Evaluating Human Population in Conservation Planning

An Example from the Sonoran Desert Ecoregion

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This publication was made possible through support provided by The Summit Foundation.

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Graphic Design: Jonathan Kerr
Production: Publications for Capacity Building, The Nature Conservancy, Worldwide Office, 4245 North Fairfax Drive, Arlington, VA 22203, USA. Fax: 703-841-4880; email: publications@tnc.org.

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Introduction

As the world enters the 21st century, conservation organizations such as The Nature Conservancy play an increasingly important role in the struggle to conserve the world's remaining biodiversity. Biologists do not know precisely how many species exist worldwide, the total probably about 10 million (Stork 1997). As ecosystems evolve, biodiversity also naturally evolves; new species emerge while others die out. The average background extinction rate for the past several million years has been estimated conservatively at about 1-3 species per year (Tuxill and Bright 1998). In stark contrast, the current rate of extinction is at least 1,000 species annually, placing modern humankind in the midst of a mass extinction more rapid than virtually any known in the earth's history (Rosenzweig 1995). Using various approaches, conservation organizations struggle to preserve the various types of habitat upon which many plants and animals rely, in the hope of conserving the biodiversity that remains. Despite success both in applied conservation and in alerting the broader public to the problem, the magnitude of the challenge to conserve biodiversity is staggering. In response, conservation organizations continue to refine methods and approaches, and redefine their task, in the hope of improving efficiency and achieving greater results.

How has the world reached a state where so much of its biological heritage is disappearing? The answer to this question can be crafted in many ways, but the common component in all responses is human beings. Although rarely considered explicitly in the evaluation of conservation settings, humans occupy virtually every terrestrial ecosystem. Thanks to unparalleled adaptive success, today the human species has come to dominate all other species in terms of the amount of the earth's resources it demands. Development, in the form of numbers and sizes of settlements, infrastructure such as transportation connections between settlements, extractive industries such as agriculture and mining, and resource demand has grown even more rapidly.

Researchers can measure human impacts on the environment by monitoring several different variables, but ultimately the issue comes down to *population.* The basic numbers tell much of the story. Prior to the emergence of agriculture roughly 12,000 years ago, an estimated 6.0 million people lived on earth (Biraben 1979) — the result of millions of years of slow population growth by humans and their hominid ancestors. By about 1800, global population had reached 1.0 billion, a consequence of relatively slow growth over the preceding 12 millennia that nevertheless dwarfed the preagricultural rate (Carnevale et al. 1999). Growth rates continued to increase in the 19th and 20th centuries, pushing world population higher and higher. By 1930, global population had reached 2.0 billion; by 1960, 3.0 billion; by 1974, 4.0 billion; by 1987, 5.0 billion; and in late 1999, 6.0 billion (Carnevale et al. 1999; United Nations 1998b; see Cohen 1995). The most recent projections by the United Nations predict that global population will total between 7.3 and 10.7 billion by 2050, depending on fertility assumptions (United Nations 1998b). The most recent long-range projections by the United Nations show world population totaling somewhere between 3.6 and 27.0 billion in 2150, extremes on either side of a middle projection of 10.8 billion (United Nations 1998a). With impacts exacerbated due to increased per capita consumption, the task of conserving biodiversity will increase even more rapidly than demographic growth as human settlement and resource use destroy or modify the habitat on which many plants and animals rely.

This paper discusses the analysis of human population in the context of conserving biodiversity. To place the study in context for conservationists who may not have systematically considered the topic before, the paper begins with a synopsis of the importance of human activity in conservation. It then explores various measures of population that help to understand likely demographic impacts on the natural environment, focusing on a spatial dimension as well as a temporal dimension. Finally, the paper analyzes population and related variables in a specific setting of conservation planning, the Sonoran Desert Ecoregion. Recently the subject of a detailed ecological analysis prepared by The Nature Conservancy and partner organizations (Marshall et al. 2000), the Sonoran Desert is an area of high biodiversity that is experiencing rapid population growth and development, making it a good empirical setting for such an examination.

Human Population and Conservation: Points of Conflict, Means of Assessment

The aims of conservation groups tend to be similar in their focus on protecting the habitat of selected plant and animal species. The activities of particular organizations often are variations on a theme rather than substantively different strategies. The reason that The Nature Conservancy and similar organizations exist is, simply stated, that there is a need for them — that is to say, natural systems in the modern world in a very real sense require protection, and biodiversity requires active conservation. Specific reasons underlying the need for conservation organizations vary, from purposeful exploitation or overexploitation of key resources that disrupt ecosystems to inadvertent impacts that are unintentional consequences of development.

Although conservation methods vary among organizations, a common thread seems to form a basis for all — first defining places (individual or multiple) to conserve biodiversity, then identifying the stresses on biodiversity at those places, and finally developing and implementing strategies to address those stresses. The role of stresses is central in this generalized conservation methodology, for in their absence places do not need protection and biodiversity does not require conservation. Implementing conservation requires that strategies for stress abatement be applied and adjusted, as necessary, to counter current and pending stresses. The *source* of virtually all stresses to biodiversity in the 21st century is human beings and their activities.[1]

Given the central role of stresses in conservation, and the origin of most stresses in humankind, it seems natural that the study of human population and related data would be crucial to the definition and implementation of conservation strategies. The examination of population can help illuminate stresses and their sources at both a regional scale and for individual sites. Moreover, demographic studies can provide insights on the magnitude of stresses, their evolution over time, and possibly their form in the future. Demographic data can vary from simply total population for a given area to information on the composition of the area's population to information on the processes underlying population change (fertility, mortality, and mobility). Sources of population data also often include information on social characteristics, economic activity, and education. These various data sources can provide insights on demographic processes as well as possible clues to stresses and their abatement.

The most detailed, reliable data on population and related topics tend to come from censuses — systematic efforts to collect demographic and related information on all inhabitants of a given area at a certain time. Although the contents of censuses vary broadly among countries, many contain most if not all of the information recommended by United Nations (1978) guidelines:

- Demographic and social characteristics (e.g., sex, age, marital status, citizenship);
- Geographic and migration characteristics (e.g., place of usual residence, place of birth);
- Household or family characteristics (e.g., relationship to head or other reference member of household);
- Fertility and mortality (e.g., children born alive, children living, deaths by age group);
- Educational characteristics (e.g., educational attainment, literacy, school attendance); and
- Economic characteristics (e.g., employment, occupation, industry, income).

Unfortunately, due to the effort and expense required for censuses, such data tend to be available only every several years. Other information may be available between censuses, although intercensal figures often are estimates or based on surveys less accurate than censuses. Depending on the availability of information and the apparent nature of conservation stresses, some or all of these data categories

1. The use of the term "stress" in the context of human beings and their activities is taken by some to have a negative connotation. This is not the intent — rather, its selection represents an attempt to define a general conceptual picture that includes potential effects on biodiversity. The Nature Conservancy and other conservation organizations recognize that conservation success is possible only through working with humans, rather than through treating humans as adversaries. That stated, human uses of the land which are incompatible with various species or ecosystems place a stress on their conservation.

may be useful in identifying and understanding stresses and their sources.[2]

In the interest of exploring conservation stresses and their sources, one can examine census data in a variety of manners. Given the wide array of potential research settings and the many types of data that may or may not be available in certain situations, it is impossible to prescribe specifically what type of analysis to conduct. However, conservationists should consider certain categories of evaluation in any such inquiry, consistent with the two basic perspectives on analysis that such data tend to support: a *spatial perspective* and a *temporal perspective*. A spatial perspective concerns the location of population and other data in geographic space with respect to other phenomena, such as conservation sites. Demographic and related data rarely are examined spatially, at least in detail. Maintaining an explicit spatial perspective is particularly important in studies that attempt to evaluate human pressures on conservation. Stresses and their sources rarely occur uniformly over geographic space; biodiversity tends to occur in certain geographic patterns as well, and examining geographic proximity of the two often is important for conservation purposes. Presentations of population density, spatial patterns of population change, and spatial patterns of the mechanisms underlying population change in a particular setting all contribute to understanding the stresses caused by human beings. The use of a spatial perspective to analyze data that are inherently quantitative makes the use of geographic information system technology a natural choice, both to organize data and to analyze and display them. The empirical analysis discussed in this paper relied heavily on such technology.

A temporal perspective, also frequently supported by demographic and related data, enables one to examine the evolution of stresses and their sources — as they have emerged over time and as they continue to evolve into the future. Once again, this is not a perspective frequently used in the analysis of demographic data. In support of conservation planning, the examination of demographic data over time yields insights on the places that are undergoing more rapid emergence of stresses and sources of stress to biodiversity, enabling decision-makers to identify potential conservation sites in imminent danger rather than those where stresses are more distant. Calculations such as average annual change and overall change for certain time periods, and the simple identification of growth versus decline, are important in the evaluation of population and related data in the context of conservation. Although geographic information system technology tends to be thought of as enhancing spatial inquiries, its fundamental foundation in database development enables calculations and graphic display that make it useful for temporal analyses as well.

Finally, it is worth noting that one should *not* strictly equate human population with impacts. Humans exist in virtually every part of the modern world, and they ultimately form important components of local ecosystems. But humans do not behave uniformly across all sociocultural systems and in all natural settings, introducing the need for additional information to augment demographic data. For instance, people living in well-designed communities and engaged in environmentally benign activities would not necessarily pose a particularly high stress on biodiversity and likely would provide less impact than that generated by fewer people involved in more environmentally disruptive activities. The distinction here is between stresses and their sources, a distinction maintained in this study. Unfortunately, detailed data on behavior are not always available for the area of interest or at the scale required. As a result, the more widely available data on population may not provide the most accurate indication of human impacts on biodiversity, whereas the data on behavior that provide a clearer indication of such impacts often are more difficult to

2. Alternative approaches to estimating population recently have made demographic data available in grid form for the entire world (see Tobler et al. 1997; Dobson et al. 2000). These estimates are available for resolutions as fine as 30 seconds and have been used as the basis for recent population-conservation evaluations on a global scale (Cincotta and Engelman 2000; Harrison and Pearce 2000). However, as estimates these gridded data sacrifice local accuracy for broad coverage. Moreover, the estimates available are total population and thus lack information on demographic structure and key processes that might illuminate causes of population change and likely future trends. In certain research settings, particularly large geographic scales, such estimates are quite useful. But for conservation planning their limitations tend to favor the use of more detailed census data.

acquire.[3] This is a cautionary note, not a call to disregard demographic data. Population figures certainly provide a sense of human impacts on the natural environment and, as such, serve as an important surrogate for data that directly reflect human activity — in the sense that the presence of more people on or close to a site tends to increase the likelihood for human impacts at that location. Due to their wide availability, population data often are a useful place to start a socioeconomic analysis, with the hope that one might augment them with other information on actual activity patterns that reflect more directly the stresses themselves.

Case Study: The Sonoran Desert Ecoregion

The Sonoran Desert, lying in the southwestern United States (US) and northwestern Mexico, is the most tropical of North American deserts (Figure 1).[4] As defined in this study, it covers parts of Arizona and California in the US, and Baja California and Sonora in Mexico, in all encompassing about 86,000 mi^2. The geographic limits of the Sonoran Desert used here generally coincide with those proposed by Dice (1943) and Dasmann (1974) in their treatments of biotic provinces of the US and the world, respectively. However, the ecoregion boundary excludes the Viscaino and Magdalena Plain biome subdivisions (see Brown 1982), which occur in the central and southern Baja California peninsula, thereby placing the boundary in general agreement with the Sonoran Xeric Scrub Ecoregion proposed by Dinnerstein et al. (1995).

The Sonoran Desert Ecoregion consists of four main biome subdivisions (Figure 2): the Arizona Uplands (26.0 percent of the total surface area), Central Gulf Coast (4.5 percent of the total), Lower Colorado River Valley (54.3 percent of the total), and Plains of Sonora (15.2 percent of the total). The ecoregion also includes eight of the biotic communities that occur in the Southwest (see Brown 1982): Sinaloan Deciduous Forest, Foothills of Sonora and Coastal Thornscrub, Semidesert Grassland and Sonoran Subtropical Grassland, "Cape" Thornscrub of Baja California, Sonoran Desert/Arizona Uplands, Sonoran Desert/Lower Colorado River Valley, Sonoran Desert/Central Gulf Coast, and Sonoran Desert/Plains of Sonora (Nabhan and Holdsworth 1999). Land use-land cover analysis based on a mosaic of satellite imagery from the late 1980s and early 1990s indicates the presence of 17 types of natural land cover, in addition to two types with urban components (Marshall et al. 2000; see Table 3 for a listing of land use categories).

