona Game and Fish 1995). The desert bighorn *(Ovis canadensis mexicana, O.c. califomia, O.c. nelsonii, O.c. Cremnobates)* that once may have numbered several hundred thousand in the deserts of the southwestern United States numbered about 25,000 in 1991 (Krausman 1997). The total numbers of bighorn have increased some, but the remaining populations are often small and isolated from each other. Only 7 of 59 populations in Arizona and only 11 of 77 populations in California have more than 100 individuals (Krausman 1997). While there is some dispute over the minimum population size necessary to maintain a population of desert bighorn, the noted wildlife biologist Paul Krausman (1997) aptly said "it appears that most populations of desert bighorn sheep are at, below, or are approaching what many researchers would consider minimum viable population levels."

The particular suite of causes for the small populations of desert bighom depends on the area, but overall habitat fragmentation due to agriculture, livestock grazing (including its associated spread of disease to bighorns), road building, housing developments, and fire suppression is the major problem. Managing bighorn on a landscape scale so as to protect the connectivity between mountain ranges that are used for lambing and foraging is a critical addition to the traditional management that has occurred almost entirely at the local scale. While overhunting could be a problem for some small populations of desert bighom, the extraordinarily high trophy value of desert bighorn could be the best incentive for their protection. For example, their trophy value is driving efforts to sustainably hunt the bighorn population in the Sierra Bacha of Sonora.

"The Colorado River squawfish...is not an animal to which Americans have traditionally given much deference -- indeed, as late as the 1960s, the U.S. Fish and Wildlife Service viewed them as trash fish and tried to poison them out of existence. Still, today, the squawfish, like others, has a message. It is the same message as Phillip Fradkin's, who gave his book on the Colorado River such a straightforward title: *A River No More."*

-- Charles F. Wilkinson
Crossing the Next Meridian (1992)

Habitats, Processes and Species at Risk

The field experts which we consulted identified as being at risk many organisms, processes and habitats over and above those which have been formally placed on endangered species lists, on critical habitat inventories, and in red books. Species at risk (see Appendix 4) will be treated in further discussions of each subregion, but certain generalizations can be offered at this point:

1. Species vulnerable to competition from exotics are at risk, especially endemic species with poor dispersal abilities and specialized habitat requirements.

2. Species without adaptations to fire are at risk wherever exotic grass plantings and invasions have increased fire frequencies in their habitats.

Riparian and artesian spring habitats are at risk wherever aquifer overdraft occur.

4. Riparian obligate species are at risk; the Merriam's pocket

mouse of mesquite bosque/riparian scrubland habitat has already been extirpated, and -- riparian birds are rarer today than a half century ago (Johnson et al. 1987).

Wildlife corridors for Neotropical migrants and between-mountain range emigrants have become fragmented wherever urbanization, agricultural conversion, water impoundment and canal construction have become extensive.

Grasslands and their biota are at risk wherever the sowing of exotic species is coupled with fire suppression, chaining or intensive grazing during extended drought periods by high densities of livestock (Bock and Bock 1992; Bahre 1991)

7 Coastal thornscrub endemics are at risk because of land conversion to agriculture and livestock pasturage. The noted Sonoran Desert botanist, Richard Felger, said that coastal thornscrub is the single-most endangered major vegetation community in the Sonoran Desert, if not the world.

Coastal wetland, sand strand and mangrove scrub communities are at risk because of the narrowness of their habitat and the alarming rate of coastal urbanization, dredging, aquaculture, and recreational vehicle use.

Wildlife species now habituated to artificial water developments are at risk wherever introduced diseases have been transmitted.

10. Native fish, otter, beaver and other aquatics remain at risk wherever water impoundments, groundwater pumping and / or livestock grazing degrade their former habitats, favor exotic species and / or substantially fragment their populations.

11. Island endemics are at risk wherever introduced livestock, rats or cats have become established in their habitats.

12. Wherever carnivores have been depleted by hunting, trapping, poisoning or habitat fragmentation, herbivorous mammal populations may have increased to densities which radically change the composition of vegetation, the regenerative capacity of certain rare plants, and the periodicities of fire and other ecological processes.

Adequacy of Current Measures to Protect Biodiversity

Although there are many stresses on the region's biodiversity, we have witnessed more areas decreed as protected (as international, national or state biosphere reserves) in the last decade than any other decade in the history of the Sonoran bioregion (Figure 10). The establishment of the biosphere reserves of the Viscaino Desert, of the Pinacate and Gran Desierto, and of the Colorado River Delta and Upper Gulf, have been major conservation achievements in northern Mexico. The combined area of the Pinacate Biosphere Reserve, Organ Pipe National Monument and the Barry M. Goldwater Air Force Range is the largest contiguous, essentially unfragmented area under protective management in the lower 48 states or Mexico. In addition, there are more resource managers trained in conservation biology working on both sides of the border than there were a decade ago, and the distribution of field scientists between nations is more equitable than ever before. However, these conservation biologists hardly have had time since the most recent biosphere reserve decrees to assess the representativeness of current protected areas, and to set priorities for additional needed reserves.

The scientists responding to our surveys mentioned a great variety of land and sea reserves already established in the region which have, among other objectives, the goal of protecting biodiversity.

Today, about 1,500,000 hectares -- roughly 8% of the land surface of the state of Sonora — is under some protection. This figure does not consider reserves lost to city development and marine areas. So far, on the two biosphere reserves, the area of Sierra de los Ajos and the protected area near Alamos are operating formally as reserves, with permanent staffing at their headquarters. All other reserves do not have any (real) protection, but that given by the edicts and their [geographic] isolation." (Búrquez and Martinez-Yrizar, 1997)

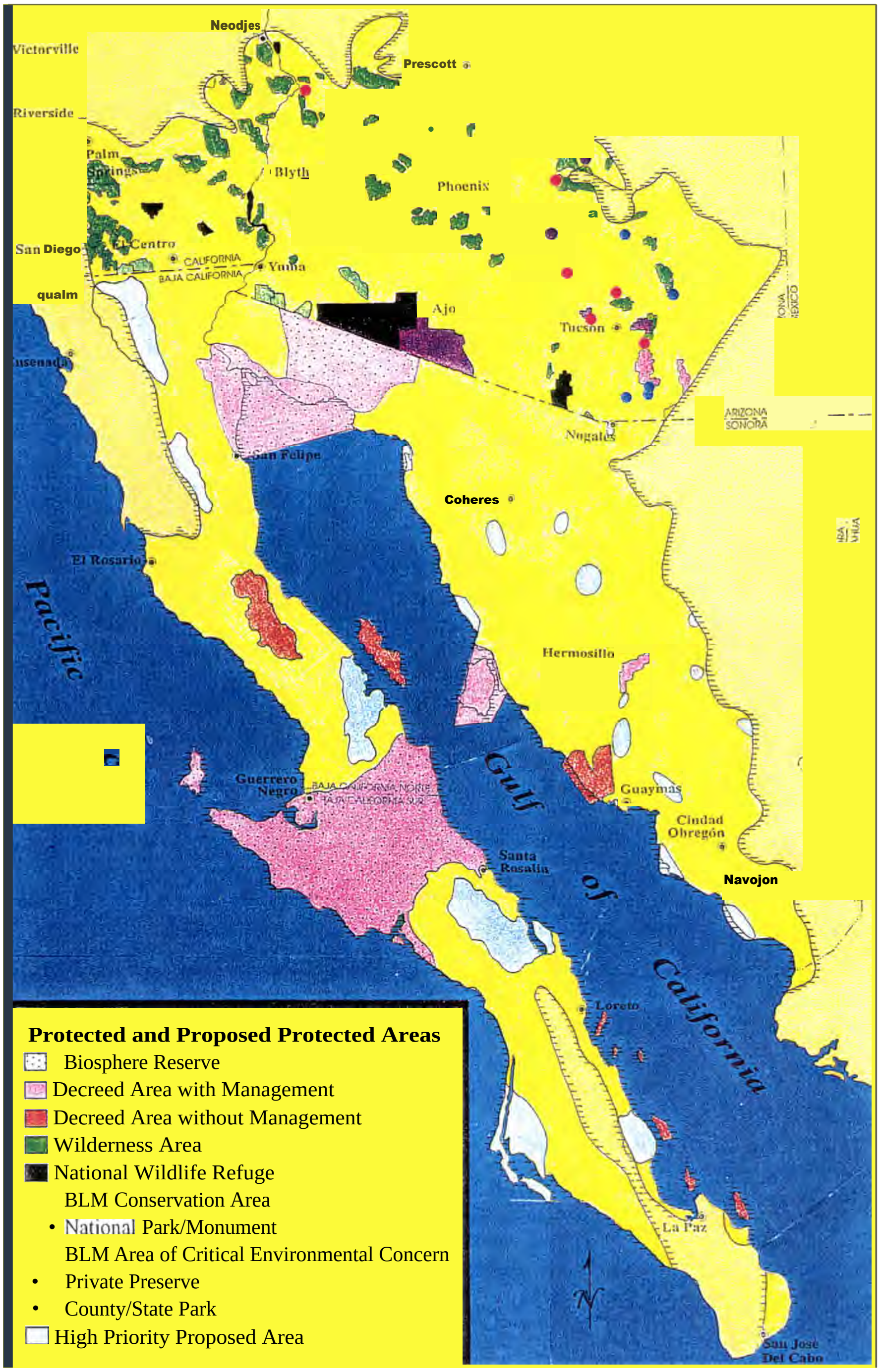
The Mexican reserves with at least some value to biodiversity conservation in the Sonoran bioregion are listed in Table 10a and the U.S. protected areas are in Table 10b.

