# FINAL REPORT

## Analysis and Assessment of Impacts on Biodiversity: Investigating Alternative Futures for the California Mojave Desert

## SERDP Project SI-1055

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# Acknowledgements

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# EXECUTIVE SUMMARY

## Introduction

The Mojave Desert is affected by many of the same environmental stresses that affect the rest of the United States. A major difference, however, is that the Mojave Desert has lower ecological recoverability compared with more mesic ecosystems. The fragility of the landscape means that even light stress may cause irreversible damage. The principal anthropogenic stressors for the region include development (residential, industrial, commercial, infrastructure), agriculture, grazing, exotic species, vehicle based recreation, water redirection, mining, and noise.

This report describes a project conducted by the Desert Research Institute, Oregon State University, Utah State University, the U.S. Forest Service and the Environmental Protection Agency, to evaluate the potential impacts of future patterns of land use on biodiversity and related environmental concerns within the Mojave Desert ecoregion of California in 1997 (the base year) and in 2020. While planning efforts and related analyses have been conducted within individual parcels of land or for specific land ownership, *these activities were not being addressed within the region as a whole*. Biodiversity analysis at this larger spatial scale is considered to be essential context for understanding the consequences of differing human actions as well as management plans at specific locations within the area.

Alternative future patterns of land use ("Alternative Futures") for the California Mojave Desert were designed, modeled, and subsequently assessed with respect to their impact on the habitats of selected species over the region. The results show stakeholders and other interested parties not only how the various futures might impact species but also provide landholders with a tool with which to negotiate impacts of land uses on biodiversity.

The specific research objectives were to:

- Identify the features of the landscape (habitat types and configurations) that are essential for the long-term sustainability of native plant and animal communities in the Mojave Desert.

- Develop methods to characterize these "biologically relevant" landscape features.

- Evaluate how human activities have altered the Mojave Desert landscape; in particular, define relationships between specific types of human activities and changes in landscape features that affect biodiversity.

- Develop and evaluate approaches for predicting the effects of landscape change (and human activities) on biodiversity and on the viability of species of special concern (e.g., the desert tortoise) that can be applied over large spatial and temporal scales.

- Apply this information and analytical techniques to assess the ecological consequences of alternative land use scenarios developed for the Mojave Desert.

In order to accomplish these objectives, a phased approach was developed - to describe the biodiversity of the region, to determine trends in development, to establish a probabilistic model of future development, to calculate and model alternative future patterns of land use as they might exist in 2020, and to assess the likely impacts of those futures on biodiversity.

## Biodiversity and Wildlife Habitat Relationship Models

Human impact on biodiversity is recognized as a critical issue of global concern, and measures of biodiversity are considered as prime indicators of ecosystem structure and function. The project focused on faunal indicators of biodiversity employing wildlife habitat relationship models as an analytical tool. Wildlife habitat relationship models (WHR) represent one common approach for modeling animal distribution patterns. WHR models use pertinent literature and expert opinion to build a database consisting of range maps, species notes, a list of special habitat requirements, and a matrix of suitability levels for each species given different habitat factors. These models are often linked with coarse cover maps of general habitat classes to build spatial predictions. They have general application for regional perspectives, but lack local specificity. The result is a trade-off for models being spatially explicit, and having region-wide generality, rather than ecological specificity.

The WHRs used in this study were based on aspect, elevation, slope, soil moisture capacity, surface water, hydrology, temperature, soils, landform, and vegetation information. After recording habitat information for 274 (including nine that were introduced) vertebrate species, it was determined that the majority of species habitat information was related to elevation, water requirement, landform, and vegetation. Species distribution models were refined through the use of existing GIS layers, including: (1) landform types in the Mojave Desert; (2) digital elevation models; and (3) a digital surface hydrology layer from lake and reservoir reach files, digital line graphs, and hand-digitized spring locations. A suitable vegetation coverage was not available.

Habitat-landform relationships were investigated for eleven focal species resulting in the development of a spatially explicit habitat model, LizLand, which was initially tested on three lizard species and subsequently used to generate habitat suitability maps for all eleven focal species. LizLand reflects observed biological processes and was compared and contrasted with the California Mojave Desert GAP model, which did not show equal precision or accuracy for lizard habitats.

## Probabilistic Model for Future Development

According to historical population data, the population of the Mojave has experienced staggering growth over the past several decades. During the period from 1970 to 1990, the population of incorporated cities within the study area grew by over 350 percent, increasing from nearly 70,000 in 1970 to over 300,000 in 1990. As such, human population represents a key driver of environmental change within the area. If trends continue, the study region's population is projected to increase by nearly 900,000 people during the period 2000-2020. It is estimated that the total population in the study area will be 680,711 and 1,346,682 by 2000 and 2020, respectively, which means a total population growth rate of 98% for the region during the 20-year period.

The study area of 7.4 million ha contains 1,542,337 ha of private land. As of 1990, approximately 124,725 ha had been developed, leaving 1,417,612 ha of undeveloped private land available for potential future development. Using land use change data obtained from 1970 and 1990 satellite images, logistic regression was used to construct a model to predict the probability of future development for each undeveloped hectare of private land in the California Mojave Desert. Six independent variables were selected that influence the development of land in the study area: 1) distance to existing development, 2) distance to primary roads, 3) distance to non-primary roads, 4) percent of surrounding development, 5) location within or outside city boundary, and 6) % slope. The resulting model predicts the probability of development for each undeveloped privately-owned hectare within the 7.4 million hectare study area as an input for the alternative futures.

## Alternative Futures

The alternative futures modeling approach used in this study is based on a conceptual process designed to assist the various stakeholders of the region to explore the impacts of future land-use decisions. *Stakeholders* are those who live, work or have a major interest (or “stake”) in the region and *future land-use* is defined as dependent on biophysical, economic, and socio/demographic drivers.

It is the evaluation of each of these three drivers that builds a background of the project as related to the futures and identifies the significant components of limiting and trigger factors. These two factors can be utilized in the construction of the assessment models and the alternative futures. It should be noted that these models (as well as designed futures) are hypothetical and/or stylized representations of various land uses and/or environmental elements. Issues that form the basis of the assessment models may come from the various stakeholders and public surveys, and may range from ecological considerations to landscape aesthetics.

The futures represent alternative pathways or assumptions for how the landscape might appear in the year 2020 with the addition of nearly one million people. Three separate types of futures were developed. The first assumes existing trends and data and extrapolates them into the future. These are “model-based” (e.g. *Trend* and *Plans Build-Out*). The second type of futures, "planning-based", combines the same approach used for the model-based with newly created spatial information that simulates the effects of land use plans, land use policies, or new construction. Other alternative futures studies have used design-based scenarios instead of or in addition to planning-based. The third group, “combinatorial futures”, combined the output from model-based and planning-based approaches to create futures that reflect these interactions.

Three types of alternative futures were developed – model based, planning based and combinatorial – resulting in a total of 33 futures, nine of which were used for further modeling. Of these, the scenarios that showed development displaced from areas north and west of Edwards Air Force Base to Barstow and areas south of Edwards and China Lake, and south and west of Twentynine Palms were deemed the most realistic from the perspective of minimizing impact on biodiversity while maintaining military mission interests.

## Implications for Biodiversity

As stated previously, the two primary objectives of the project were to develop the alternative futures of the California Mojave Desert and to assess how these alternative futures might affect biodiversity. The impacts of alternative futures on biodiversity were considered in several ways. The first was how the futures might impact specific groups of species as a function of the futures. This was accomplished as a part of the process of developing and testing the biodiversity "driver" as an impactor on the development of the futures themselves. The second was an evaluation of how the alternative futures might impact biodiversity, that is, groups of species. The third was to assess the impacts on the habitats (as defined by their associated landforms which drive the LizLand model) of species and assess the changes of the respective habitats as a function of the developed futures. Finally, the futures were evaluated as a function of their impact on a number of key species.

The principal impact of the alternative futures on biodiversity is the consequent encroachment of the potential development patterns of those futures on habitat. As an example, the *Plans Buildout* future, has the greatest amount of land use change, with a total of nearly 550,000 hectares developed (from a 1990 development of about 125,000 hectares). For this most extreme situation, the LizLand model indicated that the Mojave Fringe-toed Lizard (*Uma scoparia*) will see a 22.5% decrease in its habitat. Yet the habitat decrease percentage is for the entire area of the California Mojave Desert, and with most of the land in public ownership, this loss means that nearly all of the habitat of the Mojave Fringe-Toed Lizard occurring on private land will be lost. In fact, nearly half of that species' habitat is lost for most of the futures, with only the *Biodiversity* and the *Military Buffer Swaps* having significantly less habitat loss. This species clearly is benefited by the *Biodiversity Swap* which was essentially intended to protect the greatest number of species, but not necessarily threatened and endangered species, or species of concern. The *Biodiversity Swap* future protected wind blown sand habitats, which is also prime habitat for the Fringe-toed Lizard.