The Sonoran Desert Ecoregion is one of the most arid areas in North America, with precipitation averaging as little as 1 inch annually in its driest sections (Hastings and Humphrey 1969). Despite this aridity, the ecoregion contains remarkably high biodiversity (see Nabhan and Holdsworth 1999 for a recent summary). In terms of the number of life forms and variety of communities, the Sonoran has been called the richest desert in North America (Shreve 1934). The state of Sonora, much of which lies within the desert of the same name, contains as many as 4,500 plant species, about 20 percent of the total for Mexico (see Búrquez and Martinez-Yrízar 1997). More than 500 endemic plant species occur in the Baja California portion of the ecoregion, including adjacent islands in the Gulf of California (see Villaseñor and Elias 1995). The ecoregion contains an estimated 130 species of mammals, 20 species of amphibians and at least 146 species of reptiles (96 endemic; see Flores-Villela and Navarro 1993), 25-30 species of native freshwater fish (including 11 endemic species; see Minckley 1973; Minckley and Deacon 1968),

3. Population data in certain instances can provide valuable insights to impacts. High densities, such as those in and around urban settings, almost always represent a conservation stress, because dense concentrations of people require dense housing and infrastructure that replaces natural habitat. Sparse population densities often, though not always, indicate an absence of human stress to conservation — the exception being instances where the few people in an area are involved in large-scale activities that are incompatible with conservation (e.g., commercial agriculture). Impacts of densities between the extremes, in contrast, often are difficult to evaluate and usually require information on human activities.

4. This study is essentially geographic in its focus and, as noted, employs geographic information system technology to depict many of the data discussed. Moreover, its intent in part is instructive — to provide an example of how to incorporate the human dimension into regional and site-specific conservation planning. As a consequence, it contains several maps, both for pedagogic purposes and for conveying as much information on the human and natural environments as efficiently as possible. Because of the high cost of publishing color maps, those in this paper are black-and-white — less expensive to reproduce than their color counterparts, but also more difficult to design for purposes of conveying information.

Fig. 1. Sonoran Desert Ecoregion: Physical Geography

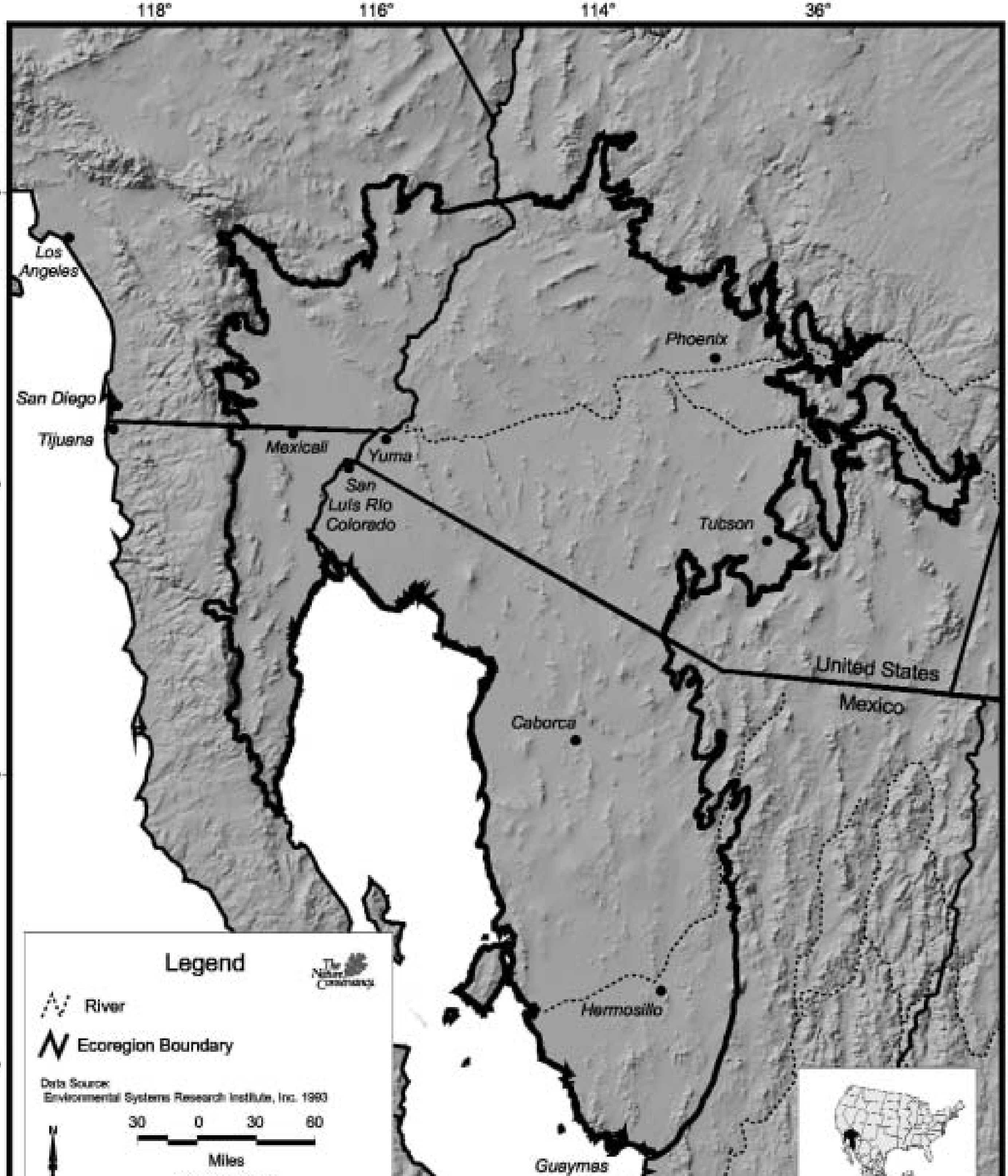
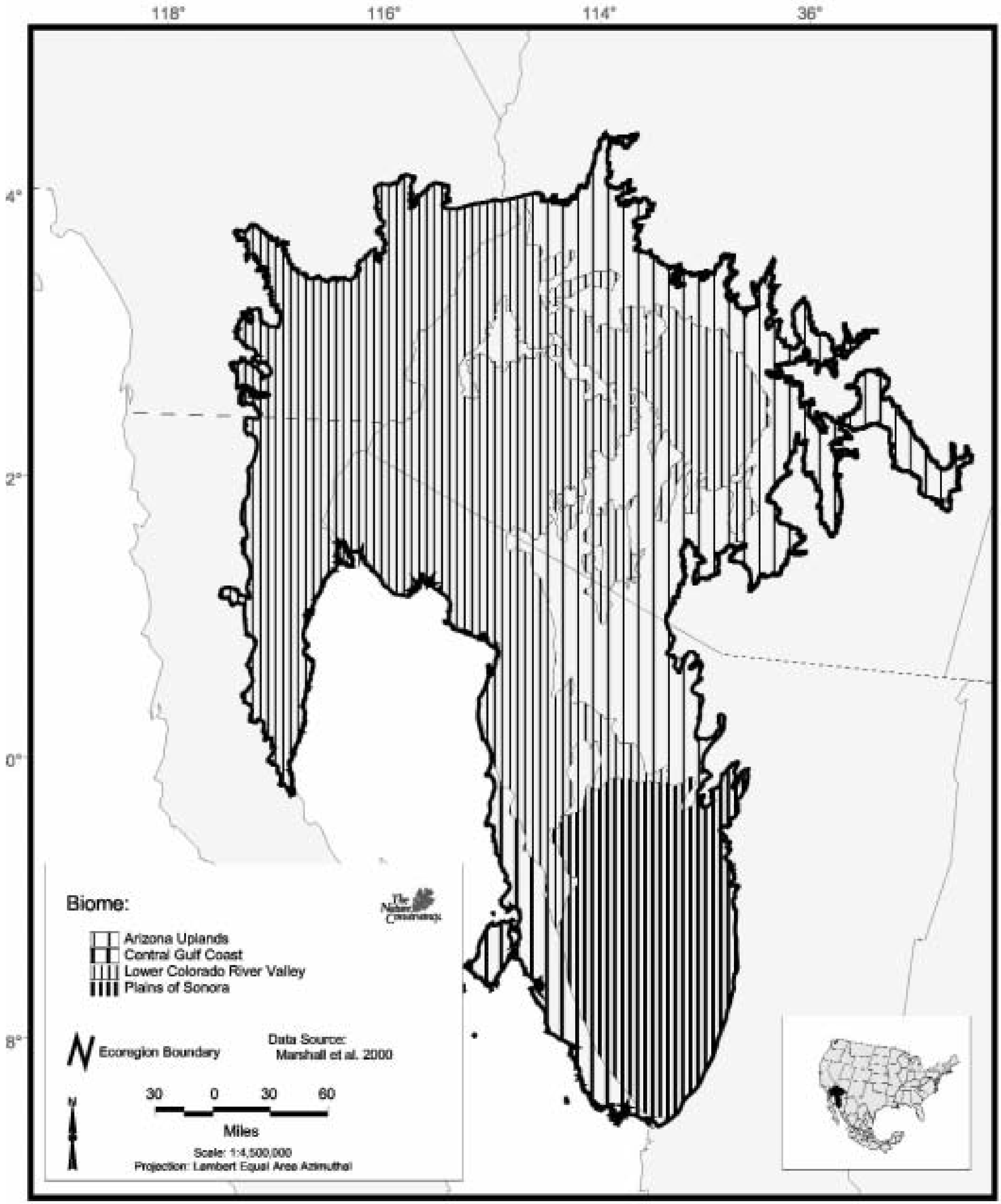


Fig. 2. Sonoran Desert Ecoregion: Major Biomes



and at least 500 species of birds. Certain portions of the ecoregion are particularly noteworthy for their biodiversity. For instance, within an hour's drive of Tucson, an estimated 1,200 species of bees provides more diversity of native bees than anywhere in the Americas (Buchmann and Nabhan 1996).

The adaptive patterns of indigenous peoples in the Sonoran Desert provide a sense of possibilities and limitations faced by humans in the region. Archaeological research indicates that humans began to inhabit the Sonoran Desert about 11,000 years ago, in a time period known as Paleo-Indian (Cordell 1997). Although the small bands of hunter-gatherers that characterized this period likely relied on a range of foods, they are best known for hunting a series of large animals that eventually became extinct during the last glacial period (Meltzer 1993). Beginning around 7,500 years ago and continuing until about AD 200, inhabitants of the ecoregion used an adaptive strategy characteristic of the Archaic period throughout the Southwest — that is, small bands of hunter-gatherers relying on a broad range of collected plants and small game animals. This broad familiarity with plants no doubt contributed to the emergence of sociocultural systems that grew their own food. Beginning around AD 200 in many parts of the ecoregion and continuing into historic times in all but the most arid areas (where nomadic hunting and gathering persisted), people began to live in sedentary settlements where they grew corn, beans, squash, and other crops in irrigated fields. The best known of these prehistoric farmers were the Hohokam, a culture centered in what today is south-central Arizona and northern Sonora (Fish 1979). Survival in this arid setting through sparse settlement and with water as a limiting resource thus dates back to prehistoric human occupations in the Sonoran Desert Ecoregion. Although much is known of ecoregion prehistory, research does not include broad, intensive archaeological surveys that would provide a basis for reliable population estimates. Given the nature of subsistence and settlement, and what is known of early historic demography in the area, population would have been sparsely distributed and probably totaled somewhere in the tens of thousands.

The hunter-gatherer and irrigated agricultural strategies that formed the basis for prehistoric adaptation of indigenous peoples in the Sonoran Desert Ecoregion continued into historic times. The most recent overviews of tribal peoples in this part of North America (Heizer 1978; Ortiz 1983) list several groups with historic ties to the region of current interest (Table 1). With the exception of the Pima, Yaqui, and many Tohono O'odham (living in the eastern part of their range), all of the indigenous groups listed survived primarily through hunting and gathering, though in many cases supplementing that subsistence strategy with limited agriculture. As a result, many historic tribal peoples lived in small settlements that shifted location throughout the year, depending on the seasonal availability of different types of food. The Pima, Yaqui, and Tohono O'odham managed to grow crops in irrigated fields, supplementing agriculture with hunting and gathering. As was the case with the prehistoric Hohokam, water control was a prerequisite to reliable food production and larger sedentary settlements. Lack of data again limits our insights on historic aboriginal population, although scholars generally agree that the total inhabitants in Pima Bajo (roughly the same as the current state of Sonora) and Pima Alto (northernmost Sonora and the southern half of Arizona) probably totaled fewer than 40,000 at the time of European contact (Pennington 1980; Sauer 1935).