"La conservación de la riqueza floristica exclusiva de la peninsula de Baja California no podra realizarse con el numero actual de areas protegidas. La planificación de futuras areas protegidas en la peninsula debera tomar en consideración los patrones de distribuciOn de estas especies endémicas, especialmente si se quiere preservar para las futuras generaciónes esta riqueza en endemismos."

"The conservation of the floristic richness found exclusively on the Baja California peninsula cannot be accomplished with the present number of protected areas. Planning of future protected areas on the peninsula ought to take into account the patterns of distribution of these endemics, especially if one wishes to preserve for future generations this rich center of endemism."

-- Jose Luis Villasenor and Thomas S. Elias
Conservación de Plantas en Peligro de Extinción: Diferentes Enfoques (1995)

Figure 10:
Protected and Proposed Protected Areas in the Sonoran Desert Bioregion



Note: Map does not include all areas proposed **for protection by surveyed scientists.**

Table 10a:
Protected Areas in the Mexican Portion of the Sonoran Desert Bioregion

Principal Biotic Community	Protected Area Name	Status	Area (ha)
Lower Colorado River Valley	El Pinacate and Gran Desierto de Altar	Biosphere Reserve	743,217
	Delta del Rio Colorado and Alto Golfo de California	Biosphere Reserve	934,756
Plains of Sonora	Centro Ecológico de Sonora	State Park [1 2]	—1,000
	Abelardo L. Rodriguez Reservoir / El Molinito	Ecological Conservation Zone [2]	28,000
Central Gulf Coast	Cajón del Diablo	Hunting Reserve	50,000
	Tiburon Island	Nature/wildlife Reserve	120,756
	Gulf of California Islands	Migratory Bird and Wildlife Refuge	418,910
	Sierra Bacha/Punta Cirio	Hunting Reserve, Private [6]	
Viscaino	El Vizcaino	Biosphere Reserve [6]	2,546,790
	Valle de los Cirios	Forest, Flora and Fuana Protection Zone[6]	--
Semidesert Grassland	Arroyo Los Nogales	Protected Zone	8,650
Other [5]	Sierra de Alamos and Arroyo Cuchujaqui	Forest, Flora and Fauna Protection Zone	96,100

Source: Alberto Búrquez and Angelina Martinez-Yrizar, Conservation and Landscape Transformation in Sonora, Mexico (1997)

1 Appropriated unofficially for rural and urban development.
2 State of Sonora Decree
3 Boundaries not formally designated
4 Biosphere Reserve as of 1989
5 Adjacent to Son. Desert Biomes
6 Protected areas noted by surveyed scientists

Table 10b:
Protected Areas in the United States Portion of the Sonoran Desert Bioregion

Principal Biotic Community	Protected Area Name	Status	Area (ha)
Arizona Upland	Buckskin Mountain	State Park	670
	Aubrey Peak	BLM Wilderness	6160
	Alamo Lake	State Park	2,257
	Arrastra Mountain	BLM Wilderness	51.920
	Tres Alamos	BLM Wilderness	3,320
	Swansea	BLM Wilderness	6.560
	Rawhide Mountains	BLM Wilderness	15,388
	Harcuver Mountains	BLM Wilderness	10,020
	Harquahala Mountains	BLM Wilderness	9,152
	Hummingbird Springs	BLM Wilderness	1,280
	Big Horn Mountains	BLM Wilderness	8,400
	Hassayampa River Canyon	BLM Wilderness	4,920
	Hells Canyon	BLM Wilderness	3,680
	Superstition	Forest Service Wilderness	63,903
	Tonto	National Monument	448
	Lost Dutchman	State Park	117
	Salome Wilderness	Forest Service Wilderness	7,580
	Salt River Canyon	Forest Service Wilderness	13,120
	White Canyon	BLM Wilderness	2,320
	Needles Eye	BLM Wilderness	3,504
	Pusch Ridge	Forest Service Wilderness	22,773
	Saguaro	National Park	33,430
	Rincon Mountains	Forest Service Wilderness	15,436
	Tucson Mountain Park	Pima County Park	6,800
	Catalina	State Park	2,204
	Picacho Peak	State Park	1,360
	Organ Pipe Cactus	National Monument	132,276
	Table Top	BLM Wilderness	13,760
	South Maricopa Mountains	BLM Wilderness	24,040
	North Maricopa Mountains	BLM Wilderness	25,280

Principal Biotic Community	Protected Area Name	Status	Area (ha)
Arizona Upland (cont'd)	Sierra Estrella	BLM Wilderness	5.760
	Woolsey Peak	BLM Wilderness	25.600
	Signal Mountain	BLM Wilderness	5.340
	New Water Mountains	BLM Wilderness	9.840
	Cactus Plain	BLM Wilderness Study Area	23.640
	Eagle Tail Mountains	BLM Wilderness	40,240
Lower Colorado River Valley	Gibralter Mountain	BLM Wilderness	7.516
	Trigo Mountains	BLM Wilderness	12.120
	Cibola	National Wildlife Refuge	6.907
	Imperial	National Wildlife Refuge	10,306
	Kofa	National Wildlife Refuge	266.160
	Salton Sea	National Wildlife Refuge	800
	Casa Grande Ruins	National Monument	472
	Muggins Mountains	BLM Wilderness	3,070
	Cabeza Prieta	National Wildlife Refuge	344.000
	Mohawk Mountains and Sand Dunes	BLM Area of Critical Environmental Concern	45.200
	Tinajas Altas	BLM Area of Critical Environmental Concern	21,200
	Gran Desierto Dunes and Yuma Dunes	BLM Area of Critical Environmental Concern	10,200
	Anza Borrego Desert	State Wilderness	
	Carrizo Gorge	BLM Wilderness	6,280
	Big Maria Mountains	BLM Wilderness	19,030
	Santa Rosa	BLM Wilderness	25,736
	Chemehuevi Mountains	BLM Wilderness	25,728
	Chuckwalla Mountains	BLM Wilderness	32,308
	Coyote Mountains	BLM Wilderness	6.800
	Fish Creek Mountains	BLM Wilderness	10,376
	Indian Pass	BLM Wilderness	13.542
	Jacumba	BLM Wilderness	13,468
	Little Chuckwalla Mountains	BLM Wilderness	11,952
	Little Picacho	BLM Wilderness	13,440
	Mecca Hills	BLM Wilderness	9,680