The Desert Tortoise (*Gopherus agassizii*), on the other hand, has an almost identical loss of habitat regardless of scenario. A comparison of the alternative futures shows little difference in habitat loss. In the *Plans Build-Out* future, approximately half of the private land within the western Mojave is converted to development, possibly placing an additional burden on the two nearby military bases (Edwards AFB and MCAGCC) to protect this already threatened species.

Most of the habitat of these eleven species is protected as a result of their occurrence on public lands. Only a few species and one subspecies are threatened by the prospect of future development. Nevertheless, increased pressure on public land management agencies to manage, and protect species diversity is a likely outcome of increased development on private lands.

## Conclusions

Where habitats intersect urban development, associated species will suffer a greater risk of habitat destruction and elimination. The burden that the military might shoulder with respect to biodiversity protection depends to some degree on the proportion of habitat critical for a particular species occurring on military lands. Eight of the eleven species studied have close to14% of their potential habitat on military lands.  Therefore, in some cases, existing DoD lands will not have to be protected to conserve habitat.  The military might, however, wish to engage in land swaps where it might exchange land that has little training value and little testing value as well as high habitat value for private land with higher biodiversity value regardless of training value.  Concomitantly, those species which have considerable habitat both on high value DoD training and testing land and on land subject to development might be at very high risk for habitat loss.

The DoD might find itself needing to negotiate land conservation with both the private sector and other land holding agencies.  The intersection of alternative futures with land ownership might shed light on those areas of concern.  Species, whose habitat occurs primarily on private developable land and on portions of military land which are used primarily for training and testing activities, raise red flags from a biodiversity conservation perspective and are likely to be given additional attention by the military.

While the research was conducted specifically in the Mojave ecoregion, the understanding gained and approaches developed are more broadly applicable. In particular, this study has contributed to improved understanding of the effects of human disturbance on biodiversity in arid landscapes in general. The analytical framework and user-friendly interface can be adopted to address land-use conflicts and the regional management of biodiversity in other environments.

# CHAPTER 1

# INTRODUCTION AND SCOPE OF WORK

The Mojave Desert is an area of unsurpassed beauty, with clear air, long vistas, snow capped mountains, lava flows and sand dunes, and wide empty spaces. While the Mojave has been described by some as “scorched outback” or “the place that God forgot”, it is also home to a unique biodiversity with 2600 species of plants and animals. In fact, one fourth of its 2000 plant species are endemic to the region (Rowlands et al., 1982). Although ecologically and geologically diverse, the Mojave ecosystem is also fragile. Many of the region’s species are considered rare, threatened, or endangered and the ecosystem recovers exceedingly slowly after disturbance. In fact, the tracks from some World War II training exercises are still plainly visible in the landscape.

The Los Angeles Times called the Mojave “California’s final frontier,” and regarding its future remarks: “The most populous state draws a bead on its last great cache of vacant real estate” (Los Angeles Times, 12/11/96). Lured by inexpensive land and open space, more and more people are choosing to make the Mojave their home. According to the Southern California Association of Governments, the fastest growing areas in the Mojave will nearly triple in size in 25 years. Proposals for industrial parks, landfills (for low-level nuclear waste, hazardous chemicals, and trash from the Los Angeles Basin), pipelines, and even agricultural development abound. Home to over two million people, the Mojave is also within a day’s drive of forty million people. The area is heavily, and increasingly, used for outdoor recreation, ranging from off-road vehicles to solitary wilderness experiences. Mining, grazing, and Department of Defense (DoD) military installations have also long been important components of the local economy.

Over three-quarters of the land area in the California Mojave Desert is managed by the federal government **(**Table 1.1). The major land steward is the Department of Interior, managing approximately 4.5 million hectares through the Bureau of Land Management (BLM) and National Park Service (NPS). The other major public land management agency is the DoD, controlling about 1 million hectares, primarily within the western Mojave. Recognizing the value of the Mojave ecosystem, the likelihood of continued land degradation and land use conflicts, the Departments of Defense and Interior, in 1993, established the Mojave Desert Ecosystem Initiative (MDEI) to coordinate management activities in the region. Similar concerns led Congress, in 1994, to pass the California Desert Protection Act (Public Law 103-433), which designated certain lands in the California Desert as wilderness and established Death Valley and Joshua Tree National Parks and the Mojave National Preserve. Although large areas have been set aside to protect “their public and natural values,” by themselves these wilderness areas and parks may not be sufficient to sustain valued features of the Mojave, nor do they resolve the land use conflicts in other portions of the region.

Table 1.1. Land area by ownership for the California Mojave Desert (after Thomas and Davis, 1996)

| Organization | Area $km^2$ | Percent of Total Area |
|---|---|---|
| **Federal** | | |
| US Bureau of Land Management | 25194.2 | 34.05 |
| US National Park Service | 20652.3 | 27.92 |
| Department of Defense | 10670.7 | 14.40 |
| US Forest Service | 220.4 | 0.30 |
| Other | 29.6 | 0.04 |
| **State** | 1739.5 | 2.35 |
| **Local** | 26.8 | 0.04 |
| **Private** | 15455.2 | 20.88 |
| **TOTAL** | 73988.7 | 100.00 |

## Civilian and Military Importance of the California Mojave Desert

The deserts of the American West and the Mojave Desert in particular, have always exerted a fascination for us. From John Wesley Powell (1879) on we have found them to possess special qualities. Our interest in the Mojave Desert culminated in the California Desert Protection Act of 1994 (Public Law 103-433). In this Act "Congress finds and declares that -"

> (1) the federally owned desert lands of southern California constitute a public wild land resource of extraordinary and inestimable value for this and future generations;
>
> (2) these desert wild lands display unique scenic, historical, archaeological, environmental, ecological, wildlife, cultural, scientific, educational, and recreational values;
>
> (3) the California desert is a cohesive unit posing difficult protection and management challenges;
>
> (4) the public land resources of the California desert are threatened by adverse pressures which would impair their public and natural values;

These values and concerns are the societal context for the research reported herein.

Within the California Mojave Desert, the U.S. Department of Defense is one of the major land owners (over 14% as shown in Table 1.1) and stakeholders in its future. The military brings to the Mojave Desert three major concerns. The first is training and testing. Training for the military is literally a matter of life and death. It is sometimes difficult for civilians to understand how seriously this is taken:

> "The battlefield fixes the directions and goals of training. The battlefield makes rigorous physical, psychological, and moral demands that require both tangible and intangible qualities. It demands the ability to fight and the willingness to fight.... Thus, training must make Marines and leaders physically and mentally tough enough to survive and win under conditions of severe hardship, searing emotion, and extreme danger" (USMC, 1991).

The second concern is that the military, being an arm of the Federal Government, must conduct its operations in conformance with most Federal environmental laws. In particular, the Endangered Species Act and the listing of the Desert Tortoise as a Federally Threatened Species have imposed major responsibilities and constraints on the military in the Mojave Desert.

The third concern is that the military must work with the public and its concerns, which is especially important with regard to land use negotiations (Creswell, 1988).

## Research Objectives

It is in the context of all the stakeholders that this research was undertaken. The overall research objective was to evaluate the effects of human activities on biodiversity[1] and related environmental concerns within the Mojave ecoregion of California both at the present (1997 was the base year) and in 2020. While planning efforts and analyses are ongoing within individual parcels of land or for specific land ownership (e.g., Department of Defense, National Park Service and Bureau of Land Management lands), at present *no one is addressing these issues within the region as a whole*. We consider that analyses at this larger spatial scale to be essential context for understanding the consequences of actions or management plans at specific sites or areas within the Mojave.

We proposed that management of an area having several installations and other land ownership by a number of stakeholders would be more effective from the perspective of biodiversity management and negotiation than management by a multitude of single agencies. We proposed to design and model alternative future patterns of land use ("Alternative Futures") over the entire California Mojave Desert and to determine habitats of selected species over the same area. We would subsequently evaluate the relative impacts which each of the futures would have on the selected species. The results would show stakeholders and other interested parties not only how the various futures might impact species but also give landholders a tool with which to negotiate impacts of land uses on biodiversity. In order to accomplish this, we needed to develop a phased approach to describe the biodiversity of the Mojave Desert,

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[1] Biodiversity, in its simplest terms, is the variety of life and its processes (Keystone Center 1991). The specific aspects of biodiversity that we will address are described in Sections 3 and 4.

determine the trend in development, develop a probability of future development model, calculate and model alternative future patterns of land use as they might exist in 2020, and evaluate the impacts of future patterns of land use (the alternative futures) against species distribution and land ownership. Figure 1.1 (Appendix A) illustrates the conceptual model of the project. The starting points are illustrated in the bottom row of boxes and analysis flows upwards. Current plans, the change in the pattern of urbanization from 1970 to 1990, the socio-demographic, economic, and biophysical factors, and assumptions regarding their changes work together to produce the alternative futures. Then geomorphology and surface lithography are combined with vegetation, species range limits, and new field data to produce models of the distribution of biodiversity (including vertebrates and focal species). Our conclusions (Chapter 9) are then derived by comparing the distribution of species against landforms and landforms against ownership.