The first Europeans in the Sonoran Desert Ecoregion were Spanish explorers in the 1530s and early 1540s, who entered the area from points south, primarily in search of financial gain (Hartmann 1989). The Spanish also led the way for European expansion into the ecoregion. Initial colonization of the southern and eastern parts of Sonora occurred by the early 17th century, and continued into all but the western part of that state and into southern Arizona by 1710 (Gerhard 1993; Jackson 1998; Ortega 1993; Spicer 1962). Early Spanish settlements consisted primarily of missions, small towns, and *presidios* (military garrisons), and settlers primarily engaged in small-scale agriculture, ranching, and mining. Early settlements tended to be unstable, fluid, and inhabited by people who were highly mobile. Hispanic expansion northward continued following the Mexican War of Independence in 1821, although the nonindigenous population remained fairly small (reaching only about 7,600 in 1760, and perhaps 15,000 by 1821, for the state of Sonora as a whole;

Table 1. Indigenous Peoples in the Sonoran Desert Ecoregion

Indigenous Group	Geographic Area, Language and Adaptive Strategy	References
Cahuilla	Southeastern CA (Morongo Reservation); Takik language; hunting and gathering, supplemented by agriculture	Bean 1972, 1978
Tipai	Southeastern CA and northern Baja California; Yuman language; hunting and gathering (supplemented by small amount of agriculture)	Luomala 1978
Cocopa	Southwestern AZ (Western Cocopah Reservation and Eastern Cocopah Reservation); Yuman language; hunting and gathering, some fishing, supplemented by agriculture	deWilliams 1983; Kelly 1977
Halchidroma	Western AZ; Yuman language; hunting and gathering, supplemented by agriculture	Harwell and Kelly 1983
Maricopa	Southwestern AZ (Salt River and Gila River reservations); Yuman language; hunting and gathering and semi-intensive (simple irrigation) agriculture	Harwell and Kelly 1983; Spier 1933
Mohave	South-central AZ (Ft. Mohave and Colorado River reservations); Yuman language; primarily hunting and gathering, supplemented by agriculture	Stewart 1983
Pima	Southern AZ (Gila River, Salt River, and Ak-chin reservations), west-central Sonora; Piman language; agriculture (irrigated), supplemented by hunting and gathering	Dunnigan 1983; Fontana 1983a; Ezell 1983; Hackenberg 1983
Quechan	Southeastern CA (Ft. Yuma Reservation); Yuman language; primarily gathering, supplemented by simple agriculture and hunting	Bee 1983
Seri	West-central Sonora (Seri Ejido); Serian language; hunting and gathering, fishing and other marine-oriented subsistence	Bowen 1983; Griffen 1959; Moser 1963
Tohono O'odham	Southern AZ and northern Sonora (Ak-chin, Gila Bend, San Xavier, and Tohono O'ohdam, reservations, Poso Verde Ejido); hunting and gathering, and agriculture, varying by location	Fontana 1983a, 1983b; Hackenberg 1983
Western Apachi	East-central AZ (Camp Verde, Ft. Apache, and San Carlos reservations); Southern Athabaskan language; hunting and gathering, supplemented by agriculture	Goodwin 1942; Basso 1983
Yaqui	Southwestern Sonora; Cahita language; primarily agriculture (irrigated)	Spicer 1980,1983
Yavapai	West-central AZ (Ft. McDowell and Yavapai reservations); Yuman language; hunting and gathering, supplemented by agriculture	Gifford 1936; Khera and Mariella 1983

Gerhard 1993). Most settlements were small and widely scattered, their size and distribution constrained by conflicts with indigenous peoples and the arid natural environment. Disease and conflict greatly reduced the indigenous population of the Sonoran Desert Ecoregion during the first centuries of European occupation, although the precise amount of depopulation among tribal peoples is unknown.

Following the Mexican-American War, in the mid-1850s Anglo-Americans from the US expanded into the newly acquired American territories of Arizona, California, and New Mexico. Much of the settlement in this area followed the general pattern of slow expansion along a military front similar to the Hispanic efforts that had preceded it, again relying on agriculture, animal husbandry, and mining as a basis for the economy (Sheridan 1995). In Mexico, during the second half of the 19th century, western Sonora became a major area of Hispanic habitation, as population expanded out of the mountains in the eastern part of the state. Habitation increased after the 1880s, following the cessation of many of the indigenous hostilities (particularly in the US). Water control on a larger scale began about the turn of the century, expanding with the construction of large dams in the US and Mexico during the 1920s and 1930s and furthering the cause of development through providing a more reliable foundation for agriculture and settlement. Finally, the establishment of rail links with other parts of Mexico and the US promoted economic growth in the Sonoran Desert Ecoregion through vastly improved communication and interaction outside the area (Sanderson 1981).

Well into the 20th century, agriculture, ranching, and mining continued to support much of the human habitation in the area, though all of these activities had grown considerably in scale. Population and economic growth surged on the Mexican side of the border early in World War II, as exports to the US grew markedly (Sanderson 1981). Population growth occurred in Arizona, and to a lesser extent in southeastern California, following World War II and the accompanying expansion of manufacturing (primarily electronics) to supplement other forms of economic activity. Until the 1970s, settlement in the Mexican states of Sonora and eastern Baja California had lagged behind their US counterparts. Recent population expansion in the Mexican part of the ecoregion has followed the emergence of economic opportunities on the American side of the border, coupled with continued degradation of the rural farmland where many migrants originate (National Heritage Institute 1998). In particular, the meteoric growth of manufacturing and assembly industry along the Mexican side of the border — the predominantly foreign-owned factories called *maquiladoras* — has provided a major source of employment opportunities, and hence has attracted considerable migration from other parts of Mexico (see Alegría 1992; Burke et al. 1992; Peach and Williams 2000).

Based on the above synopsis, it is possible to divide the history of human habitation in the Sonoran Desert Ecoregion into three main phases. Phase 1, dating from initial colonization by Paleo-Indian hunter-gathers until about 1880, featured sparse indigenous and (after the early 16th century) nonindigenous populations which survived primarily through hunting and gathering, subsistence agriculture, ranching, and mining (primarily) precious metals (see Ortega 1993; Sheridan 1995). Phase 2, dating between 1880 and 1950, witnessed more rapid, systematic population growth and the emergence of today's key cities as substantial centers of population and finance. Beginning at the time when most hostilities with tribal peoples ceased, large-scale water control (particularly during the 20th century) and the construction of transportation connections to other parts of the US and Mexico were central to this growth. Commercial wheat and cotton agriculture, cattle ranching, and large-scale mining of copper and other metals and minerals emerged and supported growth and development during the second phase. Phase 3 began after World War II and has continued until the present. Population has grown rapidly during this period, at first particularly in the US portion of the ecoregion but more recently in the Mexican portion as well. Manufacturing (on both sides of the border) and tourism and retirement populations (particularly on the US side of the border) have supplemented previously established economic activities. Although one may trace the roots of large-scale impacts to biodiversity in the Sonoran Desert Ecoregion to Phase 2 of human habitation in the area, it is precisely in the most recent phase of human habitation (Phase 3) that biodiversity in the ecoregion has come under widespread danger. Projections both for the US-Mexico Borderlands as a whole (Peach and Williams 2000) and various components of the ecoregion predict continued rapid population growth (Baja California 1996; Pima County 1998a). Thus, conservationists must develop a better understanding of human impacts in the area and develop an effective means of dealing with them.

Population and Conservation in the Sonoran Desert Ecoregion

To understand the impact of human demographics and development on conservation in the Sonoran Desert Ecoregion, The Nature Conservancy recently conducted a study that mapped and analyzed human population and related variables in this region. Such a study is particularly pertinent in this ecoregion, where a recent survey of experts identified nine of the top ten threats to biodiversity as consequences of human activity (Nabhan and Holdsworth 1999). The study maintained two perspectives, spatial and temporal. The spatial perspective considered the geographic arrangement of population, the processes underlying the geographic distribution of population, and the implications of a given arrangement for conservation in the ecoregion. Although population data typically are available in several different spatial units that vary in size, the study focused on two — each with counterparts on both sides of the border. Population and related statistics available for *municipios* in Mexico and counties in the US provided a wide range of data for several years, though for large geographic units. Statistics collected for census tracts in the US and *áreas geoestadísticas básicas* (AGEBs) in Mexico, in turn, provided information in much smaller units and hence a more refined sense of geographic distribution, but for a more limited number of variables and years. The temporal perspective, in turn, considered the human environment in the Sonoran Desert Ecoregion as it evolved over time. The study focused on census years in both countries for 1970, 1980, 1990, and 2000. It also projected population for 2010 to provide a sense of how population likely would be distributed in the near future. Data availability varied by year, and the study reflects this variability. For instance, AGEB data for Mexico are available only from the 1990 census for both urban and rural areas, and census tract data for the US are not readily available prior to 1980.

Population in the Sonoran Desert Ecoregion has grown rapidly over the past three decades. Totaling fewer than 2.3 million inhabitants in 1970, the ecoregion population exceeded 3.4 million by 1980 as a consequence of 4.1 percent average annual population growth (Table 2). Although population was broadly distributed in the ecoregion, the largest number of people resided in Maricopa (40.7 percent of ecoregion population in 1970) and Pima (11.4 percent) counties, Arizona; Riverside County, California (9.6 percent); and Hermosillo Municipio, Sonora (9.1 percent). Population continued to grow rapidly during the 1980s, the average annual increase of 3.3 percent yielding a total population of 4.7 million by 1990. The geographic distribution of people generally remained similar to that documented for 1970, although population change in individual counties and *municipios* varied considerably — some growing rapidly, others growing more slowly, and yet others actually losing population over this decade. Population growth slowed slightly during the 1990s, increasing on average 3.1 percent per year and resulting in 6.4 million inhabitants by 2000. The geographic distribution of population again remained broadly constant, though the changes in individual areas once again varied. Assuming that the demographic change documented for individual counties and *municipios* during the 1990s will continue into the near future, one can use those rates of change as a basis for population projections to 2010. The result is a shocking 8.8 million inhabitants by the end of the current decade, consistent with expectations of demographic expansion for various components of the ecoregion (e.g., Pima County 1998b), providing a hint of what conservation will face in the near future.

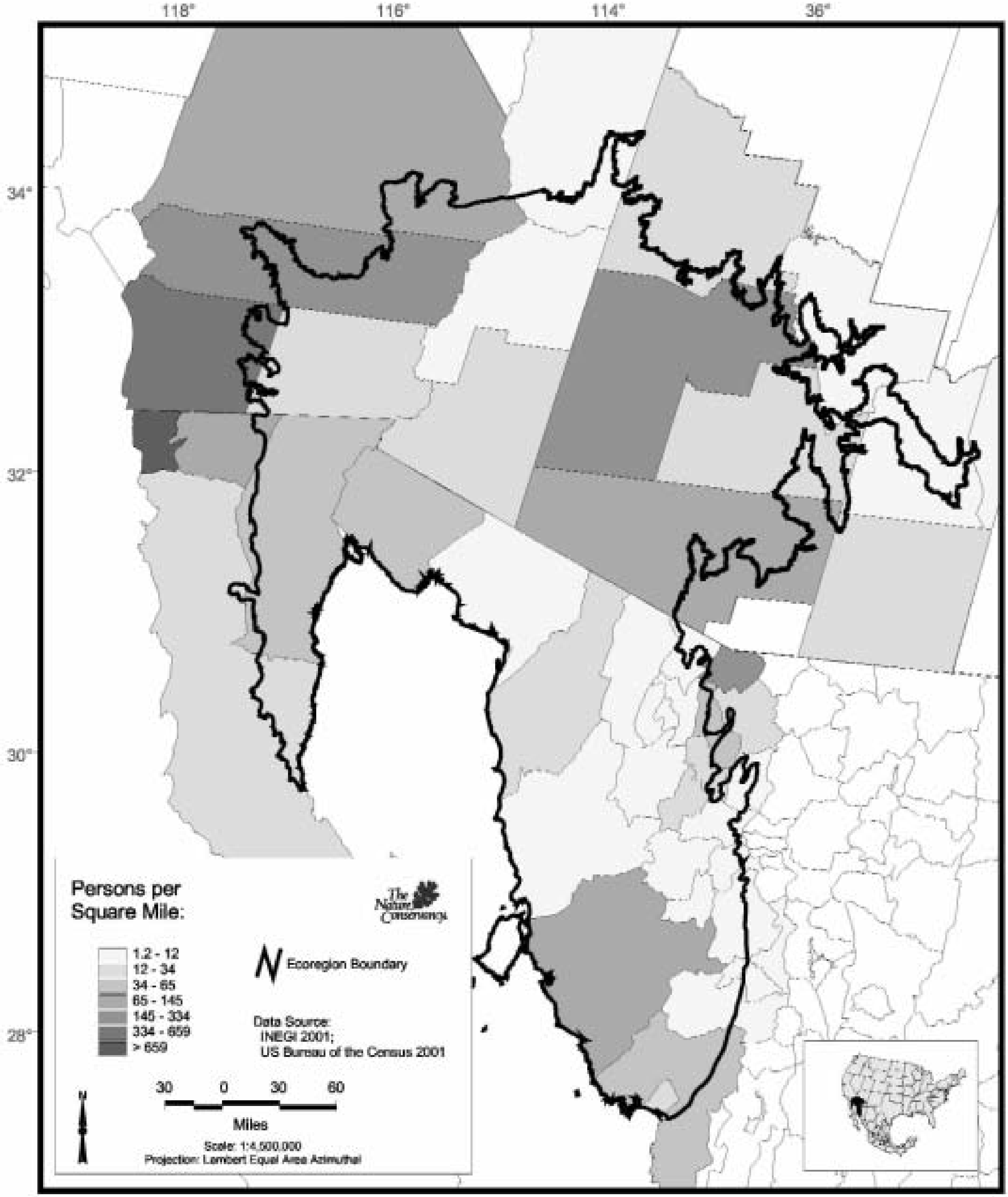
Maps provide a useful means of summarizing population and related data visually. The general geographic arrangement of population can best be presented in map form by accounting for differences in the sizes of counties and *municipios* — that is, by mapping population *density* rather than raw population counts. Figure 3 presents a map of population per square mile for the Sonoran Desert Ecoregion in 2000. Given the consistency of population distribution in the area since 1970, this map also provides an indication of population distribution for 1970, 1980, and 1990. One characteristic particularly worth noting is the generally sparse population densities throughout the