Principal Biotic Community	Protected Area Name	Status	Area (ha)
Lower Colorado River Valley (cont'd)	North Algodones Dunes	BLM Wilderness	12,896
	Orocopia Mountains	BLM Wilderness	16,294
	Palen / McCoy	BLM Wilderness	108,252
	Palo Verde Mountains	BLM Wilderness	12,924
	Picacho Peak	BLM Wilderness	3,080
	Rice Valley	BLM Wilderness	16,328
	Riverside Mountains	BLM Wilderness	8,952
	Sawtooth Mountains	BLM Wilderness	14.032
	Stepladder Mountains	BLM Wilderness	32,640
	Turtle Mountains	BLM Wilderness	57,800
	Whipple Mountains	BLM Wilderness	31.008
Semidesert Grassland	Muleshoe Ranch	Nature Conservancy Preserve and BLM Cooperative Management Area	19,248
	Empire Cienega	BLM Natural Resource Conservation Area	28,000
	Research Ranch	Audubon Society	3,200
	Canelo Hills Cienega	Nature Conservancy Preserve	140
	Buenos Aires	National Wildlife Refuge	47,200
Riparian Deciduous Forests	San Pedro	BLM Riparian National Conservation Area	23,200
	San Pedro River	Nature Conservancy Preserve	328
	Patagonia-Sonoita Creek	Nature Conservancy Preserve	300
	Cienega Creek	Pima County Natural Preserve	1.592
	Aravaipa Canyon	BLM Wilderness Area / Nature Conservancy Preserve	24,582
	Hassayampa River Preserve	Nature Conservancy Preserve	140
	Bill Williams River	National Wildlife Refuge	2,442
	Redfield Canyon	BLM Wilderness	2,640

* While these areas are divided by principal biotic community, some will obviously include the other community types.

Additional areas of the Sonoran Desert and adjacent Gulf of California have been proposed for protection by the Comisión Nacional para el Conocimiento y Uso de la Biodiversidad (CONABIO), the Centro Ecológico de Sonora, other NGOs, and academic institutions. These areas (Table 11) occur within coastal thornscrub, foothills thornscrub, and riparian areas. They harbor large herds of bighom sheep (Sierra El Viejo), and the last natural population of Masked Bobwhite Quail (Rancho El Carrizo) (Búrquez and Martínez-Yrízar 1997). An effort to create a Biosphere Reserve for all of the San Pedro Mártir range in Baja California Norte has also been advanced.

Table 11:
Proposed Sonoran Desert Protected Areas in Sonora, Mexico.

Principal Biotic Community	Proposed **Area**	**Other Biotic Communities**
Lower Colorado River Valley	Trincheras	Arizona Upland, Gulf Coast
	Bahia San Jorge	Coastal Wetlands
Plains of Sonora	Cerro Agualurca / Centro Ecológico de Sonora	Foothills Thornscrub
	El Carrizo	--
Central Gulf Coast	Sierra El Viejo	Lower Colorado River Valley
	Estero El Soldado	Coastal Wetlands
	Bahía de Lobos	Coastal Wetlands
Foothills / Coastal Thornscrub	Mazocahui/Puerto del Sol	Riparian Tropical Deciduous Forest
	Sierra Mazatan	Oak Woodlands
	Soyopa/Sahuaripa	Riparian Tropical Deciduous Forest
	San Javier/Tepoca	Riparian Tropical Deciduous Forest
	Sierra Libre	Plains of Sonora Tropical Deciduous Forest
	Sierra Bacatete	Tropical Deciduous Forest
	Las Bocas	Coastal Wetlands
Semidesert Grassland	Sierra La Mariquita and Rio San Pedro	Oak-Pine Forests Highland Wetlands

Source: Alberto Búrquez and Angelina Martínez-Yrízar, Conservation and Landscape Transformation in Sonora, Mexico (1997)

Of course, there are many other areas which are still underprotected, either because they fall outside of conservation-oriented reserves, or because they are reserves "on paper" only. Table 12 summarizes responses to questions regarding the adequacy of formally protected areas and their management to protect biodiversity.

The mere fact that a protected area is established and "managed" does not necessarily mean that all activities are halted which potentially deplete biodiversity. When asked if protected area managers still allow such activities, twenty-five answered yes, nine answered no, seventeen answered that such harmful activities now occur less than before, and five had no response.

The reality that many of northern Mexico's protected areas are less than ten years old would suggest that not all activities harmful to biodiversity ceased on the day(s) that these areas were formally decreed. However, it is a hopeful sign that already, over one quarter of the respondents see fewer harmful activities occurring within protected areas today than "before" -- before, in this case, meaning either before their decree, or for early-established parks and wildlife refuges, before 1975.

Table 12:
Adequacy of Formally Protected Areas to Protect Biodiversity in the Sonoran Desert Bioregion

	Adequacy of the Representativeness of Current Protected Areas			Adequacy of the Current Management of Habitats		
	Good	Poor	Mixed	Good	Poor	Mixed
Arizona Upland	1	10	2	3	0	9
Plains of Sonora	0	1	1	0	1	1
Viscaino/Magdalena	3	0	0	0	2	1
Gulf Coast	0	2	2	0	2	3
Lower Colorado	6	11	0	5	5	7
Foothills Thornscrub	0	1	0	0	1	0
Coastal Thornscrub	0	4	0	0	3	1
Semidesert Grassland	0	6	0	3	3	2
Riparian Forest	0	10	0	1	5	5
Palm Oasis	1	2	0	1	1	1
Riparian Scrub	0	0	0	0	0	1
Maritime Strand						
Mangrove Scrub	0	2	0	0	2	0
Islands	2	0	0	0	1	1

In a similar vein, we asked field scientists which threats to biodiversity are beginning to be adequately addressed. In their analysis of trends in different subregions, seven of the scientists felt that grazing was finally being addressed sufficiently in discussions between resource managers, ranchers and scientists; five felt that the impacts of ecotourism (eg., whale watching) and outdoor recreation were being sufficiently dealt with at the local level; and two felt that urban growth and residential land uses were being discussed fairly in certain localities. However, twenty-two of the scientists felt that no threat is being adequately addressed anywhere in the Sonoran biome where they have worked. Another scientist lamented that the current species-by-species approach to biodiversity conservation is providing only stop-gap solutions, some of which may be counterproductive over the long run.

We requested that scientists alert us to threats that have become more severe in each subregion and which species are most vulnerable to these and other threats. We also asked them to name areas undergoing rapid environmental change that could lead to further declines in diversity. Finally, we requested the nomination of areas for formal protection, including priority areas (Table 13). Table 13 is certainly not complete as it is a function of the collective knowledge of the scientists that responded to the survey. For instance, the conservation priorities cited by individual scientists should be revisted in light of the whole list of areas meriting protection. It is however, a good foundation for further development of a conservation portfolio and listing the principle threats that need to be addressed for successful biodiversity conservation.

While we need to attain protection of the priority areas of high biodiversity listed in this report and other sources, we must remember the critical role that the large expanses of BLM and Native American land in the U.S. can play in the maintenance and restoration of landscape connectivity. For example, with 42% of Arizona's land under federal control and 27% under Native American control, successful landscape scale conservation must seek effective, cooperative means to improve conservation measures on these lands. While the federal land ownership situation in northern Mexico may be different, the very presence of U.S. federal lands along the border could provide some leverage of binational support for biodiversity protection.