In order to carry out the activities as conceptualized in the model, a set of specific research objectives was defined:

- Identify the features of the landscape (habitat types and configurations) that are essential for the long-term sustainability of native plant and animal communities in the Mojave.

- Develop methods to characterize these “biologically relevant” landscape features.

- Evaluate how human activities have altered the Mojave landscape; in particular, define relationships between specific types of human activities and changes in landscape features that affect biodiversity.

- Develop and evaluate approaches for predicting the effects of landscape change (and human activities) on biodiversity and on the viability of species of special concern (e.g., the desert tortoise) that can be applied over large spatial and temporal scales.

- Apply this information and analytical techniques to assess the ecological consequences of alternative land use scenarios being considered for the Mojave.

- Develop a framework and user-friendly interface that will facilitate the use and further applications of our data and analytical techniques by decision makers in the region.

# CHAPTER 2

# STUDY AREA

The study area for this research is the portion of the Mojave Desert ecoregion occurring within the State of California, an area of nearly 74,000 km$^2$ (Figure 2.1, Appendix A). While the Mojave Desert ecoregion extends beyond California, we chose the state line as our eastern boundary for several reasons. The dominant reason is the upper limit on the size of the region that we can adequately characterize given the resources and time available. We concluded that an area of approximately 74,000 km$^2$ was as large as we could realistically cover at a sufficient level of resolution to achieve the stated objectives. The state line boundary is also consistent with not only state and county jurisdictions, but also most federal management areas (e.g., BLM districts). Finally, other research projects with which we coordinated (in particular work conducted under the auspices of the MDEI and funded by DoD's Legacy Program) had previously selected the border as their eastern boundary for data collection.

## Brief Human History of the Mojave Desert

People appear to have been in the Mojave roughly coincident with their introduction to North America, or approximately 12,000 years ago. There is a claim that broken stones found near Calico in the central Mojave represent human artifacts datable to about 200,000 years ago, but few accept this claim. The consensus is that man appeared at the end of the last glaciation, about the time the Mojave began to take on its current character (Grayson, 1993). At first it would have been more hospitable to humans surviving mostly as hunter/gatherers, but as it continued to dry out and warm up the pattern of use of the Mojave changed. In late pre-contact times several tribes of Indians lived in and around the Mojave. Most permanent populations appear to have been centered on permanent water, mainly along the Colorado and Mojave Rivers and in the wetter Coast Range Mountains. Use of the Mojave was then seasonal for hunting and gathering and for some agriculture. Camps were therefore scattered across the desert, but only occupied intermittently. The Mojave, however, also contained several major trade routes from the coast of California inland to Nevada, Arizona and beyond. These routes took the form of permanent trails, some of which still exist, which traders used to convey more commercial goods back and forth. As a consequence of all of these activities there exists today literally thousands of archeological sites throughout the Mojave Desert. Many are camp sites, but all remain important to the present indigenous peoples and are of great concern to the Federal Government.

Indigenous peoples today also primarily occupy the periphery of the Mojave Desert. Existing Indian Lands are primarily along the Colorado River, in the Coachella Valley (Palm Springs) and in the Coast Range west of the Mojave. However, they still use the desert in a variety of ways. In particular, certain locations are important as cultural and religious sites. These sites are not generally known to the public, and the California State Native American Heritage Commission and the Bureau of Land Management have an agreement to keep such sites secret. The combination of archeological sites and sites still in use by Native Americans constitute one of the major contexts for any planning or conservation effort in the Mojave Desert.

The Spanish began their settlement in California by sea or overland through the Sonoran Desert in the 16th Century. But it was not until 1776 that the Mojave River was discovered by Padre Francisco Garces as he crossed the Mojave from the Colorado River to Mission San Gabriel (present day Los Angeles). A half century later there were still no white settlers in the Desert (Pierson, 1970). After that it gradually began to see ranchers and other settlers. Over the next 50 years as Americans populated California, the desert gradually opened up to more settlers and miners. The advent of railroads marked the beginning of real incursion. Forward looking citizens working at both the state and federal levels created several extraordinary reserves including, most importantly, Death Valley National Monument and Joshua Tree National Monument (both now National Parks). After World War II, highways proliferated and popular interest in the natural history of the desert took off (Automobile Club of Southern California, 1992). Bird watchers, rock hounds, and wildflower photographers were part of a growing constituency concerned about preserving the natural character of the desert. As massive population growth began, these concerns led to the declaration and establishment of the Desert Protection Act of 1994.

The American Military began operations in the Mojave Desert in the mid 19th Century to protect settlers and travelers from attacks by the Native Americans. Their presence continued and expanded as some of the largest military installations in the country were established and all branches of the military now have a major presence there. The lands are used for training and testing as well as day-to-day operations. When these lands were set aside for military use over 50 years ago, their primary advantage was that “they were remote and of little or no value to the general public” (Creswell, pers. comm., 1996). The military gained space to maneuver, conduct gunnery and bombing practice, and pursue other activities that are too dangerous to be done in close proximity to civilians. As times have changed, the desert has become populated and valued. This has led to many new constraints on the military in addition to those generated by environmental laws.

## General Environmental Issues/Problems in the Mojave Desert

The Mojave Desert suffers from many of the same environmental stresses that affect the rest of the country, however the Mojave Desert has lower ecological recoverability compared with more mesic ecosystems. The fragility of the soil in particular means that even light stress may cause complete and permanent damage. For convenience, and partially following the BLM ( USDI,1980), we categorize anthropogenic stressors on the Mojave Desert as follows:

*Development: residential, industrial, commercial, infrastructure:* These activities affect the land cover of the Mojave Desert much as they do anywhere else. Parts of the Mojave are now very densely developed (Victorville, Barstow, Twentynine Palms) and are essentially urban and suburban. A great deal of the western Mojave is covered with less dense rural residential development. This varies from “jackrabbit shacks” designed to be the minimal structure which allowed a claim on the land, to rather extensive ranch-like clusters of structures. Highways and other road networks form a major stress causing direct mortality as well as population fragmentation (although this is not well understood). The Colorado River Aqueduct is a special case of infrastructure which may have an effect on neighboring populations.

*Agriculture:* Agriculture is not extensive in the Mojave Desert. Most existing agriculture is along either the Colorado or Mojave Rivers and west and south of Edwards Air Force Base. However, a number of unique vegetation types and plant species also occur in these regions so the potential effect of this agriculture may be more important than would simply be indicated by its areal extent. A key problem resulting from agriculture in the west Mojave is that of salinization and abandonment. Both result in blowing dust - a problem for the military and a biodiversity stressor. The nearby Imperial Valley in the Colorado Desert south of the Mojave has been almost entirely converted to agriculture with the use of imported water. Some attempts at this type of agriculture have been made in the Mojave Desert, but they have not been successful. Future attempts may occur and, if successful, would significantly alter land cover.

*Grazing:* Few activities in the Mojave Desert are more controversial than grazing. Most grazing there takes place on BLM Grazing Allotments. Parts of the Mojave were grasslands at the time of the Spanish, but few native grasslands remain. Cattle are not present in large numbers, but their impact on the environment may be considerable through alteration of the cover and composition of the vegetation, physical trampling, compaction of soil, and the human activities necessary for their maintenance.

*Exotic species:* The Mojave Desert is beset by a variety of exotic plant and animal species. Tumbleweed, or Russian thistle, (*Salsola kali*) is sometimes taken as emblematic of the desert, but, in fact, is an introduced species. Numerous exotic plant species are favored as a result of cattle grazing at the expense of native species. The most controversial exotic animals are horses and burros which cause great damage, especially around springs and compete with the native Bighorn Sheep. Much of the work of the Bureau of Land Management revolves around the difficult issues of managing the species which have important public constituencies, but are environmentally detrimental. Other exotic species have resulted from increased human activity. The creation of open water of various sorts has allowed the raven to move into the Mojave Desert where it has become a serious new predator on hatchling and young Desert Tortoises. As usual, cats and dogs have moved in along with humans in suburban and rural residential areas where they create new pressures on smaller vertebrates such as lizards and some birds.

*Vehicle based recreation:* This issue is the outstanding special environmental conflict that is most characteristic of the Mojave Desert.