Table 2. Population and Population Change in the Sonoran Desert Ecoregion: 1970, 1980, 1990, 2000, and 2010

County/Municipio	Population					Average Annual Change (Percent)		
	1970	1980	1990	2000	2010[1]	1970-1980	1980-1990	1990-2000
Total	2,284,075	3,413,294	4,720,076	6,417,428	8,804,098	4.1	3.3	3.1
Cochise, AZ[2]	619	857	976	1,178	1,420	3.3	1.3	1.9
Gila, AZ[2]	4,681	5,933	6,435	8,214	10,483	2.4	0.8	2.5
Graham, AZ[2]	3,979	5,487	6,373	8,037	10,139	3.3	1.5	2.4
Greenlee, AZ[2]	103	114	80	85	91	1.0	-3.5	0.7
La Paz, AZ	9,579	11,467	13,844	19,715	28,081	1.8	1.9	3.6
Maricopa, AZ[2]	928,821	1,448,690	2,037,216	2,949,263	4,270,035	4.5	3.5	3.8
Mohave, AZ[2]	2,327	5,028	8,415	13,953	23,142	8.0	5.3	5.2
Pima, AZ[2]	260,234	393,267	493,491	624,372	789,941	4.2	2.3	2.4
Pinal, AZ[2]	57,729	77,280	98,922	152,768	235,885	3.0	2.5	4.4
Yavapai, AZ[2]	6,612	12,266	19,388	30,153	46,916	6.4	4.7	4.5
Yuma, AZ	51,248	79,087	106,895	160,026	239,626	4.4	3.1	4.1
Imperial, CA[2]	71,512	88,426	104,931	136,667	178,042	2.1	1.7	2.7
Riverside, CA[2]	220,356	318,320	561,798	741,786	979,613	3.7	5.8	2.8
San Bernardino, CA[2]	54,487	71,601	113,470	136,755	164,752	2.8	4.7	1.9
San Diego, CA[2]	108,623	148,948	199,841	225,107	253,625	3.2	3.0	1.2
Ensenada, BC[2]	8,080	12,280	18,199	30,319	50526	4.3	4.0	5.2
Mexicali, BC[2]	31,706	40,853	48,155	61,192	77,722	2.6	1.7	2.4
Tecate, BC[2]	16,463	27,791	46,917	70,474	105,834	5.4	5.4	4.2
Altar, SN	3,886	6,029	6,458	7,224	8,081	4.5	0.7	1.1
Atil, SN	804	878	797	694	604	0.9	-1.0	-1.4
Benjamin Hill, SN	5,842	6,292	5,939	5,729	5,527	0.7	-0.6	-0.4
Caborca, SN	28,971	50,452	59,160	69,359	81,292	5.7	1.6	1.6
Carbo, SN	3,313	3,977	4,581	4,966	5,384	1.8	1.4	0.8
Cucurpe SN[2]	599	589	477	430	388	-0.2	-2.1	-1.0
Empalme, SN	34,136	41,063	46,017	48,329	53,420	1.9	1.1	0.8
Guaymas, SN[2]	43,404	48,981	64,546	65,054	65,577	1.2	2.8	0.1
Hermosillo, SN	208,164	340,779	448,966	608,697	825,215	5.1	2.8	3.1
Imuris, SN[2]	180	212	221	300	408	1.6	0.4	3.1
La Colorado, SN[2]	2,171	1,958	1,707	1,545	1,397	-1.0	-1.4	-1.0
Magdalena, SN[2]	4,925	6,297	7,025	8,543	10,394	2.5	1.1	2.0
Mazatan, SN[2]	551	656	582	542	505	1.8	-1.2	-0.7
Nogales, SN[2]	3,210	4,084	6,476	9,546	14,076	2.4	4.7	4.0
Opodepe, SN[2]	2,740	3,025	2,696	2,330	2,014	1.0	-1.1	-1.4
Oquitoa, SN	658	501	424	407	387	-2.7	-1.7	-0.5
Pitiquito, SN	4,134	5,977	7,743	9,160	10,831	3.8	2.6	1.7
Puerto Penasco, SN	12,436	26,755	36,353	31,101	26,603	8.0	3.1	-1.6
Rayon, SN[2]	2,045	1,551	1,360	1,185	1,034	-2.7	-1.3	-1.4
S.L. Rio Colorado, SN	63,604	92,790	110,530	145,276	190,922	3.8	1.8	2.8
S.M. de Horcasitas, SN	2,173	2,826	2,285	5,604	13,750	2.7	-2.1	9.4
Santa Ana, SN[2]	7,994	9,068	9,431	10,014	10,634	1.3	0.4	0.6
Saric, SN[2]	1,346	1,305	1,225	1,306	1,393	-0.3	-0.6	0.6
Trincheras, SN	2,487	2,052	2,109	1,788	1,516	-1.9	0.3	-1.6
Tubutama, SN	1,858	2,021	1,842	1,790	1,740	0.8	-0.9	-0.3
Ures, SN[2]	5,626	5,892	5,780	5,445	5,133	0.5	-0.2	-0.6

1: 2010 projections prepared by extrapolating 2000 populations based on of 1990-2000 average annual growth rates for each jurisdiction.
2: County or *municipio* only partially included in the Sonoran Desert Ecoregion.
Sources: Dirección Nacional de Estadística 1972a, 1972b; INEGI 1982a, 1982b, 1996, 2001; US Bureau of the Census 1972a, 1972b, 1982a, 1982b, 1991a, 1991b, 2001.

Fig. 3. Sonoran Desert Ecoregion: 2000 Population Density



ecoregion, even as late as 2000 at the county-municipio scale. Even in the case of Maricopa County, which contained 2.9 million persons in 2000, population density barely reached 300 persons per square mile. The majority of counties and *municipios* in the ecoregion had population densities less than 20 persons per square mile. One also can get a clear sense of geographic patterns of population change over time through cartographic presentation. Population grew throughout much of the ecoregion for the three decades between 1970 and 2000, in some cases maintaining remarkably high rates of average annual increase over more than an entire quarter-century (Figure 4). Much of the growth occurred near the US-Mexico border and along the coast in Mexico. The most rapidly growing counties and *municipios* — such as Mohave County, Arizona, and Tecate Municipio, Baja California — still contained fairly small populations in 2000, indicating relatively small absolute changes in population. Other areas that exhibited slightly slower growth rates, including Maricopa County (3.8 percent) and Hermosillo Municipio (3.1 percent), added considerable numbers due to their relatively large populations. Population decline between 1970 and 2000 occurred primarily in the mountainous portion of the state of Sonora, likely a consequence of the decline in mining in that area over the past several decades.

In any setting, there are three possible causes of population change: births, deaths, and migration. Depending on the relative magnitude of each mechanism with respect to the others, total population can increase, decrease, or remain constant. Although the populations of both Mexico and the US continued to grow during the 1990s (Population Reference Bureau 1999), neither population exhibited excessively high fertility compared to mortality, the means by which rapid population growth often occurs. Mortality and fertility data for counties and *municipios* in the ecoregion tend to confirm these general national trends (Instituto Nacional de Estadística, Geografía, e Informática [INEGI] 1993a, 1993b, 1998a, 1998b; US Bureau of the Census 2001), although natural increase (more births than deaths) is greater within the ecoregion than at respective national levels. Moreover, the high rates of increase occurring in many of the counties and *municipios* in the Sonoran Desert Ecoregion (in excess of 4 percent annually) suggest that migration may be the dominant cause of population change. An evaluation of available data confirms this suspicion. The 1990 census in each country reported change in residence over the preceding five years (for all individuals aged five years and older in 1990). A map of these data at the county-*municipio* level (focusing solely on movements between countries or states to isolate as much as possible relocations *into* the ecoregion) indicates considerable in-migration over that five-year period (Figure 5); in many US counties in the ecoregion, more than 20 percent of 1990 inhabitants reported a residence elsewhere in 1985. Although the mapped data do not account for out-migration, which certainly occurred during the same time period, annual estimates of county population and the components of change indicate positive net migration throughout the US portion of the ecoregion (US Bureau of the Census 2001). Similar data on short-term mobility are available from the 1980 censuses for both countries. These data also indicate high levels of in-migration across the ecoregion for the five years preceding that census (INEGI 1982a, 1982b; US Bureau of the Census 1982a, 1982b).

Figures 3 through 5 provide a good indication of the geographic distribution of population in the Sonoran Desert Ecoregion, the change in distribution over time in different parts of the ecoregion, and the contribution of migration to this change. But the data examined are limited to fairly large geographic units, distributing various statistical values across entire counties or *municipios*. Because people tend to live in clusters rather than in uniform distributions across geographic space, the study also considered smaller areas of spatial aggregation to develop a finer sense of population distribution. Data for Mexico were examined in AGEBs — basic geostatistical areas, the smallest unit for which data have been presented for the entire country. Data for the US, in turn, were examined in census tracts, geographic units comparable in geographic size to AGEBs. A map of population density in 1990 for tracts and AGEBs provides a finer sense of population distribution (Figure 6). This map reveals two interesting tendencies. One is the expected pattern of population distribution, with most ecoregion inhabitants living in clusters amidst vast areas that are sparsely populated. The second is the presence of *sprawl*, low-density development