"Let us assume that the next stage in the West will not be a mere continuation of the present. What then might we expect? What should we work for? Now no one could reliably predict a detailed blueprint for a posthydraulic society.. .But one could confidently say that there are certain general strategies the West is going to have to pursue if it wants to find its way toward a more open, free, and democratic society. Those strategies must begin with a new relation to nature and a new technics."

--Donald Worster
Rivers of Empire (1985)

Emerging Conservation Needs and Priorities

When field experts conversant with the Sonoran bioregion were asked what they felt should be the number one priority for conservation, they responded in a variety of ways, noting policy issues, research and education needs, action strategies, as well as earmarking species, habitats or landscapes in critical need of conservation. We have organized their suggestions topically, and list their comments within each topic in no particular (weighted) order.

1. **Research Needs** - Among the research needs cited as conservation priorities were the:

   A. Realize biogeographic studies to discern regional patterns of biodiversity.
   B. Determine areas of high diversity of invertebrates, and compare those with areas identified as high in species richness of plants and vertebrates.
   C. Identify through banding and capture-recapture the most frequently used corridors for nectar-feeding bats, hummingbirds, monarchs and other pollinators at risk.
   D. Identify areas of high endemism across taxonomic groups.
   E. Determine which habitat types have less than 8% of the area protected.

Table 13: Worsening Threats, Vulnerable Species and Areas and Areas Meriting Protection in tht Subregions of the Sonoran Desert Bioregion
(* indicates a conservation priority)

Arizona U lands

Threats that are becoming more severe	Vulnerable Species	Vulnerable Areas	Areas that Merit Protection
- Urbanization - Habitat fragmentation - Bankside vegetation clearing - Increased erosion - Native wash channelization - Invasion by exotic species - Groundwater depletion	- Sonoran Purple Martins, owls, and other cavity nesters - Ferruginous Pygmy Owl - Spadefoots and other toads - Organpipe shovelnose snake - Western diamondback rattlesnake - Tucson shovelnose snake - Sidewinder - Long-tailed brush lizard - Ironwood - Hohokam & Delameter's agaves - Black grama and Plains lovegrass - Virtually all of the native perennial grasses	- Tucson basin (incl. south side of Tortolita Mountains, Rincon Valley, Tanque Verde Valley, Oro Valley) - Salt River basin - Verde Valley - Tonto basin - Avra Valley - Gila basin - Bosque-form mesquite forests	- Tonto Creek - Baboquivari Canyon - Verde Valley crucifixion thorn-covered ridges

Lower Colorado River Valley

Threats that are becoming more severe	Vulnerable Species	Vulnerable Areas	Areas that Merit Protection
- Urbanization especially in the Yuma, Phoenix, & coastal areas - Land clearing for agriculture - Habitat fragmentation - Overgrazing by livestock - Water manipulation - Exotic species- mustards, tamarisks, etc - Potential for fire due to exotic herbs - Tourism - Off-road vehicles, especially in dunes - Camper-trailers on BLM land - Ironwood harvesting - Poaching - Mining in Sonora - Increased sanity and selenium levels - Mega-dumps in the desert - Human occupancy - Exaggerated carrying capacity through import of resources	- Sonoran pronghorn antelope - Flat-tailed horned lizard - Saltbush/wolfberry flats - Palo verde nurse plant associates - Ironwood nurse plant associates - Saguaro - Both nightblooming cereus cacti - Acuna cactus - Barrel cactus - Senita - Sonoran panicgrass - Ocotillo - Cardon - Mesquite - Sandfood - Many decomposers and pollinators	- Davis dam south to U.S.-Mexico border - Yuma Mesa - White Tank Mountain area - Lower Colorado River wetlands - Sierra Estrella - Santans Mountains - Sacaton Mountains - Puerto Peñasco - Mexicali Valley - Tinajas Altas - Cottonwood / willow forest	- Quitovac* - Pozo Nuevo* - Tinajas Altas* - Laguna Percebu* - Punta Estrella* - Sierra de Juarez* - Laguna Salada* - Algodones Dunes* - Sierra Estrella - White Tanks, Yuma Proving Ground - Wellton Slough / Tacna Marsh - Sierra San Felipe and Matomi - Alto Golfo - Sand dunes near Laguna Prieta - Sand plains - Granitic Ranges - NE Puerto Peñasco

Table 13 (continued)
(* indicates a conservation priority)

Plains of Sonora

Threats that are becoming more severe	Vulnerable Species	Vulnerable Areas	Areas that Merit Protection
- Land clearing - Mine expansion - Buffelgrass planting - Urbanization	- All hardwood trees but especially ironwood - Two night-blooming cacti - Northernmost palm populations - Endemic grasses - Blue yuccas - Hohokam agaves		- Cananea-San Pedro* - Sierra del Tigre* - Sierra San Javier - Sierra Mazatán

Central Gulf Coast of Sonora

Threats that are becoming more severe	Vulnerable Species	Vulnerable Areas	Areas that Merit Protection
- Urbanization - Tourism - Recreation - Resort building - Clearing for agriculture (especially south of Kino Bay) - Increased cattle grazing in unsuitable areas (e.g. near Pto. Lobos) - Exotic species- especially buffelgrass - Ironwood / fuelwood cutting	- Ospreys - Chuckwallas - Ironwood - Desert tortoises - Boojums - Endemic cotton - Figs	- Coastline north of San Carlos	- Sierra de la Libertad* - Sierra Seri* - Laguna de la Cruz* - Sierra del Viejo* - Bahia de San Jorge* - Cajon del Diablo* - Lobos region and areas between San Carlos and Ensenada - Chica Venetia - Desemboque-San Carlos coastline and interior - Sierra Libre

Viscaino/Magdalena Plain

Threats that are becoming more severe	Vulnerable Species	Vulnerable Areas	Areas that Merit Protection
- Groundwater pumping - Agriculture in the south - Illegal collecting - Poorly managed use of yuccas	- Pronghorn Antelope - Boojums - Palms - Yuccas - Cardons - Endemic brittlebush	- Sierra San Francisco - Viscaino plain - Areas of Bahia de los Angeles and El Rosario - Guerrero Negro-Vizcaino-San Ignacio	- Sierra El Mechudo* - Planicies de Magdalena* - Sierra La Giganta* - Bahia de Concepcion* - Valle de los Cirios* - Vizcaino Guerrero area* - Sierra Guadalupe*

Table 13 (continued)
(* indicates a conservation priority)

Foothills of Sonora Thornscrub/ Coastal Thornscrub

Threats that are becoming more severe	Vulnerable Species	Vulnerable Areas	Areas that Merit Protection
- Livestock overgrazing - Clearing for pasture - Clearing for agriculture - Exotic species- especially buffelgrass - Fuelwood cutting; charcoal manufacturing - Ornamental plant collecting	- Brasilwood - Ironwood - Mesquite - Endemic grasses - Barrel Cacti	- Rio Yaqui to south of the Rio Fuerte - Mazatan Region	- Sierra Bacatete* - Cañon de Chinipas* - San Javier - Tepoca - El Palmal* - Sahuaripa - Bacanora* - Mazatan* - Soyopa* - Cruz del Diablo* - Mazocahui - Puerta del Sol* - Las Bocas* - Sierra Libre - Navojoa-Agiabambo Pitahaya forest - Sierra de Barobampo (Sinaloa)

Cape Region Thornscrub

Threats that are becoming more severe	Vulnerable Species	Vulnerable Areas	Areas that Merit Protection
	- All endemics		- Sierra la Laguna*