> According to one study, the CDCA [California Desert Conservation Area] had 15,000 miles of paved and maintained roads, 21,000 miles of unmaintained dirt roads, and 7,000 miles of vehicle-accessible washes. However, these routes are not uniformly distributed, and desert topography and vegetation do not prevent, and may even encourage, cross-country travel by motorized vehicles. Desert soils and

> vegetation retain the marks of this kind of travel for many years, except in a few places where occasional rains, windstorms, and flash floods erase them. Thus, one vehicle traveling cross-country can create a new route of travel. The proliferation of roads and trails in the CDCA has resulted in a serious problem in many areas and provides a most difficult management issue for the BLM and public (USDI, 1980).

Through a great effort of education and enforcement of access rules, much progress has been made in the last decade controlling the problem of off-road vehicle traffic, but it still remains a defining issue in the Mojave.

*Water redirection:* What little water naturally exists in the Mojave Desert is the subject of intense management. In particular, the Mojave River itself has been subjected to numerous channelizations and diversions. Wells in other areas have most likely interacted with springs to the detriment of native plants and animals although this is not well documented. Importation of water has caused problems by favoring exotic species that could not otherwise live in the desert. Furthermore, water diversion may reduce what little soil moisture is available, especially in riparian areas.

*Mining:* Mining for an extraordinary variety of minerals and materials has been a major activity in the Mojave for nearly 150 years. Mining impacts include the extraction of minerals from dry lakes, which can result in changes in the pattern of biodiversity that is dependent on the unique geochemistry of these systems. Underground mining requires roads for access and creates tailings which alter land cover. Ironically, some bat species appear to have benefited from mining as they now inhabit abandoned mines. Yet, these abandoned mines, themselves, can pose an environmental hazard to the public. Mining is ubiquitous but is not responsible for large scale changes in land cover.

*Noise:* Without vegetation to muffle sound, noise pollution can be a bigger problem in deserts than elsewhere. There is some evidence that noise from vehicles adversely affects some species. A variety of sources contribute to noise with aircraft perhaps posing an exceptional problem.

## Military Environmental Issues/Problems in the Mojave Desert

Probably the most serious environmental concerns of the Military in the Mojave Desert are those generated by the Endangered Species Act. Creswell (1994) discusses in detail the problems which arise in the day-to-day management of military bases as conflicts must be resolved between two valued national policies: national security and wildlife conservation. In his view, the conflicts are exacerbated by institutional cultural differences between the military and the Fish and Wildlife Service, the Agency responsible for enforcing the Endangered Species Act. He also argues persuasively that at times the interpretation of the Act exacerbates the conflict. That is, a species is not listed until it is already in danger of extinction making it very difficult to manage and in a sense creating a “surprise” for the military. He notes that in general military bases are islands of more natural and diverse habitat frequently placed in a sea of civilian development. From the military perspective it seems that they are being penalized for having healthier populations of endangered species while civilians are less penalized because they have often already allowed the species to decline and even go extinct. Further, it is often the case that more intensive research has been undertaken on military bases so that their populations are better known than those of the surrounding areas. Again, the bases perceive that they are penalized for having better information. These two factors, healthier populations and more information are often used as arguments by civilian developers who wish to conclude that all management for endangered species can be "dumped" onto the military. This strikes the military as unfair. They argue, in turn, that they should be responsible for only their "fair share" of the endangered species load, although just how a "fair share" is to be calculated, is unclear.

The Military versions of many of the stressors listed above are similar both in cause and impact to those generated by the civilian population. The infrastructure of bases and the usual activities of military personnel create many environmental effects in essentially the same manner as civilian activities. Other military activities are not similar:

*Maneuvers:* The movement and deployment of military personnel and equipment is often conducted over open landscape. Tanks, soldiers, and temporary bases all may impact the substrate and biodiversity directly.

*Ordnance:* Ranging in size from small bullets to large bombs, ordnance has a direct effect on the landscape, and often on biodiversity. Unexploded ordnance also may render parts of the landscape unusable for any civilian activity.

*Noise:* Many military activities are extremely noisy. Helicopters especially can create noise in close proximity to wildlife. The problem of noise is greatly exacerbated by developments which are allowed to proceed adjacent to military installations.

*Smokes and Obscurants:* Smoke emanating from exercises, and clouds of various kinds of obscurants generated as part of an intentional effort to conceal military activity, can pose both a health hazard as well as affecting the behavior of a variety of animals. They may also pose a direct threat to vegetation as well.

## Brief Natural History of the Mojave Desert

The Mojave Desert as we know it today and as mentioned previously, has resulted from the climate change associated with the end of the last glacial episode about 12,000 years ago. During this time, it has become much warmer and drier and developed its character as one of the foremost deserts of the world (Grayson, 1993). Today's climate and weather is a classic desert pattern. It is hot and dry on average, but it is also importantly the case that rainfall is highly variable. The underlying physical structure of the Mojave Desert is that of Basin and Range. This consists of a series of sharply uplifted mountains often steeper on one side than the other and with relatively flat basins in between as a result of alluvial and lacustrine fill. This geology and regional geomorphology is typically associated with very little soil and sparse vegetation. The lack of surface protection associated with the thin soils and sparse vegetation, in turn, means that hydrologic and aeolian erosional forces dominate in shaping the landscape (Mabbutt, 1977). Severe rainstorms create direct splash erosion followed by flash floods which create much of the patterns of mountain slopes and basins through erosion, sediment transport and sorting. The Basin and Range geomorphology also helps to create severe cadiabatic winds characteristics of deserts which scour the landscape and deposit fine sands resulting in sand dunes and dune fields (Tchakerian, 1995). Further, wind unhampered by vegetation, can impose constraints on the activity patterns of many species of animals as they attempt to avoid desiccation.

Given the harshness of the environment and its relatively young age, it is remarkable that the flora of the Mojave Desert is estimated to contain between 1750 and 2000 species (Rowlands et al., 1982). These include forms ranging from the smallest annual to the magnificent *Washingtonia* palms of the larger oases. With this number of species it is not surprising that several different attempts have been made to classify the types of vegetation occurring throughout the Mojave Desert, although there is no detailed vegetation map available for the area. Rowlands et al. (1982) review some eight vegetation classification systems with the numbers of classes ranging from 7 to 30. Some of the most important classes are Creosote bush Scrub, Sagebrush Scrub, Joshua Tree Woodland, and Pinyon-Juniper Woodland. Many of the vegetation types are restricted to a particular soil or substrate type such as the group of species found on sand dunes, or those found on calcareous outcrops derived from dolomite or limestone. Others are restricted to locally wetter areas such are riparian zones and springs. Perhaps Creosote bush is the most characteristic plant of the Mojave Desert. Individual clones of this species have been estimated to be as much as 11,700 years old implying that these individuals have been present since the very beginning of the formation of the present day desert landscape (Vasek, 1980; Sawyer and Keeler-Wolf, 1995).

At least since Walt Disney’s *Living Desert* (1954), people have come to realize that the desert, far from being devoid of animal life, as it may seem at first glance, in fact has a rich assortment of both invertebrate and vertebrate species. For this study, we recognize 274 vertebrate species including 8 amphibians, 44 reptiles, 65 mammals, and 157 birds (Appendix E). Invertebrates are less well-known, but may number in the tens of thousands of species. For example, over 2,000 species of ants alone are known to occupy the Mojave Desert. The biodiversity examined in this effort was on vertebrate species.

# CHAPTER 3

# A CONCEPTUAL APPROACH TO FUTURES MODELING

The alternative futures modeling approach used in this study is based on a conceptual process designed to assist the various stakeholders of the region with exploring the impacts of future land-use decisions (Figure 3.1, Appendix A). *Stakeholders* are those who live, work or have a major interest (or "stake") in the region and *future land-use* is defined as dependent on biophysical, economic, and socio/demographic drivers. As part of the conceptual process, it is felt necessary to maintain a clear language of key terms. The language would have to be professionally neutral in order to ensure that a broad audience of users would feel comfortable with its use and application. If professional terms were to be included, they would have to be redefined in easily understood terminology that also allowed them to be interrogatory (e.g., the development of a set of questions to be asked and where to file the answers).

The approach outlined in Figure 3.1 diagrams the various activities and linkages needed to address anticipated objectives and outcomes. In brief, a format is provided for interrogating a full range of environmental planning and management issues by a diverse group of stakeholders (see, for example, Jensen and Bourgeron, 2001). In order for the process to be flexible, inclusive, and repeatable, it would also have to be independent of location, content, scale, time, and technology. If the approach is to be useful, it must allow for the analysis of any geophysical region regardless of it spatial location. The approach must not only be able to allow for the analysis of different biophysical and cultural content areas but also have the capacity to discover as part of its analytical structure and procedures new content areas not initially defined.