Fig. 4. Sonoran Desert Ecoregion: 1970-2000 Average Annual Population Change

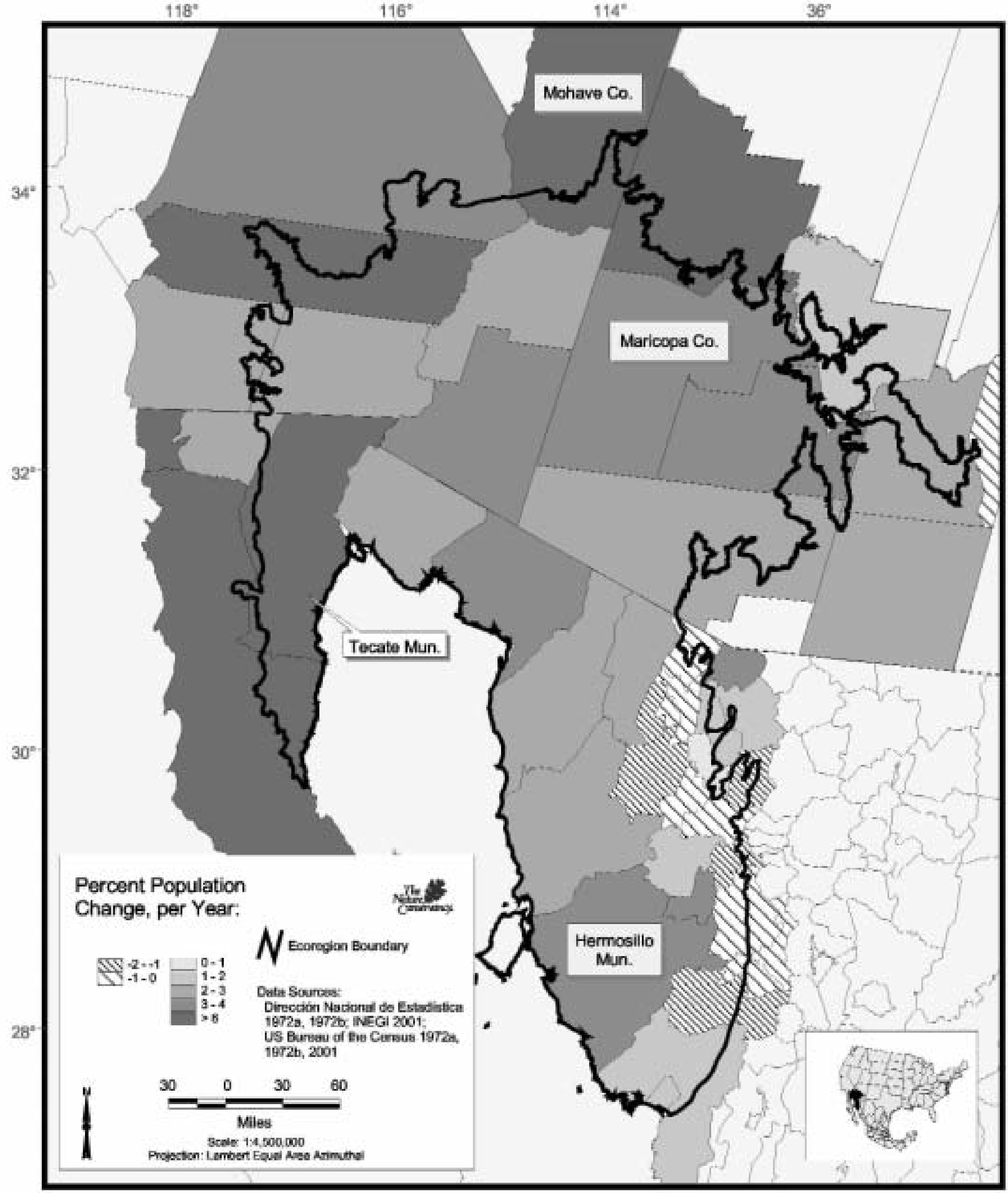


Fig. 5. Sonoran Desert Ecoregion: 1985-90 Mobility

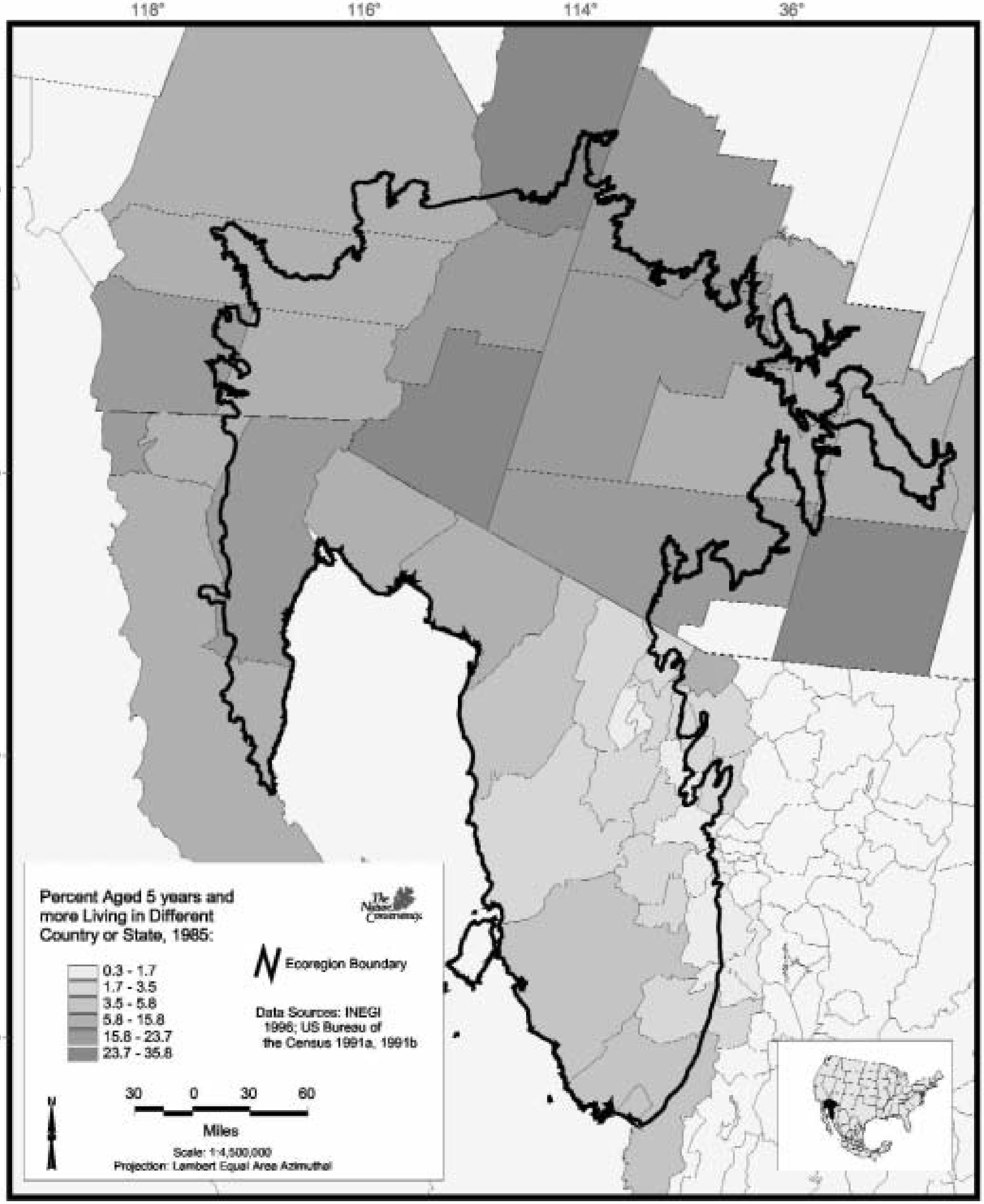
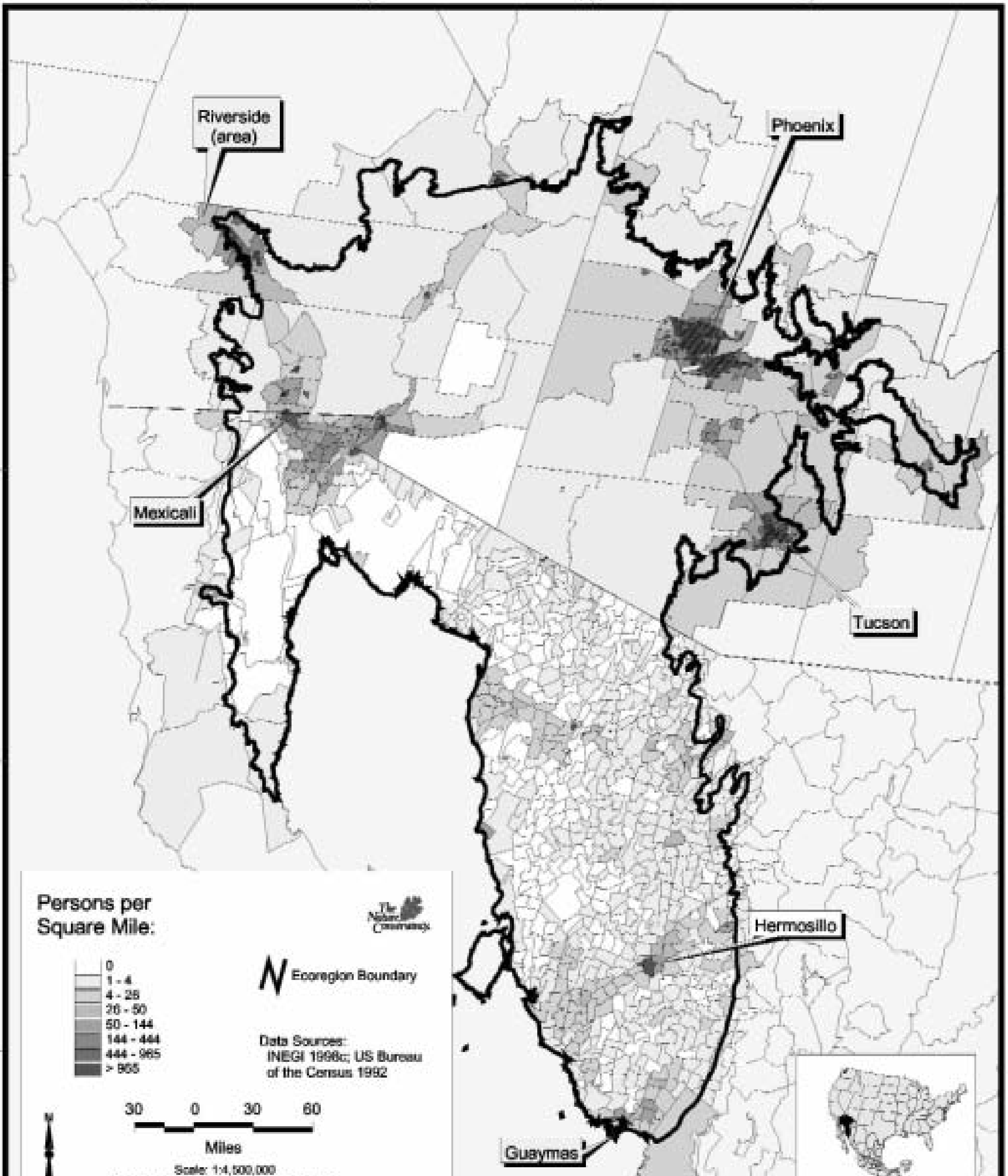


Fig. 6. Sonoran Desert Ecoregion: 1990 Population Density



(beyond the edge of services and employment) around population centers (see Brown et al. 1998). Long a problem in the US, sprawling settlement has occurred around all major population centers in the ecoregion north of the border, including places wholly included in the study area (such as metropolitan Phoenix and Tucson, AZ) as well as those lying beyond the study area whose sprawling peripheries encroach on the ecoregion (such as Riverside, CA, itself lying west of the ecoregion). Somewhat surprisingly, sprawl was apparent in the Mexico portion of the ecoregion in 1990 as well, particularly around the cities of Hermosillo, Guaymas, and Mexicali. Sprawl tends to be associated with several negative consequences, including long commutes, pollution, and declining city centers, in addition to changes of particular concern to conservationists such as habitat destruction and fragmentation and the expansion of the urban heat island (Balling 1988; Balling and Brazel 1987; Nabhan 1990; Pope 1999).

The finer geographic detail provided by a map at the tract-AGEB level of resolution provides a good basis for the evaluation of human encroachment on conservation sites. As part of the ecoregional planning process, conservation planners at The Nature Conservancy and partner organizations convened a meeting of experts from Mexico and the US to define sites important for their biological components (Marshall et al. 2000). The results of that meeting, and subsequent efforts to refine site definitions, produced a collection of locations containing plant and animal species of interest to conservationists. Overlaying those sites on a map of population density for 1990 yields a map that enables an examination of population density in the vicinity of places of interest for their biodiversity (Figure 7). Such maps provide conservation planners with useful information on stresses and sources of stress to consider along with biological variables in making their decisions on sites to target for protection. The degree to which conservation sites occur in areas of low population density is the subject of ongoing research.