Semidesert Grassland

Threats that are becoming more severe	Vulnerable Species	Vulnerable Areas	Areas that Merit Protection
- Habitat fragmentation due to ranch sub-division - Livestock grazing - Recreation	- Pronghorn antelope - Masked bobwhite quail - Plains leopard frog - Tarahumara frog - Yellow mud turtle - Massasauga - Black grama - Tobosa - Pima pineapple cactus	- Sulphur Springs Valley - Oracle Junction area - Altar Valley - Santa Cruz Valley - Sonoita-Elgin grasslands - Sierra Vista area	- Tumacacori Peak / Rock Corral Canyon* - EE Ranch (near McNeal, AZ) and tobosa grass stands to south - Babocomari Ranch and adjacent lands - Santa Rita Experimental Range - Greater Altar Valley-Empire Ranch - San Rafael Valley

Table 13 (continued)
(* indicates a conservation priority)

Riparian Deciduous Forests

Threats that are becoming more severe	Vulnerable Species	Vulnerable Areas	Areas that Merit Protection
- Urbanization - Livestock grazing - Groundwater mining, water impoundment - Exotic fish, frogs, and crayfish - Tamarisk - Bermuda grass - Africanized bees - Recreational vehicle use - Recreation development	- Abert's Towhee - Cactus Ferruginous Pygmy Owl - Elf Owl - Zone-tailed hawk - Black-capped gratcatcher - Yellow-billed cuckoo - Buff collared nightjar - Native fishes and all native ranid frogs - Double-leaved cottonwood - Large canopy mesquites - Fremont cottonwood	- Middle San Pedro (Hereford to Benson) - Peck Canyon [Atascosa Mtns.] - California Gulch [Pajarito Mtns.] - Tucson basin - Chino Canyon - Brown Canyon - Baja California - Phoenix metropolitan area and adjacent communities	- Cienagas south of Nogales north of Imuris* - Imuris gallery forests* - Tubac gallery forests* - Some major rivers in Sonora - Verde River - Hassayampa, expanded protection - Lower San Pedro (Pomerene to Winkelman) - Gila River - Colorado River - Upper Tanque Verde Wash - Pockets along middle Rillito in Tucson - Chino Canyon of Santa Ritas Mountains - California Gulch of Atascosa Mountains - Santa Cruz River - Nogales to Rio Rico - Rio Fuerte

Palm Oasis Forest/Woodland

Threats that are becoming more severe	Vulnerable Species	Vulnerable Areas	Areas that Merit Protection
- Buffelgrass / Fires - Development / habitat destruction	- Sabal and Brahea palms - Blue yuccas (hesperaloe) - Washingtonia palms	- Cañon Guadalupe, BCN - Cañon Tajo, BCN - Ures - Soyopa canyons - Nacapule Canyon - San Carlos area	- Magdalena Palm Canyon* - Nacapule Canyon* - Sierra San Pedro Martir

Riparian Scrubland/Mesquite Bosque

Threats that are becoming more severe	Vulnerable Species	Vulnerable Areas	Areas that Merit Protection
- Groundwater mining - Exotic grasses - Fuelwood cutting - Land clearing - Subsidence	- Merriam's pocket mouse - Mesquite	- San Xavier / Pla. de Agua	- Cascabel - Black Mountain / Pla. de Agua

Table 13 (continued)
(* indicates a conservation priority)

Maritime Strand

Threats that are becoming more severe	Vulnerable Species	Vulnerable Areas	Areas that Merit Protection
- Coastal development	- Sandfood - Beach nesting birds	- Beaches north of Guaymas - El Golfo de Santa Clara - Bahia de Los Angeles	- Everything between Kino and Guaymas - Salinas

Man rove Scrub

Threats that are becoming more severe	Vulnerable Species	Vulnerable Areas	Areas that Merit Protection
- De-salting of river estuaries (Rios Mayo and Yaqui) - Marina / harbor development	- Red, black and white mangrove - Invertebrate nursery grounds - Migratory birds	- Estero Soldado - Bahia de la Cruz	- Estero Soldado* - Punta Sargento - Punta Santa Rosa - Estero Lobos - Bahia de la Cruz - Rio Mayo delta - Rio Yaqui delta - Topolohampo Lagoon System (Sinaloa)

Islands

Threats that are becoming more severe	Vulnerable Species	Vulnerable Areas	Areas that Merit Protection
- Exotic species - Recreation - Fishing villages - Mining	- Angel de la Guardia pocket mice - San Esteban chuckwalla - Desert tortoise - San Esteban Agave - All other endemics	- Beaches on San Esteban - Alcatraz (Kino Bay)	- Isla San Marcos* - Isla Alcatraz* - All islands' tourist stops

2. **Educational needs -** Among the educational needs cited as conservation priorities were the need to:

A. Increase or redirect public understanding so that laymen appreciate the dynamics and constraints of arid ecosystems.
B. Synthesize and disseminate basic knowledge about the value of desert ecosystems to build a larger public constituency.
C. Train indigenous residents of remote rural areas in techniques for surveying, monitoring, restoring and conserving endemics and locally endangered species.
D. Train and build capacity of more "rangers" and environmental educators in all Mexican protected areas.

3. **Need to shift society's consumption patterns, behaviors and perceptions -** Among the behaviors, consumption patterns and perceptions seen as priorities for conservation education were the need to:

A. Increase family planning to control human population growth.
B. Shift away from social and economic systems that reward consumptive behaviors and short-term gain while damaging natural systems.
C. Amend patterns of consumption to dramatically reduce the occupancy footprint.
D. Foster conservation through promoting sustainable development and less consumptive lifestyles or land uses.
E. Alter human values so that we are truly responsible for the real implications of our actions.
F. Reward conservation-oriented residents and businesses by creating disincentives for consumptive behaviors that create life risks.
Seek alternative economic activities for communities or families formerly dependent on extractive activities, particularly in and around protected areas.
H. [redacted]elop additional collaborations between field scientists, conservationists and progressive ranchers to purchase or place deed restrictions on land threatened with subdivision.

"Desert residents are using more water than is being replenished into the region's water supply accounts. If this 'deficit spending' continues, the available non-renewable supplies of water will eventually be depleted. We owe it to future generations to carefully consider the choices we make today in where and how we use our precious desert waters... [While] individual action in conserving water is critical, ...it is not enough. We also need to support conservation efforts on a larger scale. For example, working together we can raise awareness about the critical importance of riparian habitats to the future health of Sonoran Desert ecosystems [from] promoting laws and regulations that protect the existing flows of streams and washes, to championing planning and zoning regulations that preserve sensitive riparian areas and native vegetation."

– Nancy Laney
Desert Waters: From Ancient Aquifers to Modern Demands (1997)

Foster reciprocal exchange of technical information on biodiversity and threats across the international border, and between resident cultures of the region.

Land/water management and resource protection policies - Among the land, water and resource management policies seen as conservation priorities were the need to:

A Halt or mitigate all barriers which are fragmenting corridors and critical habitats required by native migratory and resident species.

Establish zoning to control (urban) development with buffers of 16 km. width around all protected areas especially where wildlands include natural corridors such as rivers and washes.

Limit growth of residential and commercial occupancy to within natural carrying capacity.

Preserve largest tracts of remaining habitat rich in unique biota by limiting intrusions into them, including urban sprawl.

E. [redacted]date the preservation of a certain portion of natural habitats remaining in new residential developments and industrial parks.

Give priority protection to areas which have artesian flows of water into oases, cienegas or other wetlands, and to springs/seeps of all kinds.

Ensure protection of coastal lagoons and estuaries as spawning and nursery grounds.

Establish cross-boundary chains of reserves along riparian and "nectar" corridors used by migratory birds and wide-ranging mammals.