Although the California Mojave Desert represents a very large spatial scale, it is important that the conceptual approach have the capacity to increase or decrease the scale of analysis within the scale definition of its data. Given appropriate data, seasonal variations in time should not constrain the analysis or synthesis of the study whether in retrospect or prospect. It is clear that Geographical Information Systems (GIS) incorporated in complex computer models is an efficient and productive package of technology. However, the approach must be compatible with other field intensive applications of data, analysis, and synthesis utilizing basic cartographic techniques. If any of these variables were to constrain or stall the analysis, it would be seen as a limitation to the comprehensive nature of the approach.

The conceptual approach illustrated in Figure 3.1 is cyclical and non-linear in its application in order to allow various components the opportunity to repeat themselves (i.e., an iterative process). The user must be able to enter and leave the conceptual model at any point in order to address new issues as they develop over time, site, context, or program (Toth, 1988). As an approach, the conceptual model must provide a system for categorizing information and data, and placing it in an easily retrieved form for future use (Schein, 1988).

The conceptual approach also provides the opportunity to address limits or thresholds with respect to the principal drivers. As each of the drivers is developed, it is important to address the question of “limiting” and “trigger” factors that may possibly be resident in each. A *limiting factor* is defined as an environmental factor which limits the growth or development of an individual or community. A *trigger factor* is a changed or new factor that sets off a chain of unforeseen events in an environment or ecosystem (Billings, 1978). These two factors help to identify those operationally significant phenomena from which future decisions and mitigation strategies can be made, and as such, they could also be indicators with respect to thresholds in any of the three drivers.

Although the conceptual approach depicted in Figure 3.1 appears linear, its actual configuration is three dimensional and forms a cycle of activities which emphasizes various elements within the approach. As is outlined, the “implementation” of various plans would create, over time, a new set of biophysical and cultural issues which would form the “background” of new planning and management concerns.

The conceptual framework also takes into account both the site and its larger context or surroundings. In addition to these two spatial aspects, the potential patterns of land uses or activities are a third element (i.e., a *program*) that needs to be addressed as part of the analysis. *Site* is defined as a given section of landscape having distinct physical or measured boundaries, such as “Edwards Air Force Base” or the “City of Barstow”. *Context* is the background or environment relevant to the site; it is the area in which the site is situated within the California Mojave Desert. *Program* is defined as a range of issues or activities describing land uses.

Before any data search and/or collection begins, a “pre-analysis” of background issues must be carried out. This research activity takes into account the context, site, and program as defined earlier. Stohlgren (2001) suggests that there are four major features of data acquisition in ecological assessment: (1) clearly articulated goals and objectives; (2) a commitment to preserving the integrity, longevity, and accessibility of the data for future unforeseen uses; (3) a detailed vision of how the data will be gathered, stored, summarized, statistically analyzed, displayed, and archived; and (4) an understanding of the quality and limitations of the data. It should be understood that data can be added and updated throughout the conceptual approach illustrated in Figure 3.1. Likewise, the various managers and stakeholders in the planning region can enter into the approach at any stage in the process.

The biophysical, socio/demographic and economic drivers are all examined in order to establish an understanding of each and their interrelationships. It is the research of each of these three drivers that will build a background of the function and structure of the project as related to the futures and identify the operationally significant components of limiting and trigger factors defined earlier. These two factors can be utilized in the construction of the assessment models and the alternative future scenarios. It should be clear that these models (assessment and scenarios) are hypothetical and/or stylized representations of various land uses and/or environmental elements. Issues that form the basis of the assessment models may come from the various stakeholders and public surveys. They may range from ecological considerations to landscape aesthetics.

The alternative future scenarios can also use the assessment models as part of their construction and definition (combinatorial) (Steinitz, 1996). It should be clear, as indicated on the diagram, that these scenarios can also be recommended by various desert managers, stakeholders, and the general public (surveys). Once the scenarios are completed, assessment models can be performed in order to determine whether or not the scenarios are compatible, permutable, or would threaten to terminate (terminal) any or all of the three drivers. It should be noted that just prior to the evaluation activity there is a check point to determine whether any of the scenarios are approaching thresholds related to limiting and/or trigger factors previously identified in any of the drivers. If the evaluation of scenarios indicates a compatible relationship, various strategies and policies can then be constructed and recommended to managers and stakeholders for implementation. If the evaluation indicates a permutable consequence, various mitigation strategies may be employed to modify the landscape to the land uses or the land uses to the landscape. In any event, these new land uses will generate new questions, problems, or issues which, in the continuing cycle of the approach, would enter in the pre-analysis phase to begin their future examination and resolution.

# CHAPTER 4

# THE BIODIVERSITY DRIVER

Habitats impacted by anthropogenic disturbance, yet remaining somewhat pristine, are some of the last remaining areas to support diverse, viable populations of native species (Noss and Cooperrider, 1994). The Mojave Desert is an immense landscape of mixed uses, including large tracts of protected habitat. Some of these areas are managed specifically for the persistence of species and system integrity but may not be able to adequately protect the desert's biodiversity due to the placement of the reserves or the degree of habitat alteration. Comparative models of biological land values can be used for selection purposes while there is still time and undeveloped land to protect important desert habitats.

In the face of urbanization, the remaining locations of native species are of great importance. However, not all populations can be protected due to land use conflicts, lack of funds, or competing and often conflicting social values. To sustain populations of terrestrial vertebrates for the long term, essential tracts of habitat must be protected. How those areas are chosen becomes a difficult decision. The choice of areas to select for conservation is a difficult decision for managers and scientists due to the multiple factors involved. Habitats and species of concern, knowledge of their ecology, private sector and agency goals, and multiple biological solutions all have an effect on the decision making process. One of the most complicated objectives is how to conserve as many species as possible, or provide the greatest degree of protection, while minimizing the amount of land, money, or conflict involved (Camm et al., 1996; Mittermeier et al., 1998; Pressey et al., 1993). As land uses continue to change, and natural areas suffer greater degrees of impact, the urgency for conservation increases (Scott et al., 1990). Difficulties arise when deciding upon the most important features, species, or processes to conserve in a diverse area, and how to measure or evaluate them for their significance to the overall health of the system (Vane-Wright, 1991).

As large-scale spatial data becomes increasingly available, managers have the opportunity to do a comparative study of conservation strategies, or to test alternate selection methods, in order to make the best management and conservation decisions. Spatially-explicit biological information, such as GAP data (Scott et al., 1993), is available for many states across the nation. From this, biodiversity indices can be estimated and rapidly assessed over large areas. Spatial data can be used to model habitats and environments, to evaluate conservation choices designed to meet desired levels of species protection and to locate areas that are in need of preservation (Lesslie et al., 1988; Kiester et al., 1996).

In most cases, habitat loss or destruction due to increasing human use has been the main cause for the decline of species. In response, reserves have often been created whenever the opportunity arose; whatever could be saved was better than nothing at all (Pressey, 1994). The complete representation of all important species, habitats, or processes was not of prime concern and was usually not achieved (Noss and Cooperrider, 1994; Margules, 1989). In some cases, *ad hoc* approaches actually hindered the progress of conservation by depleting limited protection funds and allowing sensitive species to be exposed to disturbance in unprotected areas (Pressey, 1994; Bedward et al., 1992; Lombard et al., 1995).

This section describes the approach used to develop large-scale (i.e., “large area”) models of biodiversity in the California Mojave Desert. These models constitute an integral part of the Future Scenarios development process. We focus on several different indices of biodiversity, assuming that no single measure best portrays regional biodiversity. Use of the indices necessarily requires an understanding of how wildlife habitat relationship models (e.g., Salwasser, 1982) are built, as well as their limitations (Raphael and Marcot, 1986; Edwards et al., 1996) for management and conservation. To better represent the spatial context of the desert's animals, we evaluate the models based on species-specific area requirements, using “home range” as a measure of species population needs. The emphasis is on terrestrial vertebrates only, as the data structures for plants (e.g., current vegetation species and communities) and other taxa (e.g., invertebrates) are inconsistent to nonexistent.

## Modeling Regional Biodiversity: Use of Biodiversity Indices

A variety of indices can be used to evaluate an area as a precursor to ranking sites for conservation purposes (McKenzie et al., 1989; Terborgh and Winter, 1983; Purdie and Blick, 1986; Kershaw et al., 1994). Indices include straight numerical evaluations, as well as anthropogenic-based opinions such as areas which are undergoing the fastest rate of destruction and species loss (Smith and Theberge, 1986; Mittermeier et al., 1998; Brooks et al., 1992; Lesslie et al., 1988). Indices for site description would be universally comparable if consistent definitions were used. However, many indices are calculated for values that are considered important for a certain project or are site specific (e.g., Rossi and Kuitunen, 1996; Burnett et al., 1998). Over the course of time, definitions and formulae of specific indices are altered for the purposes of scientific study (see Vane-Wright et al., 1991). Comparison of two disjunct sites with any index requires equal sample area sizes, the assumptions that all individuals for a species are presumed to be equal, all species are presumed to be equally different from each other, and each species is of equal importance (Peet, 1974).