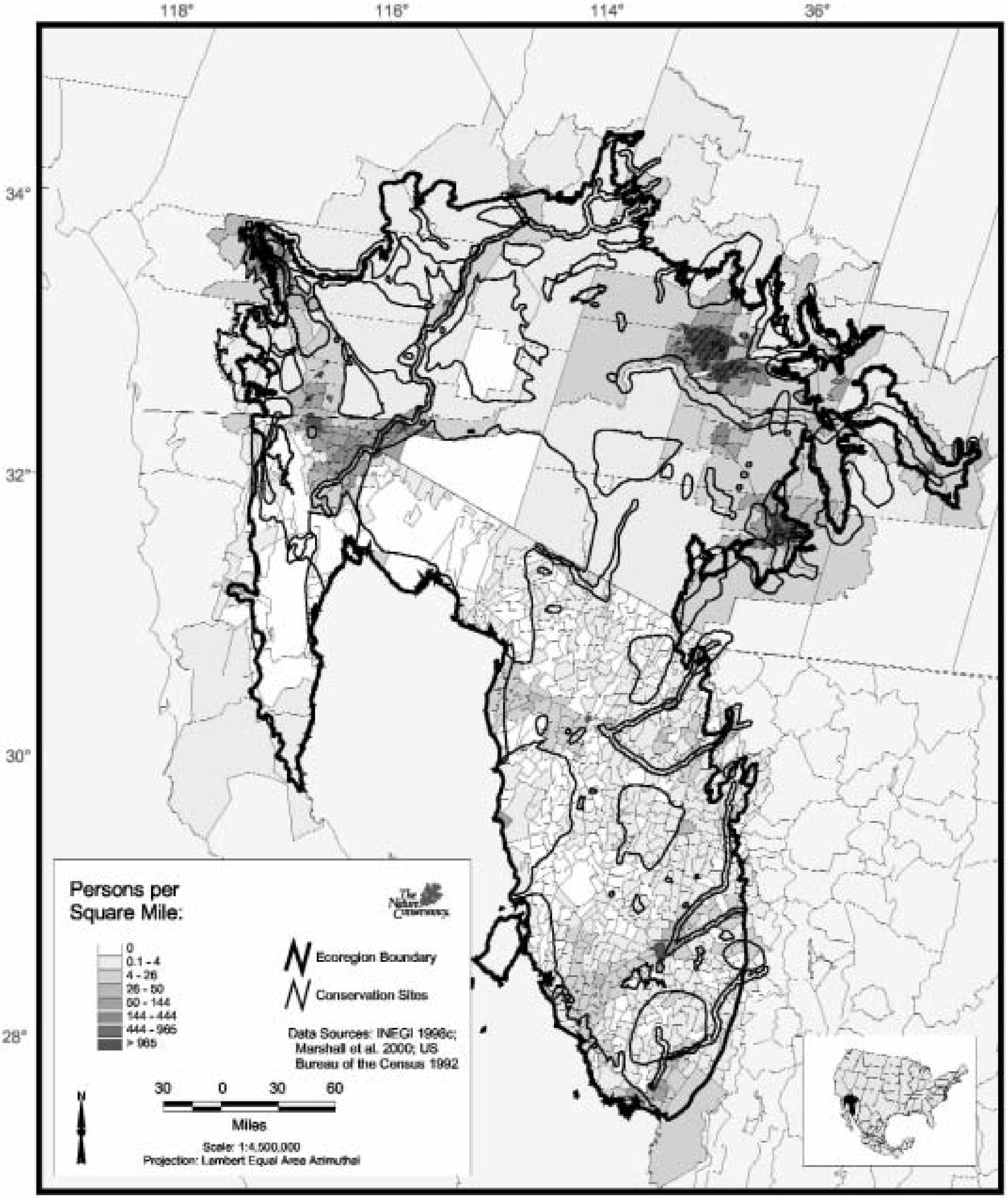
Ultimately, the maps that can be generated for any subject are limited by data availability, and mapping human data in the context of conservation planning is no exception. What is gained by focusing on the tract-AGEB level of spatial aggregation is sacrificed in part by the lack of availability of AGEB data for all of Mexico for any year except 1990 (2000 census data being unavailable as this paper went to press). Census tract data for the US, in contrast, are available for censuses other than 1990, enabling the calculation of population change over time and providing a basis for projecting census tract population density in the future. Overlaying distributions of conservation sites on such maps provides an indication of those sites in proximity to areas of high population density for 2000 (Figure 8), as well as those sites in proximity to areas experiencing rapid population change (Figure 9). In terms of evaluating threats to biodiversity based solely on population, the two most useful measures are density and change — the places with relatively high density and rapid growth likely posing the greatest challenge to conserving biodiversity.

Implications for Conservation Planning in the Sonoran Desert Ecoregion

Conservation planning traditionally relies heavily on the analysis of ecological data. Although such planning efforts often consider the human dimension — notably human impacts on biodiversity — they usually do so only tangentially rather than in a manner that yields the types of detailed analysis and insight useful for the planning process. The discussion of the Sonoran Desert Ecoregion presented in this paper suggests that data on human population can play an important role in understanding the geographic distribution of stresses to biodiversity. Given the human origin of most of these stresses, and the types of analysis of demographics and development that are possible, a natural question to ask is how the evaluation of population and related data can contribute to the conservation planning process. There are, in fact, different roles that such evaluations can play in conservation planning — both in defining which sites to conserve and in determining how to conserve them.

Portfolio design is the first place where the analysis of population data can play an important role in conservation planning. A portfolio is a collection of conservation sites in an ecoregion which, taken together, represents the breadth of that area's biodiversity. Although the process of portfolio development can vary between ecoregions and organizations involved in the development effort, the process tends to involve the selection of particular conservation sites

Fig. 7. Sonoran Desert Ecoregion: 1990 Population Density and Proposed Conservation Sites



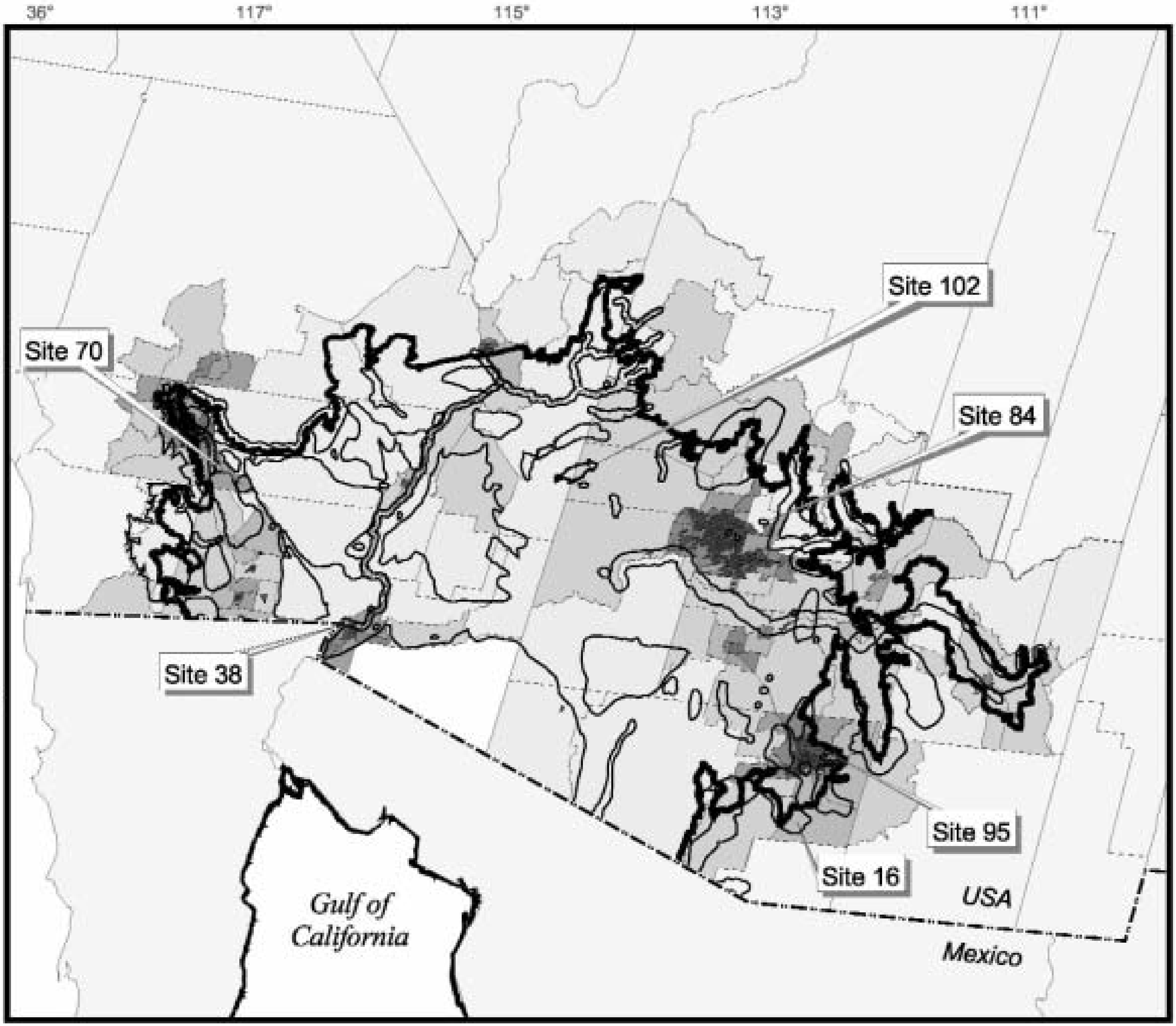


Fig. 8. Sonoran Desert Ecoregion: 2000 Population Density and Conservation Sites

Persons per Square Mile:

- 0
- 0.1 - 4
- 4 - 26
- 26 - 50
- 50 - 144
- 144 - 444
- 444 - 965
- > 965

Ecoregion Boundary

Conservation Sites

Data Sources:
Marshall et al. 2000;
US Bureau of the Census 2001

0 40 80
Miles

Scale: Approximately 1:4,000,000
Projection: Lambert Equal-Area Azimuthal

N

The Nature Conservancy

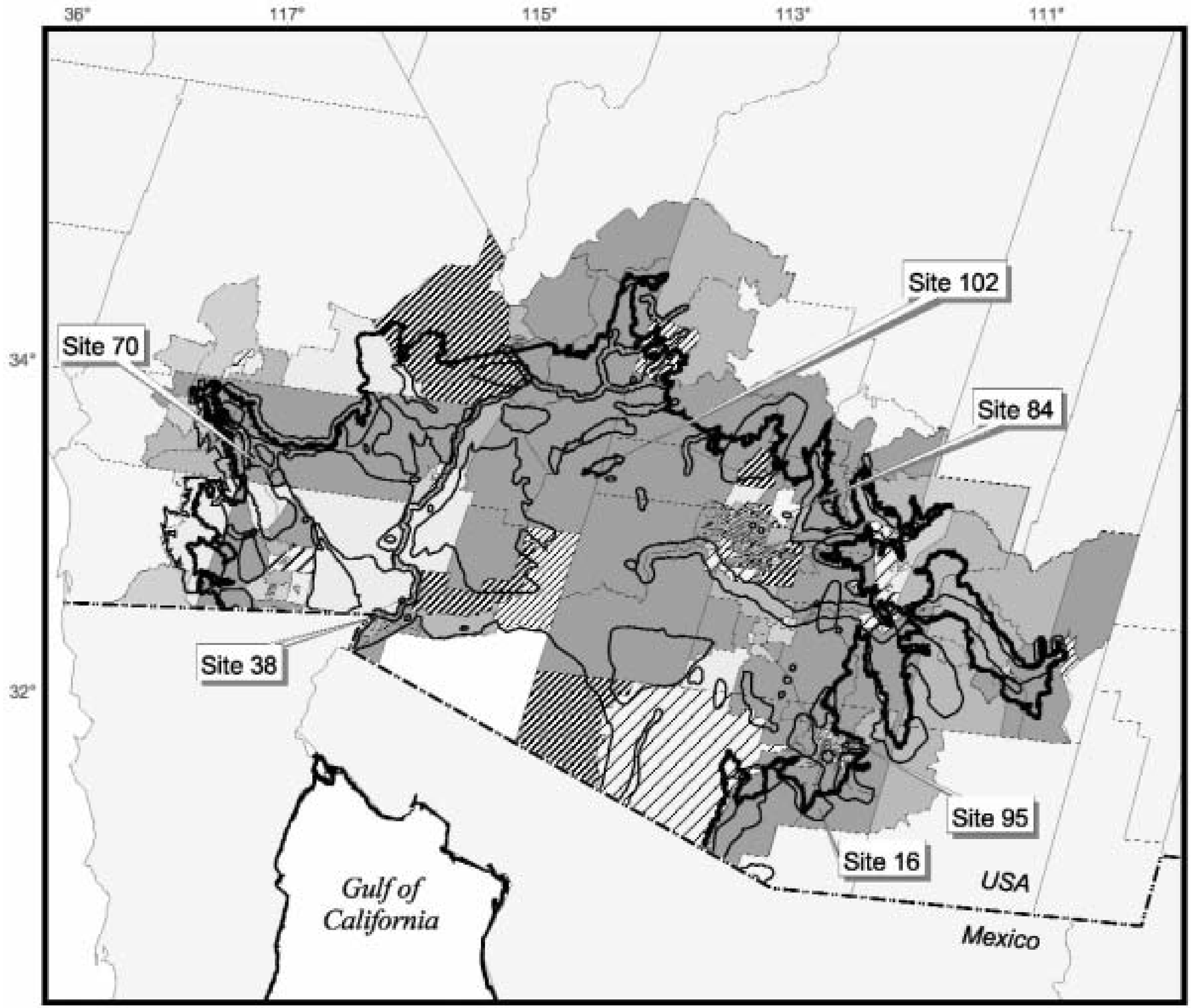


Fig. 9. Sonoran Desert Ecoregion: 1990-2000 Average Annual Population Change and Conservation Sites

from a larger set of alternative places being considered for conservation. The set of potential sites tends to be defined largely on the basis of biological criteria and represents the locations of species that are key components of an ecoregion's biodiversity. The selection of conservation sites from this larger collection also often relies heavily on biological data, notably the presence of one or more species crucial to the biodiversity of an ecoregion. But site selection also can, and in many cases should, involve the consideration of stresses, and sources of stresses, to provide a thorough indication of long-term conservation potential. Mapping and analyzing human population and related data can contribute to the likelihood of conservation success.