Establish incentives to keep current farmland from being subdivided for urban or suburban development, and give tax breaks for pesticide-free crop production.

J. Place strict controls on the introduction and planting of exotics.

K. Protect lowland basins between mountain ranges as migratory corridors.

"Probably more than 5% of [North American] lands and waters are overrun by the most aggressive of the more than 2000 species of exotic or alien plants [including] nearly 200 of approximately 250 National Park Service units [and] 60% of The Nature Conservancy's preserves. [We must] support proposals by resource managers to address species invasions. Proposals to combat weeds or, especially, introduced mammals, often generate opposition from people who do not understand the environmental cost paid for allowing the newcomer to remain... Remember we have forfeited the 'easy' solutions when we failed to halt these invaders ...or when we first became aware of their presence. Now we have to face the need to use more drastic measures."

-- Faith Thompson Campbell
"While mapping wildlands, don't forget the aliens," Wild Earth (1997)

Land, water and vegetation management practices - Among the on-ground management practices recommended were the need to:

A. Reduce the maximum number of cows (cattle units) allowed per grazing allotment.

B. Burn grasslands regularly.

C. Establish a regional ecological restoration plan and restore riparian habitats to their former structure.

D. Prohibit wholesale clearing of native vegetation for exotic pasture grass planting for livestock.

E. Retain and protect willows and cottonwoods recruited after catastrophic floods.

F. Keep cattle out of riparian areas during periods of willow and cottonwood seedling establishment.

G. Limit groundwater extraction where it is greater than annual recharge rates.

H. Eliminate dams and other artificial water impoundments that have silted-in wherever there is a capacity for streams to flow uninterrupted again.

Limit flood control and artificial channelization engineering schemes to only those areas where human welfare is directly and frequently affected.

J. Prohibit plantings of exotic species or ecotypes along highways and along irrigation canals.

K. Limit any cutting of mesquite or ironwood to pruning by handaxes, and avoid any chainsawing of these trees below 1 meter aboveground.

L. Manage irrigation tailwaters and primary-treated sewage to restore the wetlands of the Colorado River delta.

What's Next?

It is clear that there is much reported by the field scientists surveyed here that bears reflection, discussion, debate and action. It is also abundantly evident that scientists' attention is not spread evenly across the biotic communities of the bioregion -- some habitats such as mangrove swamps, riparian gallery forests and semidesert grasslands south of the U.S./Mexico border are irregularly visited by biologists and poorly monitored relative to their significance. The status of nocturnal animals -- from long-tongued bats to jaguars to hawkmoths -- are poorly known compared to that of day-timers. Similarly, the rare herbaceous plants which episodically emerge and flower during the heat of the summer are hardly known compared to winter wildflowers. And despite the fact that the Sonoran Desert is an arid horseshoe rimming a hypersaline sea, both its marine life and island life are underappreciated by desert ecologists with regard to their contributions to biodiversity. Few scientists link the effects in desert watersheds to this marine biodiversity.

There are four problems identified as the emerging issues which still require considerable discussion if they are to be resolved for the region:

1. The need for urban planning and agricultural lands restoration to allow for continuous corridors for wildlife passage through urban areas where their movements are currently blocked.
2. The need for guaranteeing river flow into coastal lagoons and estuaries of the Gulf of California (including the Colorado River delta) to ensure nutrient and fresh water flow essential to nursery grounds for invertebrates, fish, and waterfowl.
3. The need to redirect the management of critical habitats in state parks, wildlife refuges and national monuments away from recreation or protection of single species or features; focus needs to shift to overall biodiversity and the integrity of habitats so that

interactions between species and natural communities persist.

4. [redacted] need for planning that reduces impacts of coastal and island development in the Gulf of California region where endemism is the highest.

What is most obvious from this report is that the Sonoran Desert has suffered from a dramatic intensification of multiple threats and pressures over the last fifty to twenty-five years. No one organization, no single strategy, can possibly deal with the magnitude and diversity of these threats on both sides of the border. It is time for conservation biologists and activists to carefully assess where each of their efforts can have the most effect on protecting biodiversity, and develop a comprehensive plan of complementary actions to save this desert region's remaining biological riches. Without such a coordinated effort across borders, and across habitat types, we will enter the next millennium incapable of mobilizing sufficient support to safeguard a representative sample of the region's biodiversity against the myriad stresses now affecting it.

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Appendix 1
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Appendix 2
State of the Desert Biome Surveys

STATE OF THE DESERT BIOME
Sonoran Desert Bioregion Mini-survey

Please return by October 10, 1997

Your name: E-mail: ______________________

Affiliation/address: ______________________

Years working in the desert: ______________________

Rate the ten most significant threats to biodiversity in the Sonoran Desert region with the gravest threat ranked 10 and the least significant threat ranked 1. Do not use any number twice. Leave negligible threats blank and feel free to add your own threats ranked among the ten.

_______ In-migration of people to reside in the region

_______ Population growth (increased fecundity/delayed mortality) of current residents

_______ Over-consumption of resources/land by the elite

_______ Recreational impact of residents and tourists on fragile lands

_______ Lack of planning/zoning/enforcement to reduce impact of growth

_______ Mining, its pollution and its associated use of water

_______ Surface water impoundment and/or diversion

_______ Aquifer mining and lowering of groundwater level

_______ Over- or inappropriate grazing by livestock

_______ Planting of exotic grasses and competition with natives

_______ Invasiveness/competition by accidentally-released organisms

_______ Urbanization and habitat fragmentation

_______ Conversion of wildland to farming and/or field abandonment

_______ Predator control

_______ Overexploitation of valuable wild plants (eg. ironwood)

_______ Hunting, fishing and animal overharvesting

_______ Non-target exposure to pesticides and other toxic chemicals

_______ OTHER: ______________________

What should be the number one conservation priority for the region?

What species are most vulnerable to extirpation here?

STATE OF THE DESERT BIOME
Sonoran Desert BioRegion

Please return by October 17, 1997

Your name: ______________________ Date: __________

Affiliation: ______________________

Address: ______________________

E-mail: ______________________

Please fill out responses on this page for JUST ONE of the following Sonoran Desert subregions of adjacent biot communities. Make additional copies for each separate subregion. MARK WHICH ONE WITH A BELOW:

❑ **Arizona Uplands**
❑ **Plains of Sonora**
LI **Viscaino**
❑ **Central Gulf Coast**
❑ **Lower Colorado River Valley**
❑ **Foothills of Sonora Thornscrub/Coastal Thornscrub**
❑ **Semidesert Grassland**
❑ **Riparian Deciduous Forests**
❑ **Palm Oasis Forest/Woodland**
❑ **Riparian Scrubland**
❑ **Maritime Strand**
❑ **Mangrove Scrub**
❑ **Island (name):**

How long have you worked in this area/habitat? ________ What years? __________

For the period since 1975 (or the time since then when you've worked there) how would you assess the following issues:

Invasive Species:

Have they increased dramatically in coverage? ❑ Yes No
Are they. . . Stable ❑ Negligible ❑ Declining
Are there adequate measures to control them? ❑ Yes ❑ No

Urbanization:

Has it increased dramatically? O Yes ❑ No
Is it . . . ❑ Stable ❑ Negligible ❑ Declining
Are their adequate planning measures to manage it? ❑ Yes ❑ No

MiningNegetation Clearing:

Has it increased dramatically? ❑ Yes ❑ No
Is it . . ❑ Stable ❑ Negligible ❑ Declining

Livestock Grazing:

Are current practices causing longterm biodiversity depletion? CI Yes O No
Are practices. . . ❑ Improving ❑ Radically Changing LI Remaining Stable

Hunting/Predator Control and Tree, Cactus or Agave Cutting/Extractive Harvests:

Have they increased dramatically? ❑ Yes D No

Are they . . . ❑ Decreasing ❑ Stabilizing ❑ Better Regulated

Wildlands Habitat Fragmentation:

Has it increased dramatically? ❑ Yes ❑ No

Is it . . . ❑ Stable ❑ Neglible ❑ Declining

Are there adequate planning measures to control it? Yes ❑ No

Water Damming and Diversion/Aquifer Pumping:

Is water less available to native vegetation and wildlife? ❑ Yes LiNo

Has surface water availability ❑ Stabilized ❑ Improved

Is the aquifer overexploited? ❑ Yes JJNo

Has outdoor recreation increased dramatically? ❑ Yes D No

Is it . . . ❑ Stable ❑ Neglible ❑ Decreasing

Have protected areas been established in this subregion? Yes ❑ No

Which ones?