## Types of Indices

*Richness:* The most commonly used index of biodiversity is species richness. Alpha richness, the sum of all species occurring in an area, and point richness, the sum of species occurring at a single point in space, are two of the easiest values to calculate (Meffe and Carroll, 1997). In general, the term “biodiversity” is often assumed to be the same measurement as species richness and is frequently used in place of richness (McIntosh, 1967).

*Diversity:* Originally, diversity did not have an accepted definition and the term was considered unusable. Over time though, the idea of quantifying patterns of species abundance persisted and formulae were developed. The general calculation of diversity is the number of species in an area weighted by their abundance. Weighting is used in order to represent the evenness of the distribution of individuals within each species type. In some cases values other than abundance, such as productivity or size, are used for weighting. Diversity at different levels is classified into three groups: alpha diversity, the diversity within a habitat; beta diversity, the change in species composition across habitats; and gamma diversity, the change in species composition across landscapes or ecoregions (Whittaker, 1972; Kiester, 2001; Levin, 2000).

*Rarity:* Rarity is often considered the best predictor of population vulnerability, but can have more than one definition (Terborgh and Winter, 1983). With multiple definitions of rarity, it can be difficult to compare locations across ecosystems to decide which sites are in the greatest need for protection. Wheeler (1988) considers a rare species to be those present in less than 5% of the samples for an area. Rarity is often used to designate an area as a "hotspot," a site that contains a large percentage of rare species (Myers, 1988). Williams et al., (1996) define hotspots of rarity as sites that have the greatest number of species with limited ranges. Only a species with a large geographic range, wide habitat specificity, and a large population size is not considered rare; a species with any other combination of aspects is described as rare.

*Endemism:* The general definition of an endemic species is one that is native to a specific region, or is found only in a particularly narrow geographic range (Terborgh and Winter, 1983). Different ecological factors such as dispersal distance or temperature tolerance can also be used to define the range of an endemic species. The decision to label a species as endemic also varies with the time line that is considered; an organism can be defined as an endemic species depending on whether it was present before or after an ice age, plate separation, or speciation event (Meffe and Carroll, 1997).

## Wildlife Habitat Relationship Modeling

In order to calculate indices, information on individual species is needed. This typical comes from wildlife habitat relationship models (WHR). A wildlife habitat relationship model describes the predicted distribution of a species across the landscape. WHR models are created by defining and spatially delineating the types of habitats a species is constrained to and the processes that drive those selections (Morrison et al., 1992). There can be several WHR models for a given species. Examples include models that describe species locations during different seasons, the level of use of different habitat types, or the suitability of areas of predicted habitat.

Wildlife habitat relations models (WHR) (Salwasser, 1982) represent one common approach for modeling animal distribution patterns. WHR models use pertinent literature and expert opinion to build a database consisting of range maps, species notes, a list of special habitat requirements, and a matrix of suitability levels for each species given different habitat factors (Verner and Boss, 1980). These models are often linked with coarse cover-maps of general habitat classes to build spatial predictions. They have general application for regional perspectives, but lack local specificity (e.g., Gap Analysis, Scott et al., 1995).

In contrast are models built with finer-scaled data. Frequently referred to as Habitat Suitability Indices (HSI), the models typically use statistical tools (e.g., regression) to assess the strength of a relationship between species presence or abundance and a suite of ecological predictor variables. Data for these models are gleaned primarily from previously published studies and used to build suitability curves defining the relationships between species abundance and a set of habitat variables (U. S. Fish and Wildlife Service, 1981). The accuracy of an HSI depends in part on its generality. Stauffer and Best (1986) showed that different HSI models may often be needed for different habitat types. They concluded that for some species, models built with data collected across a number of habitat types may be too general to be accurate in any one habitat type. Nonetheless, HSIs are designed to make predictions about habitat suitability at scales that are relevant to local managers, such as that of a reserve or national park. At these scales they are likely to be more accurate than coarser-scale WHR models.

Unfortunately, HSI models have no spatial component, representing instead quantitative relationships between species presence or abundance and the predictor variables. While the variables modeled in HSIs usually have relevance to underlying ecological processes that influence the animal's presence or abundance, the lack of spatially explicit depictions of these variables makes it difficult to evaluate how they might be constrained, or in turn affect, land-use decisions. Given the desire for representative models having spatial representation in the whole of the California Mojave Desert, the models used here are best described as WHRs. This resulted in a trade-off for models being spatially explicit, and having region-wide generality, rather than the ecological specificity of HSIs.

## Data Sources

Data sources for the spatial analyses were the California LizLand Project for biological data, and GIS data from the USGS for geophysical layers (Mojave Desert Ecosystem Program, 1998). Spatial data from the California GAP CD-ROM includes land ownership, watershed boundaries, land use information, road, and river locations (Davis et al., 1991). Each set of data was provided as an independent GIS coverage or grid layer. Supporting species data came from the U.S. Fish and Wildlife Threatened and Endangered Species list for California (1998) and the California Department of Fish and Game Species of Concern National Heritage database (CNDD, 1999).

The California Gap Analysis Program (GAP) Jepson-defined ecoregion was used for the Mojave Desert biodiversity modeling boundary (Davis et al., 1991). The ecoregion was clipped at the California-Nevada state line and defined the limit of the study area region (Figure 2.1). The projection for all GIS data layers was inherited from the Mojave Desert Ecosystem Project (MDEP, 1998) in order to utilize all previously completed GIS work. Additional data layers used included a landform map developed by Dokka (1999), a digital elevation model from the MDEP (1998), a lake and reservoir coverage from California GAP (Davis et al., 1991), reach files from the U.S. Environmental Protection Agency (source: MDEP, 1998), USGS digital line graphs prepared by the MDEP (1998), spring locations digitized by hand from Bureau of Land Management (BLM) 1:24,000 topographic maps (1976-1997), and the California GAP land status coverage (Davis et al., 1991).

## Wildlife Habitat Models

We acquired digital wildlife habitat relationship models for all species from the State of California, Department of Fish and Game (DFG), California Wildlife Habitat Relationships Program (CFGWHR**,** 1999). We excluded all species whose distributions were not predicted to occur in the desert based on their spatial relationship to the study area boundary (Karish, 2001). Many species, which were not considered true residents of the Mojave, were retained due to the generality of the original WHR polygons. All non-native species were eliminated except for two introduced and protected mammal species, the feral ass and feral horse. We also included all migratory bird species that spend at least one season in the ecoregion. The WHR models produced by the DFG are based on available knowledge, including point data, but are typically created by predicting species to occur in certain habitat types (Morrison et al., 1992). The large spatial resolution of the source mapping also affects the accuracy of the models; most of the DFG distribution maps make use of polygons encompassing large areas. In order to produce and use distribution maps that were more precise, we considered several possible determinants which related species to the land and could be used to further refine the WHR models with spatial environmental models.

These determinants included aspect, elevation, slope, soil moisture capacity, surface water, hydrology, temperature, soils, landform, and additional vegetation information. Natural history and habitat data for these factors were recorded from the DFG’s California's Wildlife volumes for each species (Zeiner et al., 1990). After recording habitat information for all 274 (includes 9 introduced) vertebrate species, it was determined that the majority of species habitat information was related to elevation, water requirement, landform, and vegetation. Species distribution models were refined through the use of existing GIS layers, including: (1) landform types in the Mojave Desert (Dokka, 1999); (2) digital elevation models; and (3) a digital surface hydrology layer from lake and reservoir coverages reach files, digital line graphs, and hand-digitized spring locations (BLM, 1976-1997; source: MDEP, 1998). A suitable vegetation coverage was not available.

The distribution models were refined using a subtractive approach that removed areas from the distribution grids based on the species' natural history data. Cells of predicted distribution were removed only when the information was a definite excluding factor. For example, if the information stated that a species was not usually found on a certain landform type, but did not state that it was restricted from that landform type, that area was not removed from the species distribution map. Omission errors were minimized in favor of commission errors (Edwards et al., 1996). The final step in the model refinement process was to remove areas of current urban development from the distribution models for those species not predicted to occur in urban areas by the CFGWHR (1999). Urban development was obtained through analysis of Landsat TM data and outlines the expanse of urbanization in the study area as of 1995. If a species was not refined by elevation, landform, hydrology, or urbanization, the original distribution became the final distribution used to develop the indices of biodiversity.

## Biodiversity Index Calculations

All individual indices were rescaled to a 1-100 scale so they could be combined or compared with other biodiversity indices. Each index was rescaled by multiplying every grid cell value by 100 and then dividing each cell by the highest value in the entire grid. This rescaled the highest index value to 100 and all other values accordingly.