Biodiversity obviously serves as a central decision-making criterion in assembling a portfolio of sites designed to conserve this important indicator of biological breadth. But in some instances, the biodiversity characteristics of more than one site will be similar — perhaps containing the same number or type(s) of key plant or animal species. In such a situation, two different decision-making scenarios are possible where the consideration of human data is concerned. One is the selection of sites that are safe from stresses at the time of planning and in the foreseeable future, due to lack of geographic proximity to dense population or development, slow-paced development or population growth, or some combination of the two. In such a scenario, planners consider the subset of sites that meet specific biological criteria and select those sites that will require less active protection and that may have larger geographic buffers surrounding them to enhance key ecological functions. As an example from the Sonoran Desert, Sites 95 and 102 both provide similar contributions to ecoregion biodiversity, in the sense that both contain the same number of conservation target species — six targets and four taxa each (Marshall et al. 2000; see Figures 8 and 9). However, Site 102 is more distant from both dense population and rapid population growth than Site 95, and thereby is likely to be safer from heavy human impacts — suggesting that conservationists might enjoy greater success through investing their time and resources for active conservation action in Site 102 rather than Site 95.

A second possible decision-making scenario is selecting a site for conservation that is in greatest imminent danger of destruction. Such a selection normally would occur when a site contained biological components absolutely essential to an ecoregion's biodiversity. In such a situation, time would be of the essence, and the mapping and analysis of human population would enable the identification of those sites likely facing the greatest immediate threats of damage or destruction. On a regional scale, examining maps of population density and change over time with respect to conservation sites can help planners to identify which sites face the greatest danger of damage or destruction throughout the ecoregion — and as a result, which require more rapid decisions (and actions) about protection. As shown in Figures 8 and 9 once again, Sites 16, 38 (southern portion), 70, and 84 all occur in areas of relatively dense and rapidly growing population, indicating current or near-term threats that require rapid attention. Depending on their biological characteristics, conservationists may wish to identify one or all of those sites for near-term action.

Once decisions are made on which sites to conserve, conservationists face the problem of stress abatement at those sites. The development of stress abatement strategies typically occurs at the level of individual sites, primarily due to the need to define a problem that is feasible for conservation organizations to undertake at the level where they actually conduct their activities. The potential conservation site identified in the Sonoran Desert Ecoregional analysis as containing the largest percentage of conservation targets is *Site 13*, a large locality composed of Barry Goldwater Air Force Range and Organ Pipe National Monument in the US and El Pinacate Biosphere Reserve in Mexico (Figures 10 and 11). Although its various components are protected from development and resource extraction on both sides of the border, the public has access to much of Site 13 — introducing the possibility of human impacts in the form of recreation and vandalism. The portions of Site 13 facing the greatest potential danger from such stresses can be evaluated by mapping and analysis of population in small units. Denser and more rapidly growing populations both occur on the western edge of the site, suggesting that greater monitoring, enhanced public education, and more tightly defined access might be considered in that area.

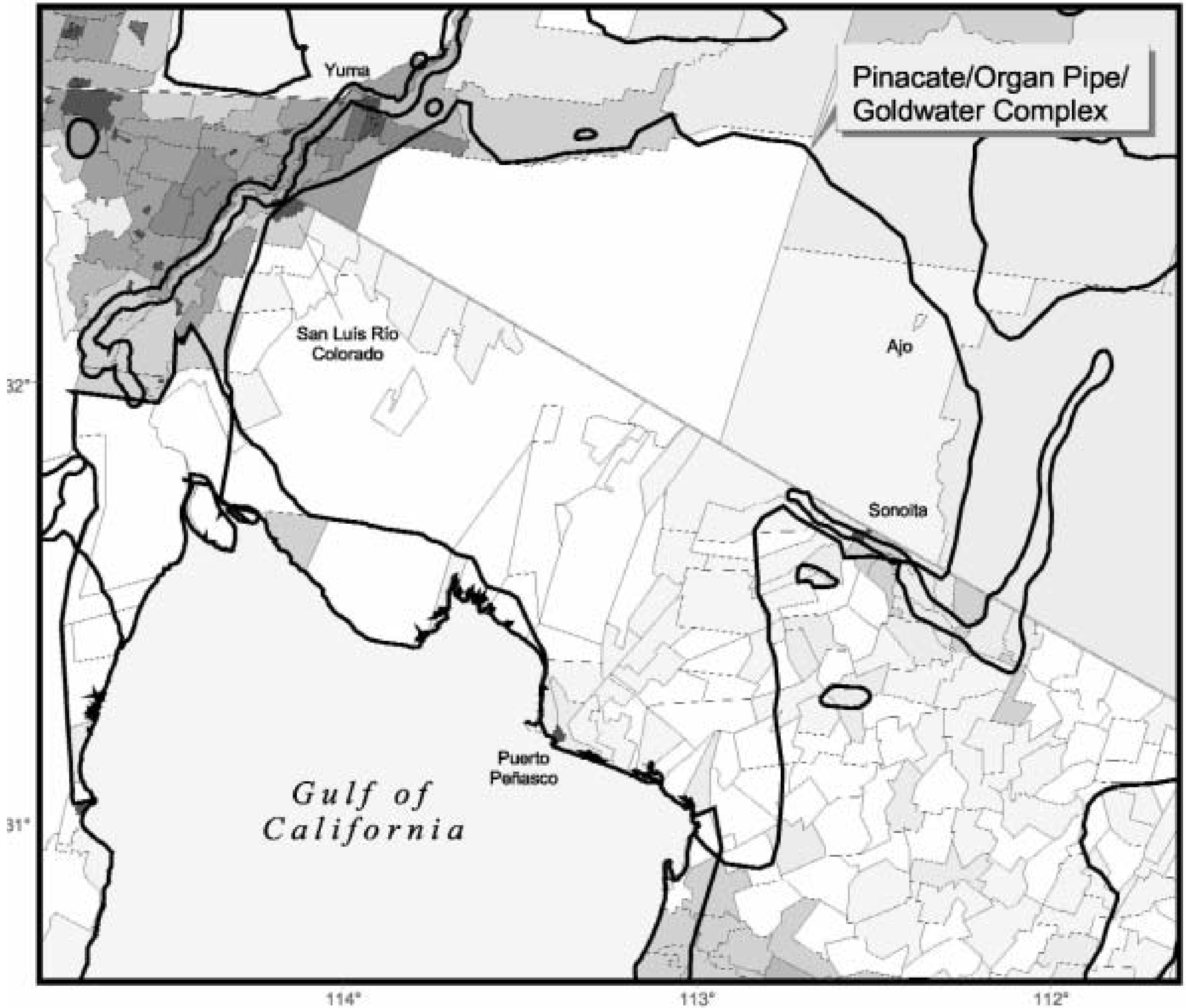
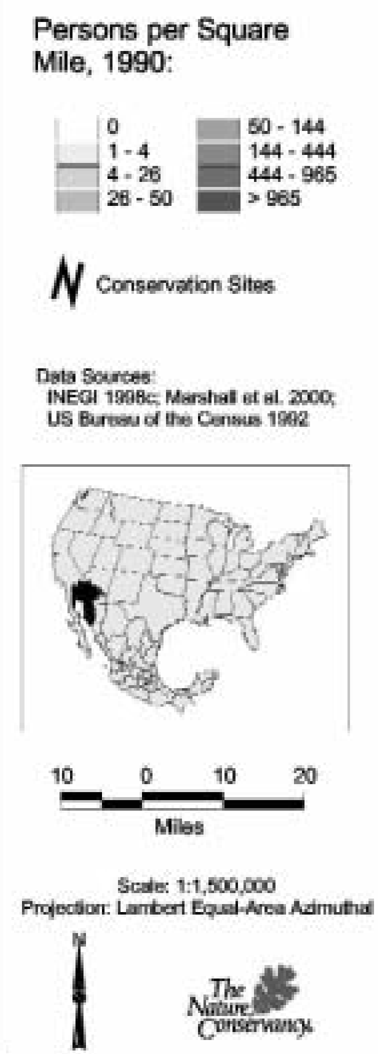


Fig. 10. El Pinacate/ Organ Pipe/ Goldwater Complex: 1990 Population Density



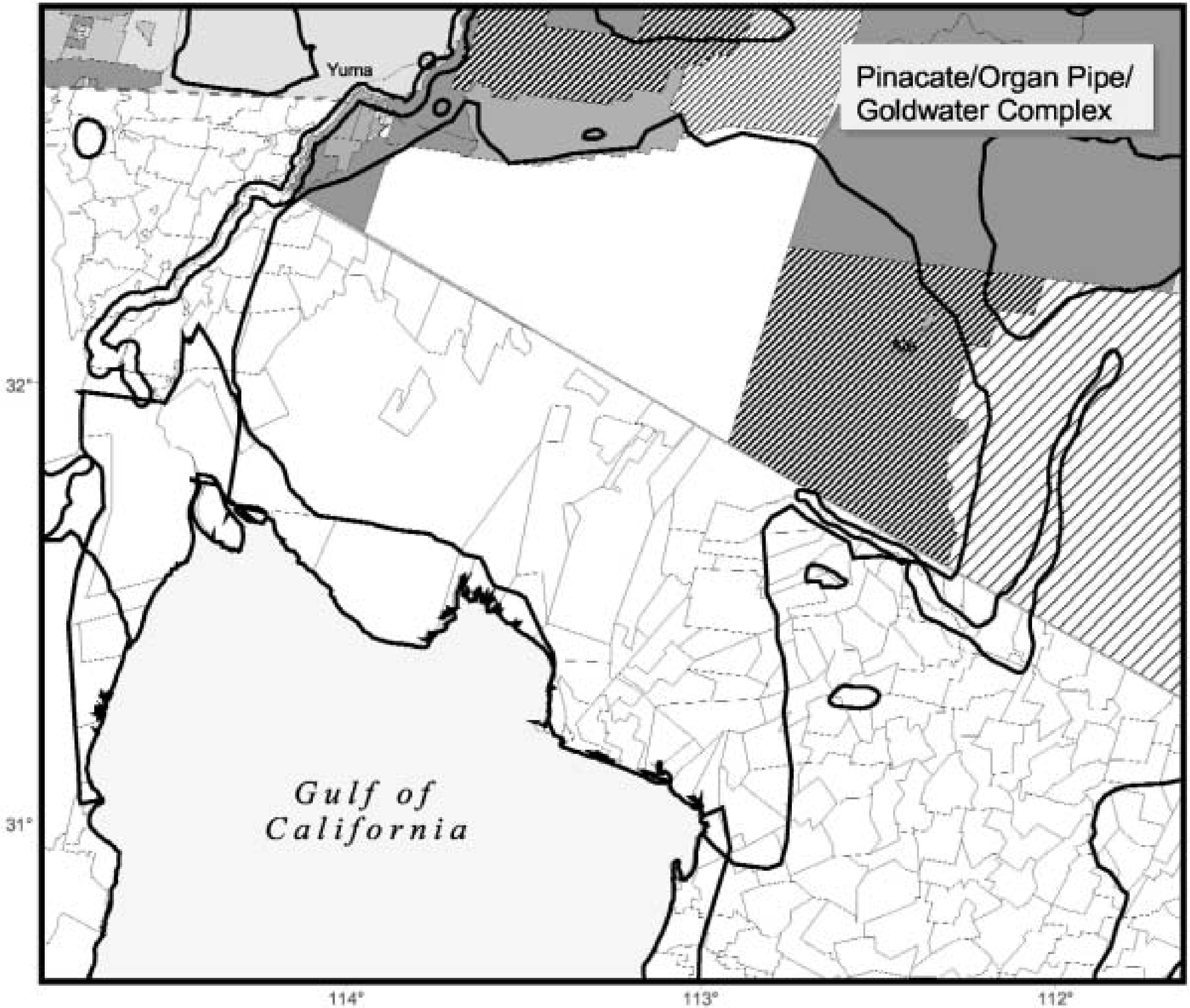


Fig. 11. El Pinacate/ Organ Pipe/ Goldwater Complex: 1990-2000 Population Change (US only)

The problems in conservation settings that emerge from the analysis of population and related data are those that in many ways face other sectors of society, namely the best use of available resources. This introduces the possibility that conservationists might enlist the efforts of others in their struggle to conserve biodiversity. The main problem, ultimately, is large human populations that place particularly high demands on available resources — a situation which will only get worse as both population and per capita demand grow. The solutions to high population in many settings, such as family planning and the further education of women in developing countries, tend to lie beyond the scope of most conservation organizations. In many parts of the world, including the Sonoran Desert Ecoregion, the underlying cause of high population is not as much natural increase as it is mobility, with large numbers of people moving into the region on both sides of the US-Mexico border. In such a situation, the important point of intervention is a different sort of planning — namely, local, urban, and regional planning. It is here that conservationists might find some of their most willing, prepared, and ultimately important allies (see City of Tucson 1998; Maricopa County 1997; Pima County 1998a, 1998b; Salkin 1999). Through working systematically with the individuals and government agencies that make decisions about areas to allow development, conservationists can provide key information on localities where development would be very costly to biodiversity — hopefully leading to the consideration of alternative locations for human habitation and use.