Are others proposed?

Do current protected areas adequately represent the biodiversity of the subregion? Yes DN0

If no, what is missing?

Are current protected areas there adequately managing habitats to protect/recover biodiversity?

❑ Yes ❑ No ❑ **Mixed**

Are protected area managers allowing activities which continue to deplete biodiversity?

❑ Yes ❑ No ❑ Currently less than before

Are there other areas which merit formal protection? (name):

What species should be considered the keystone or focal species for this area?(name):

Which are being threatened or dramatically depleted? (name):

What threats have you seen become more severe in recent years?

What threats do you believe are being adequately addressed?

Which specific basins or ranges have been undergoing very rapid change?

What should be the number one priority for conservation in this area?

List names/addresses of any particularly knowledgeable people about the biota of this area:

Appendix 3
Focal Species/Keystone Species Suggested by the Surveyed Scientists:

Arizona Uplands - Elf Owl - Sonoran Purple Martin - Gilded Flicker - Bobcat - Desert Bighorn Sheep - Great Plains Toad - Couch's Spade foot - All toad species - Woodrats - Kangaroo rats - Merriams pocketmouse - All perennial grasses - Blue paloverde - Foothills paloverde - Saguaro - Ironwood - Prickly Pears - Delameter agave - Hohokam agave - Crucifixion thorns - Thomberg fishhook cactus	**Lower Colorado River Valley** - Flat-tailed homed lizard - Fringe-toed lizard - Sonoran Pronghom - Desert rodents - Lesser longnose bat - Creosote bush - White bursage - Palo verde - Ironwood - Honey mesquito - Ocotillo - Triteliopsis lily - Acuffa cactus - Washingtonia palms - Termites - Pollinators	**Semidesert Grassland** - Baird's Sparrow - Botteri's Sparrow - Masked bobwhite quail - Hook-nosed snakes - Hognose snake - Ground snake - Green toad - Little striped whiptail - Pronghom antelope - Antelope jackrabbit - Lesser longnosed bat - Pygmy mouse - Cottonrat - Black grama and tobosa grasses - Pima pineapple cactus - Little flower agave - Decomposers - Dung beetles - Grasshoppers - Termites	**Riparian Deciduous Forests** - Gray hawk - Zone-tailed hawk - Yellow-billed cuckoo - Elf Owl - Cactus ferruginous pygmy owl - Abert's Towhee - Black-capped gnatcatcher - Buff-collared nightjar - Summer tanager - Southwestern willow flycatcher - Caracara - Prairie falcon and other large predatory birds - Native fishes - Native ranid frogs - Beaver - Jaguar and all other large mammals - Mesquites - Willows - Cottonwoods - Gray Therian - Hackberries - Catclaw - Sycamore	**Viscaino** - Bobcat - Sonoran Pronghom - Bighom sheep - All cacti - Boojums - Cardon - Palms - Limberbush - Schidigera - All root succulents - Endemic brittlebush - Agaves
Magdalena Plain - All endemics	**Foothills of Sonora Thornscrub/ Coastal Thornscrub** - Sonoran pronghom - Organpipe - Tree morning-glory - Ironwood - Mesquite - Tree ocotillo	**Cape Region Thornscrub** - *All endemics*	**Plains of Sonora** - Ironwood - Organ pipe cactus - Tree morning-glory	**Gulf Coast of Sonora** - San Esteban chuckwalla - Lesser longnosed bat - Desert bighorn sheep - Ironwood - Cardon - Boojum - Night-blooming cereus
Palm Oasis - All palms	**Riparian Scrubland**	**Maritime Strand**	**Mangrove Scrub** - Black mangrove - White mangrove - Red mangrove	**Islands** - Marine migrating birds - Angel de la Guarda mouse - Lizards

Appendix 4
Plants and Animals at Risk in the Sonoran Desert Bioregion

Plants
Abutilon parishii
Agastache barberi
Agave aktites
Agave chrysoglossa
Agave delameteri
Agave felgeri
Agave murpheyi
Agave ocahui
Agave parviflora
Agave pelona
Agave polianthiflora
Agave rhodocantha
Agave schotti var. Treleasei
Agave subsimplex
Agave zebra
Allium parishii
Amoreuxia gonzalei
Amsonia grandiflora
Amsonia kearneyana
Astragalus crotalariae
Astragalus magdalanae var. Peirsonii
Astragalus nitans
Astragalus nutans
Astragalus tricarinatus
Berberis harrisoniana
Boutloua annua
Bouteloua eriostachya
Bouteloa johnstonii
Brahea prominens
Chamaesyce platysperma
Cheilanthes arizonica
Cheilanthes pringlei
Colubrina californica
Coryphantha scheeri var. robustispina
Coryphantha vivipara var. alversonii
Crossosoma californicum
Croton wigginsii
Cryptantha ganderi
Cryptantha holoptera
Cynanchum wigginsii
Distichlis palmeri
Ditaxis californica
Echinocactus horizonthalonius var. nicholii
Echinocereus fereiranus var. lindsayi
Echinocereus lauii
Echinocereus ledingii
Echinocereus nicholii
Echinocereus triglochidiatus var. arizonicus
Echinocereus erectocentrus var. acunensis
Echinocereus erectocentrus var. erectocentrus
Erigeron anchana
Erigeron piscaticus
Eriogonum apachense
Eriogonum capillare
Eriogonum ripleyi
Erythea elegans
Erythrea rozelii
Ferocactus eastwoodiae
Ferocactus johnstonianus
Ferocactus viridescens
Fouquieria columnaris
Galium angustifolium ssp. borregoense
Gilia maculata
Gossypium turneri
Graptopetalum bartramii
Helianthus niveus var. tephrodes
Hesperaloe nocturna
Hymenoxp quincemaculata
Ipomopsis diffusa
Larrea tridentata var. arenaria
Lepidium flavum var. felipense
Linanthus floribundus ssp. hallii
Loeflingia squarrosa ssp. artemesiarum
Lupinus excubitus var. johnstonii
Macropetalum supinum
Mammallaria goldii
Mammillaria mainiae
Mammalarria meigeana
Mammallaria saboae
Mammallaria thornberi
Mammallaria viridiflora
Marina orcuttii var. orcuttii
Muhlenbergia brandegeei
Nolina beldingii var. deserticola
Nolina palmeri
Notholaena lemmonii
Opuntia munzii
Opuntia wigginsii
Opuntia fragilis
Palafoxia arida var. gigantea
Panicum sonorum
Paspalum palmeri
Peniocereus greggii
Peniocereus striatus
Perityle ajoensis
Perityle saxicola
Pholisma arenarium
Pholisma sonorae
Pilostyles thurberi
Poa griffithsii
Puccinellia parishii
Purshia subintegra
Rhus kearneyi
Salvia dorrii ssp. mearnsii
Salvia eremostachya
Salvia greatae
Sophora arizonica