*Richness:* Richness was a straightforward estimation of the total number of species predicted to occur in an area. For total species richness, all species distribution layers were combined into one grid and the number of overlapping layers per cell in the output was calculated. This process produced a graphic that displayed the areas where the greatest concentration of species distributions was predicted to occur (Figure 4.1, Appendix B). Species richness was calculated separately for each of the four taxa (birds, mammals, reptiles, and amphibians) to examine the differences in the spatial depiction of the richness indices. Richness was also calculated for special status species. A special status species was considered to be any animal listed as federally threatened or endangered, or state threatened, endangered, or protected.

*Endemic Richness:* Each species was categorized as endemic to the Mojave Desert on the basis of natural history information and distribution maps (Zeiner et al., 1990). In the case of migratory birds, the species was considered endemic if it was found only in the Mojave for the period of time it was present in the state, regardless of the season.

*Rarity:* A rarity index was calculated by converting the Natural Heritage Network, California Natural History Diversity Database (CNDDB, 1999) state rankings into scaled values for all rare-ranked species. The CNDDB ranks species by assigning a value of 1 to 5 to each species based on the rarity of the species. A value of 1 means the species is extremely endangered throughout its range, as defined by the following measures: <6 viable occurrences, or <1,000 individuals, or <2,000 acres (< ~800Ha) of occupied habit (CNDDB, 1999). A value of 5 means the species is demonstrably secure and common throughout its historic range (CNDDB, 1999). The rarity ranking for a species was applied to the cells of its distribution map and all cells that were coded for presence were reclassified to the species' rarity value. A total rarity value grid of all ranked species was created by summing the reclassified maps. A rarity index map was developed by dividing the total rarity value grid by a richness grid of all rare-ranked species. This process was repeated for rare species by taxon.

*Multiple Index Combinations*: Single biodiversity indices are valuable to examine specific aspects of species distribution across the landscape. However, most conservation decisions must take into account several factors at once. In order to evaluate many aspects of diversity with a single index, several permutations of combination indices were developed from the single index models, including: (1) all species richness + endemic species richness; (2) rarity + endemic species richness; (3) all species richness + rarity; and (4) all species richness + endemic species richness + rarity. The combination indices were then calculated by adding together two of the individual index models in different combinations and rescaling the outputs to the 1-100 scale.

## Species Home Range Capture Rate in Conservation Reserves

The California GAP status rankings indicate the levels of protection from disturbance accorded to individual land parcels (Davis et al., 1991). Status one depicts areas permanently protected with a management plan that allows natural disturbances to occur, with the exception of fire. Wilderness areas and National Parks are examples of status one lands. Status two indicates the area is permanently protected with a management plan that allows use or management practices which may degrade the natural state. State Parks and Reserves are examples of status two lands. Status three indicates permanent protection for the majority of the area but the land is subject to broad, low intensity uses or local intensive uses. BLM lands are an example of status three lands according to California GAP. Status four indicates no protection; typically these are listed as private lands.

Percentage of species predicted to occur in protected lands was calculated for the purpose of evaluating terrestrial vertebrate protection within the current reserve system of the Mojave Desert. This was accomplished by aggregating status one and two lands into discrete reserve groupings. For a parcel to be added to a reserve grouping, the nearest boundary of the parcel had to be within 1 km of one boundary of the group. It was assumed that the movement of species can occur between parcels of this distance. Each reserve grouping was next converted into a separate grid layer and the total amount of area of each species' predicted distribution within each reserve was calculated by dividing the area of a species' distribution within a reserve by the estimated area of the home range of the species. The result was the percent of species with 100 and 500 home ranges captured by each reserve. If 100 or 500 home ranges of a species were contained within a reserve, that species was considered captured by that reserve at that home range level.

All inholdings within the current reserve system were converted to status one or two to examine the difference in capture rates under a conservation scenario. The inholdings had previously been coded as status three and four according to California GAP (Davis et al., 1991). Consolidating inholdings eliminated fragmentation within the reserves but did not add additional land adjacent to the current reserves unless the parcel had at least two sides surrounded by status one or two lands. Capture rate models were developed based on the consolidated grids as well.

## Results: Patterns of Regional Biodiversity

In order to more accurately spatially define a species habitat, certain refinements were made. The majority of species had at least one refinement applied to their distribution, the most common refinement model being the application of elevation. Only a few species had more than one refinement process applied. For example, the process of refining the lyre snake distribution involved elevation and landform models (Figure 4.2, Appendix B). As elevation and landform are added to the original prediction model, the area becomes restricted (and, presumably, more accurate). A few species, most noticeably aquatic birds and amphibians, had large areas removed from their original predicted distributions due to their strong ties to sources of water. For species not predicted to occur in urban areas, current development was removed from each of the distributions.  A list of all species and the models used to refine their predicted distributions can be found in Appendix E**.**

## Biodiversity Indices

*Richness:*  The total species richness index predicts higher numbers of species to occur around the boundary of the Mojave Desert in the southwest and southeast of the study area (Figure 4.3, Appendix B).  Also noticeable in the southwest is high species richness in the Mojave River Valley.  In the southeast, the two areas of high species richness are located along the Colorado River at the border of the study area, and in the mountainous areas to the east.

It is apparent that the distributions of the richness indices are decidedly different for each taxon (Figure 4.4, Appendix B).  This may be a reflection on the primary habitat types favored by the majority of species in each taxon.  Amphibian richness (a) reveals the strong dependence of this taxon on water sources, as does bird species richness (b), mostly due to waterfowl.  High richness values also occur in the mountains, foothills, and ecoregion border areas to the southwest.  Mammal species richness (c) is distributed more uniformly over the desert, with the majority of high richness values concentrated in the southern and eastern mountains, and in the Mojave River Valley.  Reptile species richness (d) is similarly distributed across the entire desert.  The highest concentrations are in the central desert at lower elevations.

*Endemic Richness:*  Endemic species richness is similar in distribution to reptile richness (Figure 4.5, Appendix B**),** a not surprising result given that reptiles make up a large fraction of the endemic species.  The areas of highest predicted values are found primarily across the center of the study area.

*Rarity:*  The rarity index depicts areas that contain overlapping distributions of rare desert species.  The highest rarity values were found in the north, west, and east parts of the desert (Figure 4.6, Appendix B).  The areas to the north and east may have higher values due to species found in unique environments.  High values in the area to the west may be due to species impacted by human uses.

*Multiple Index Combinations*:  The multiple index grids depict those areas of biological importance based on combinatorial indices, such as richness plus endemism plus rarity (Figure 4.7, Appendix B).  Four additional combination grids were generated.  The first combined the species richness and the endemic species richness grids, and depicts central desert locations near water as important areas for conservation (Figure 4.8a).  The combination of the total species richness grid and the rarity index grid weights rare species and depicts Death Valley National Park, and areas near urbanization and around water sources as important locations (Figure 4.8b).  The combination of the endemic species richness grid and the rarity index grid weights species which are both endemic and rare-ranked.  The outcome depicts the majority of the central desert as important for conservation (Figure 4.8c).  The combination of all three index models is the fourth alternative for determining the locations of sensitive areas.  The species which are endemic and rare-ranked are weighted the most heavily, followed by species which are endemic or rare-ranked only.  The outcome of this combination predicts that the areas of greatest concern are found throughout the southern half of the desert (Figure 4.8d). The amount of land required to capture the top 25% of each index varied considerably by index combination.

## Species Home Range Capture Rates in Conservation Reserves

The unconsolidated reserve coverage was broken up into 38 distinct areas which ranged in size from 25 ha to 1,401,386 ha (Figure 4.9a and b, Appendix B). The percentage of land gained by consolidating inholdings with the described methods ranged from 0 to 82% depending on the reserve (b). In the current reserve system, 73% of all species were captured at the 100 home range level and 64% of species were captured at the 500 home range level. Using the consolidated reserves coverage, the percent of species captured at the 100 home range level rose to 77% and to 69% at the 500 home range level.

## Discussion

The future demands placed on the environment due to potential land use changes in the California Mojave Desert may seriously impact the diversity of the desert. Specific impacts may be determined by ecologists and analytical models can be structured to examine alternative desirable outcomes, such as areas needed to be added to the current reserve system to attain a specific level of diversity protection, the least amount of area required to preserve viable populations of all threatened and endangered species, or the best attainable species representation with the least amount of private land used for a conservation program. The comparison of several spatial depictions of biodiversity indices can provide Mojave Desert managers and planners with an important tool to make conscious and informed decisions concerning the choice of locations for conservation, protection, or development.

The development of the process for refining WHR models produced powerful, malleable programs for use in futures modeling. The weaknesses of these WHR models lie in the unequal depth of natural history information and inaccuracy of the base data. This is somewhat moderated by the flexibility of the models, which can be updated as new knowledge about species is acquired. The outcomes of the refined species distribution models were satisfactory despite the lack of available ecological data for the majority of species. In many cases, the refinement of a WHR model resulted in an extreme reduction in predicted distribution, even when only one model was used.