Local, urban, and regional planning refers to the process of guiding development at various levels of government to meet particular objectives for human occupation. Much development throughout the world, including the US, occurs in the absence of such guidance. Planning has been identified as one of the main means of stopping sprawl (Pope 1999). If we accept the inevitability of population growth in the Sonoran Desert Ecoregion over the coming decades, as predicted both in this paper and elsewhere, a useful approach is to take steps to promote the type of growth and use of the natural environment that minimize impacts on biodiversity. Local, urban, and regional planners recognize downsides of poor development as unnecessarily high commuting time, pollution, and resource use in addition to sprawl, and thus have a number of reasons to fight such development (Pima County 1998a, 1998b; Yuma County 1985). The entire ecoregion is not open to development, particularly in the US portion where federal and state ownership constrains who can use particular tracts of land and how they can use it. But most of the land surrounding the major communities in the Sonoran Desert Ecoregion is privately owned — an unfortunate situation because these are precisely the portions of the region likely to experience sprawl as population continues to grow (Figure 12). Continued population growth, coupled with a decline in agricultural activity since about 1970 (see Búrquez and Martinez-Yrízar 1997; Lorey 1990; US Department of Commerce 1996) due largely to problems with the water supply, indicates that the development of population centers is a key concern in the Sonoran Desert Ecoregion. Steps to control the spread of this development include focusing growth on certain areas in what ultimately are multi-center communities (deSouza and Stutz 1994; Muller 1981), promoting denser development within existing urban areas, and avoiding areas with particularly high environmental importance (see Lutz 1996). These steps meet the goals of many land use and community planners and also serve the cause of conservation.

Concluding Remarks

The study discussed in this paper attempted to accomplish two related tasks. The first was to introduce the mapping and analysis of human population and related data to conservation planning. The world at the outset of the 21st century is one in which, more than ever, the success of the human species comes at a high cost for most others, placing the very survival of many in imminent danger. Developing a better understanding of how people are arranged over geographic space, how they came to be arranged over space, and the geographic distribution of human impacts on biodiversity all emerge as central to the challenge of conserving that biodiversity. The second task was to discuss the mapping and analysis of population data in an empirical context, the Sonoran Desert Ecoregion. Recently the subject of an ecological analysis, and an area that has experienced considerable population growth and development in recent decades, this ecoregion provides a good setting in which to apply several of the general concepts presented early in this essay.

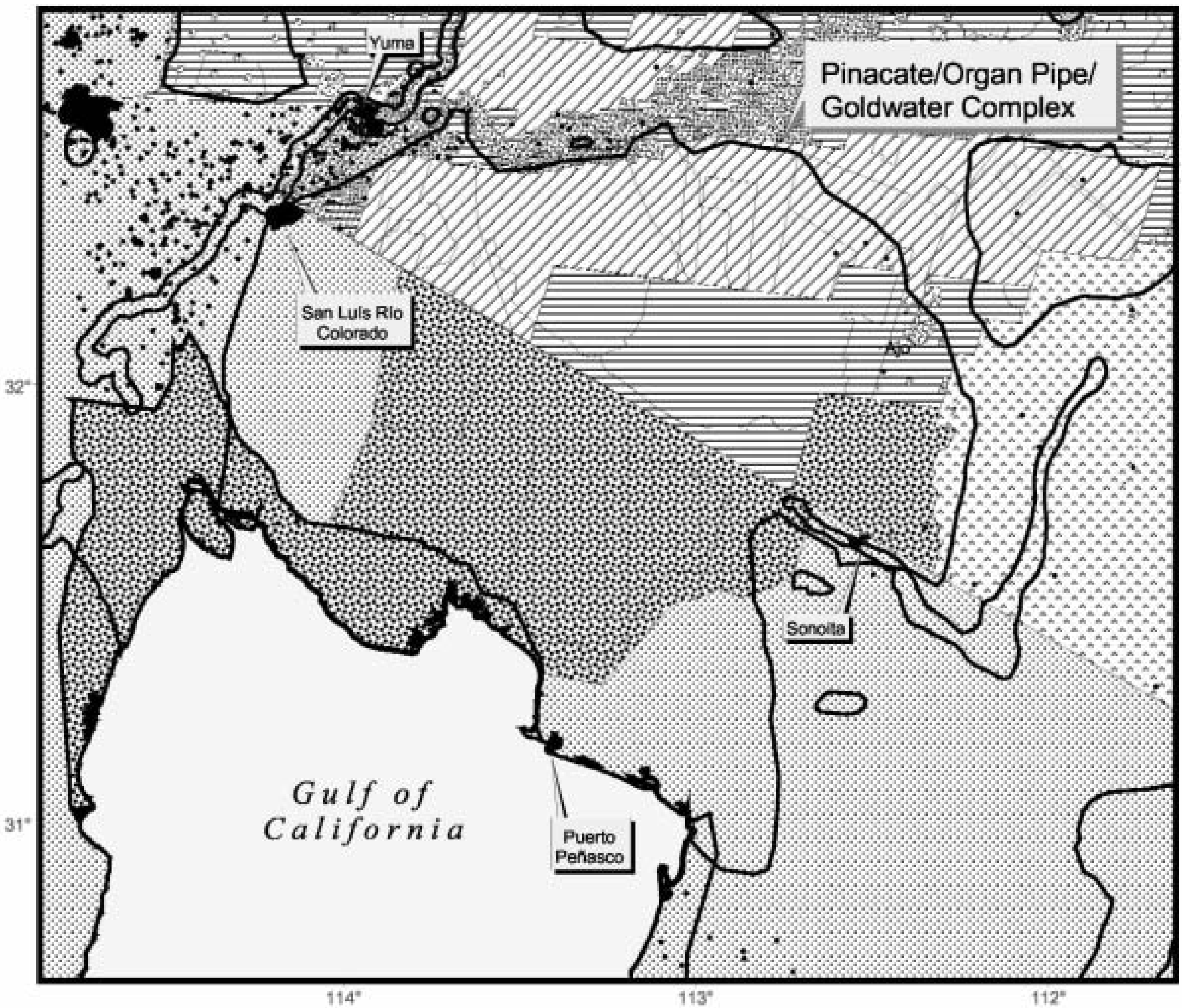


Fig. 12. El Pinacate/ Organ Pipe/ Goldwater Complex: Land Tenure and 1990 Population

Land Ownership/
Management:

- Federal, State, or County Park
- Native American
- Private
- State or City Property
- US Dept. of the Interior
- US Military

• 1 Dot = 500 Persons (1990)

Conservation Sites

Data Sources:
INEGI 1998c; Marshall et al. 2000;
US Bureau of the Census 1992;
Sonoran Desert Ecoregional Planning
Team (unpublished land tenure data)

10 0 10 20
Miles

Scale: 1:1,500,000
Projection: Lambert Equal-Area Azimuthal

N

The Nature Conservancy

Maps and associated analyses reveal areas of concentrations of population, rapid population growth, causes of growth, and the presence of suburban sprawl on both sides of the border. Combined with distributions of current and proposed conservation sites, these maps yield insights at both the regional and site levels on current and future human-related stresses.

This study has relied primarily on population and related demographic data in a research setting where the ultimate question is not only how people are distributed over space but also *what they are doing* and how their activity might affect conservation. Data that might reveal more about the interface between human population and human activity unfortunately are scarce for the Sonoran Desert Ecoregion. Table 3 contains a summary of land use data based on satellite imagery from the late 1980s and early 1990s, in conjunction with the distribution of population in 1990 (the most recent available in appropriately small units for the entire region). A comparison of these two data types shows the presence of large numbers of people in other types of land cover beyond the two urban categories where one would expect large populations — indicating other points of potential human stress. However, a more useful analysis might explore population change over time and how that change has related to changes in land use for the same years. Such an analysis, coupled with a study of population distribution over time and space, would provide an even clearer picture of the role that humans play in the ecology of the Sonoran Desert Ecoregion and help establish future patterns of land use and land cover as the more desirable conservation planning horizon.

Another consideration that deserves greater attention than given in this study is water, a topic considered only anecdotally above. Water always has been the limiting resource to human habitation in the Sonoran Desert. It also plays an absolutely central role in regional ecology, a rare but necessary resource for plants and animals. Settlement demands, and par-

Table 3. Land Use-Land Cover Categories and 1990 Population

Land Cover/Land Use	Area (ac.)	Pct. of Area	Pct. Of Population
All Types	55,151,147	100.0	100.0
Agave-Bursage Scrub	17,203	0.0	0.0
Agricultural-Urban	4,193,787	7.6	21.2
Creosote-Bursage Scrub	20,182,473	36.6	5.7
Desert Plains	3,957,633	7.2	0.7
Desert Playa	73,148	0.1	0.0
Interior Chapparral -Encinal	235,433	0.4	0.0
Industrial-Urban	359,498	0.7	11.3
Interior Riparian Marsh	3,943	0.0	0.0
Interior Riparian Scrub	194,303	0.4	0.1
Interior Riparian Woodland	73,996	0.1	0.0
Jatropha-Bursera Scrub	2,844,319	5.2	0.1
Mangrove	3,154	0.0	0.0
Mesquite Bosque	4,515,854	8.2	10.4
Other	5,217	0.0	0.0
Palo Verde-Mixed Cactus	16,019,253	29.0	49.4
Saltbrush-Saltmarsh	572,059	1.0	0.9
Semi-Desert Grassland	422,585	0.8	0.2
Sinaloan Foothills/Thorn Scrub	1,122,190	2.0	0.0
Water	355,099	0.6	0.0

ticularly the requirements of agriculture, led to aquifer drawdown in excess of recharge rates in Arizona as early as the 1920s; more recently, more than a third of the surface basins are experiencing an annual decline in excess of 0.3 meter (Nabhan and Holdsworth 1999). The consequences of excessive water use are extensive loss of vegetation and broad reduction of the riparian areas throughout the ecoregion. As with land use-land cover, the precise relationship between population and water remains undetermined, but is a key to understanding the impacts of humans on conservation.

Conservation planning in the early 21st century requires the clear definition and evaluation of stresses and their sources. People now inhabit virtually every ecosystem that conservationists examine. Moreover, humans are the ultimate source of virtually all stresses and, in some cases, are the stresses themselves by virtue of their presence and associated habitat destruction. Analyzing the geographic arrangement of population over space is a valuable step in defining this major challenge to conservation — and provides a basis for working with evolving populations in the interest of conservation (see McNeely and Ness 1996). Conducting such inquiries makes it possible not only to take specific steps within conservation organizations to integrate human data systematically in their work, but also provides a clearer basis for informing and interacting with local, community, and regional planners who are responsible for controlling patterns of development. Ultimately, it may well be a collaboration of conservation organizations with such public officials that provide the greatest hope for conserving the biodiversity that remains. The type of analysis described in this paper provides the first part of a foundation for such collaborative efforts.

Acknowledgments

This research underlying this study was part of the Population-Environment Overlay Mapping Project, a pilot project generously supported by a grant from the Summit Foundation to The Nature Conservancy. The paper has benefited from comments provided at various stages of its preparation by Susan Anderson, Nina Chambers, Steve Cornelius, Rob Emanuel, John Hall, Eduardo López, Rob Marshall, Joaquín Murrieta, and Ivan Parra. Kirk LaGory and Dee Wyman each made several particularly useful recommendations shortly prior to its publication.

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