Plants (continued)
Stephanomaria schottii
Streptanthus carinatus
Tithonia thurberi
Triteliopsis palmeri
Tumamoca macdougallii
Washingtonia filifera
Xylorhiza cognata
Xylorhiza orcuttii

Invertebrates
Cicindela oregona maricopa
Pyrgulopsis arizonae
Pyrgulopsis montezumensis
Sonorella allynsmithii
Sonorella sanxavierii
Tyronia gilae
Tryonia quitobaquitae

Fish
Agosia chrysoglaster
Catostomus clarki
Catostonus insignis
Cynoscion macdonaldii
Cyprinodon macularius eremus
Cyprinodon macularius macularius
Gila elegans
Gila intermedia
Gila robusta
Ictalurus pricei
Meda fulgida
Poeciliopsis occidentalis sonoriensis
Rhinchthys osculus
Tiagora cobitis
Xyrauchen texanus

Amphibians
Bufo microscaphus microscaphus
Bufo retiformis
Gastrophyne olivacea
Pternohyla fodiens
Rana tarahumara
Rana yavapaiensis

Reptiles
Cnemidophorus burtii xanthonotus
Crotalus catalinensis
Crotalus exsul
Gopherus agassizii
Heleoderma horridus
Heleoderma suspectum
Phrynosoma ditmarsii
Phrynosoma mcalli
Sauromalus hispidus
Sauromalus obesus townsendi
Sauromalus varius
Thamnophis eques megalops
Thamnophis rufipunctatus
Uma notata rufopunctata
Uma scoparia

Birds
Aechmophorus clarkii
Buteo albonatatus
Buteo nitidus mexicanus
Buteogallus anthracinus
Camptostoma imberbe
Caprimulgus ridgwayii
Caracara plancus
Ceryle alcyon
Charadrius alexandinus nivosus
Coccyzus americanus
Colinus virginianus ridgwayi
Dendrocygna autumnalis
Dendrocygna bicolor
Egretta thula
Epidonax trailli extimus
Falco perigrinus anatum
Glaucidium brasilianum cactorum
Haliaeetus leucicephalus
Himantopus mexicanus
Ictinia missippippiensis
Ixobrychus exilis hesperis
Laterallus jamaicensis coturniculus
Parabuteo unicinctus
Strix occidentalis lucida
Tyrannus crassirostris
Tyrannus melancholicus

Mammals
Antilocapra americana sonoriensis
Choeronycteris mexicana
Euderma maculatum
Eumops perotis californicus
Eumops underwoodii
Felis yagouroundi tolteca
Lasiurus blossevillii
Lasiurus ega
Leptonycteris curasoae yerbabuenae
Macrotus californicus
Myotis lucifugus occultus
Myotis velifer
Myotis yumanensis
Peromyscus eremicus papagensis
Peromyscus eremicus pullus
Peromyscus merriamii
Plecotus townsendii pallescens
Sigmodon hispidus eremicus
Sigmodon ochrognathus
Bighorn island mammals, herps

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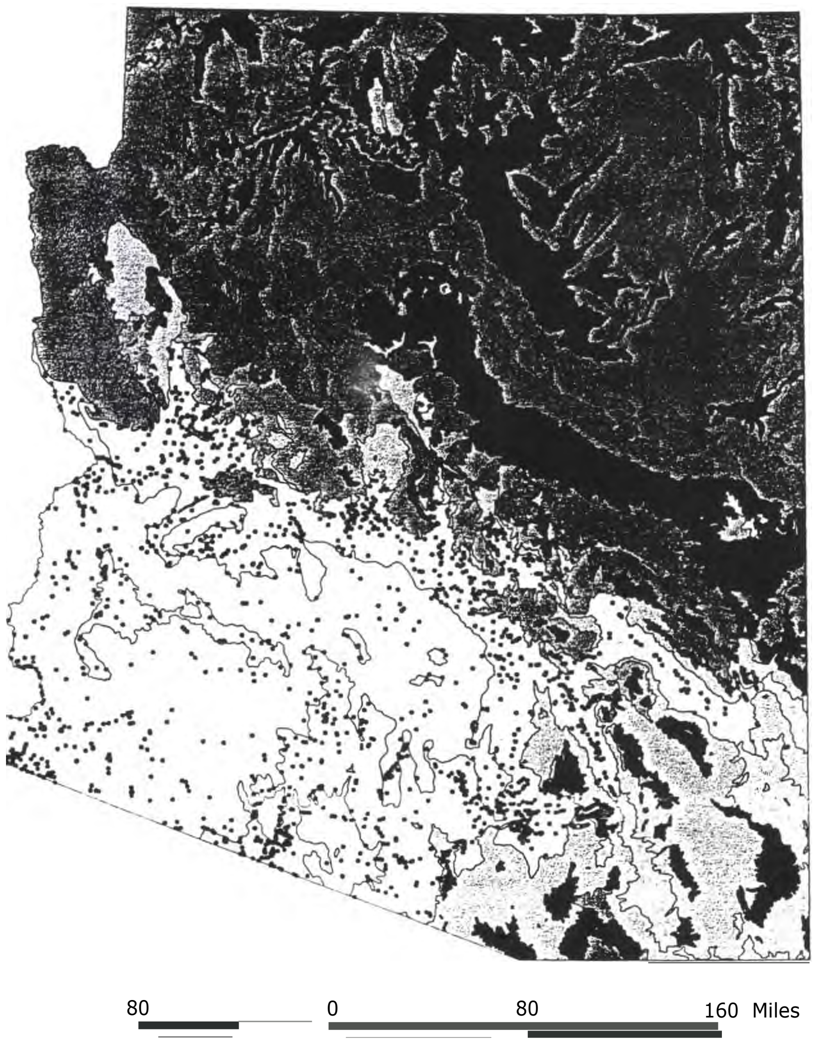
Appendix 5
Distribution of Special Status Species of the Sonoran Desert in Arizona



• Element Occurrences
Biotic Communities
ALPINE TUNDRAS
AZ.UPLAND SONORAN DESERTSRUB
CHIHUAHUAN DESERTSCRUB
GREAT BASIN CONIFER WOODLAND
GREAT BASIN DESERTSCRUB
INTERIOR CHAPARRAL
LOWR COLOR. SONORAN DESERTSCRUB
MADREAN EVERGREEN WOODLAND
MOHAVE DESERTSCRUB
PETRAN MONTANE CONIFER FOREST
PETRAN SUBALPINE CONIFER FOREST
PLAINS & GREAT BASIN GRASSLAND
SEMIDESERT GRASSLAND
SUBALPINE GRASSLAND

Arizona Game and Fish Department, Heritage Data Management System, December 4, 1997

Appendix 6
Elements of Conservation Capacity in the Sonoran Desert Bioregion

- Lesser Long-Nosed Bat Roost Site Counts- sponsored by University of Arizona. National Autonomous University of Mexico, and agencies
- Vaquita Monitoring - CEDO (Center for Studies of Deserts and Oceans)
- Sea Turtle Monitoring - CEDO
- Cross Border High School Water Quality Monitoring Program-Patronato por la Proteccíon del Rio Magdalena and Friends of the Santa Cruz
- Roots-Raices-Ta:tk Environmental Education Cleanups in Pinacate- ISDA (International Sonoran Desert Alliance)
- Volunteer Endangered Plant Watches- Arizona Native Plant Society
- Cross-Border Hummingbird Banding- University of Arizona and National Audobon Society
- Wildlife Tracking Program- Sky Island Alliance
- Cabeza Prieta Bighorn Sheep Waterhole Counts-U.S. Fish and Wildlife Service
- Cabeza Prieta/Organpipe Nat. Mon./Pinacate Sonoran Pronghom Monitoring- Sonoran Pronghorn Recovery Team and Task Force

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