The high species richness values appearing along the edges of the desert may occur for several reasons. The diversity of landforms near the foothills in the southwest harbors a greater number of habitat types and conditions relative to the rest of the desert, which in turn provides for a greater number of species than can exist in these areas. A second related factor is bird species richness which, as a single taxon index, has the greatest richness values in these areas. The bird taxon outnumbers all other taxa in the total species richness index and the index reflects this weighting. Also located in the southwest is the Mojave River, a focal point for water-oriented birds and amphibians.

In the southeast, the two areas of high species richness are due to the Colorado River along the border of the study area and the variation of land form types in the eastern mountains.  Again, these two locations attract high numbers of birds, reflected in the total species richness index.

The location of high endemic richness values in the central portion of the desert is primarily due to specialized reptiles and their distribution in unique desert environments.  When the reptile species richness index is compared to the endemic species richness index, the distributions of values are similar.

The interpretation of the rarity index is not as straightforward as the richness indices.  The calculation is an averaged value of the sum of rarity rankings for all species predicted to occur at that location, divided by the sum of the total number of species at that location.  Values that are high for the index can indicate an abundance of generally rare species, the spatial overlap of a few very rare species, or a combination of these two occurrences.  High value locations near urbanized areas may be due to the rarity of species caused by human disturbance.  High values around the mountains in the eastern part of the desert may be due to the unique landforms in the area, or possibly a combination with human disturbance such as all-terrain-vehicle use and cattle grazing.  The values at the north end of Death Valley National Park may be due to the distribution of very specialized species.

Managers may have the opportunity to make conservation decisions based on multiple factors but are often constrained by time, money, or available area.  Although single indices are strong predictive tools individually, they are only useful if one specific element of biodiversity is the target of a management plan.  If plans call for a more complete representation of biodiversity types, combination indices will be more applicable because they can take more than one objective into account.  Three of the combination indices represent an integration of two of the individual indices.  These are appropriate for specialized goals such as the use of the rarity/endemism index to capture species of particular importance to the Mojave Desert.  The fourth combination, all three individual indices combined, captures all elements of biodiversity in the desert but weights endemic or rare species two or three times more heavily depending on their classification.  In a conservation sense, this is a positive choice for protection because important species are repeatedly included in the calculation.  If the choice of decision makers is to have each species weighted only once, species with multiple classifications can be removed from all but one index before the indices are combined.

These procedures to create and compare biodiversity models are powerful and malleable tools but carry substantial caveats.  All of the indices, single or combination, are based on generalized wildlife habitat models.  Although the refinement process is extremely useful to narrow the WHR models, it is important to remember that they are predicted distributions that are often based on scarce information.  The calculated biodiversity models incorporate and magnify any potential errors in the original WHR models.  The strength of the WHR approach is the ability to incorporate new data as it is gained or desired, thereby providing an adaptable tool for use in regional conservation planning.

Comparing capture rates of species home ranges can be considered an alternative form of assessing the biological value of lands.  In many cases, the easiest way to increase protection is to annex or incorporate parcels of land near existing reserves.  The process developed here makes the comparison of increases in capture rates between reserves a straightforward procedure. The amount of land annexed or consolidated can be manipulated based on management desires, and the process run again to compare results. Once again, the process is a strong and useful planning tool, but is based on WHR models as well as estimated home range data.

# CHAPTER 5

# THE SOCIO/DEMOGRAPHIC AND ECONOMIC DRIVERS

Protecting natural systems while accommodating human development requires the ability to understand, predict and project the direct and indirect effects of urban growth at different spatial and temporal scales. Spatial modeling of landscape systems is essential to describe, with relative accuracy, the past effects and predict future impacts of urban growth on the systems (Sklar and Costanza, 1991; Costanza et al., 1990). Development of such predictive models has been limited in the past due to large data and processing requirements. These restrictions have been eased, however, with advances in computer, GIS, and remote sensing technology.

A growing body of research has examined the interaction between human communities and the landscape (Burke et al., 1991). Several software-based simulation models have been developed for integrated planning and analysis of urban development at different spatio-temporal scales. For example, Dale et al. (1998) developed a spatially-explicit method to assess the impacts of land use on natural resources in eastern Tennessee. The GIS-based models predict land cover response to various impacts, and simulate the susceptibility of species to changes in habitat and landscape patterns based on soils, geology and slope.

The Patuxent Landscape Model (PLM) simulates economic factors that influence land use patterns to model ecological processes for the Chesapeake Bay region at the watershed level (Voinov et al., 1999). The PLM, still under development, integrates about 6,000 spatial cells, each containing a dynamic simulation model of 20 state variables divided into 14 modules. After calibrating the PLM with data from 1973 to 1985, the model will be used to create landscape use and development scenarios for the 1985 to 2020 period. The PLM will greatly facilitate the development and assessment of land management policies for the Chesapeake Bay watershed (Voinov et al., 1999).

Some studies have addressed the ecological impacts of urban sprawl at larger scales. For example, census data, digital soil maps, and nighttime satellite images of the U.S. that reveal artificial light allowed researchers to estimate the current extent of development in the U.S., and its impact on soil resources (Imhoff et al., 2000). Another study analyzed the historical relationship between farmland and human settlement patterns in the U.S. over the last 230 years (Maizel et al., 2000). The analysis correlated ecological factors such as climate, slope, and soils, with various land uses. Areas characterized by poor climate, steep slopes, and soils unable to support crops or pasture, were unsustainably farmed or not farmed at all. That study also found that urban expansion has converted large areas of prime farmland to non-agricultural uses (Maizel et al., 2000).

An urban growth study of the Baltimore-Washington region examined the linkages between physical, ecological, and social processes that have affected that landscape over the last 200 years (Forsman, 2000). Land-use and land cover dynamics in the region were analyzed through remote sensing, GIS, and environmental modeling. Similarly, Levia and Page (2000) used cluster analysis to identify farmland prone to residential development in Sterling, Massachusetts, based on farm size, slope, and the distance of each farm from the nearest major highway and city center. The methodology is being used to estimate the probability of development and hence predict future farmland conversion.

The Urban Simulation model (UrbanSim) spatially forecasts land use change resulting from urban growth (University of Washington, 1998). By incorporating the interactions between land use, transportation, and public policy, UrbanSim was developed to interface existing travel models with new land use forecasting and analysis capabilities for Metropolitan Planning Organizations. UrbanSim incorporates existing land use plans, zoning, and land use on a parcel basis to estimate the likely future effects of development based on a set of land use-cover determinants including original use, accessibility, environmental conditions, cost of conversion, and policy constraints. UrbanSim uses a spatial simulation approach similar to that of the PLM to replicate ecosystem processes at the regional scale (University of Washington, 1998). As a result, UrbanSim is expected to be an important tool for land use planning since it will predict environmental stress associated with urban development and land use change based on various demographic, economic, environmental, and policy scenarios (University of Washington, 1998).

The California Urban and Biodiversity Analysis model (CURBA) predicts the likely impacts of development on land use change by linking spatial biophysical and socioeconomic information (Landis et al., 1998). CURBA was constructed using logistic regression equations which correlated development between 1986 and 1994 with slope and proximity to highways, riparian buffers, jurisdictional boundaries, local growth policies, and recent population and job growth. CURBA data sets are organized and accessed at the county level. CURBA has been used to model the spatial effects of development for eight counties in California. Several scenarios (e.g., *No Constraints*, *Prime Farmland Protection*, *Compact Growth*, and *Environmental Protection*) were developed under various base assumptions for three counties to analyze the effects of development on habitat change and fragmentation. The effects of each scenario on land use were visualized and analyzed through county maps (Landis et al., 1998).

This section describes population forecast and the construction of the model to predict the probability of future development for each undeveloped hectare of private land in the California Mojave Desert. The total study area of 7.4 million ha contains 1,542,337 ha of private land. As of 1990, approximately 124,725 ha had been developed, leaving 1,417,612 ha of undeveloped private land available for future development. Using an approach similar to Landis et al. (1998), development probabilities were based on a series of independent variables that describe the terrain and distance from various infrastructures for each undeveloped hectare of private land. The logistic regression was fit using land use change data obtained from 1970 and 1990 satellite images. When combined with population forecasts and assumed future settlement densities, the logistic model can be used to predict the extent of future development across the 7.4 million hectare region under an array of designed and modeled land use scenarios. The resulting development patterns can then be assessed against biological and socio-economic factors to examine development impacts at the landscape level.

## Modeling Population Forecasts

The study area includes 30 cities and towns (Table 5.1) with a total population of 471,515 residents in 1990. Of this, 190,262 (40%), 223,779 (47.5%), 55,656 (12%), and 1,818 (0.4%) inhabitants lived in the portions of Los Angeles, San Bernardino, Kern, and Inyo Counties, respectively. The average population density for the municipalities in 1990 was 2.30 people per ha (Table 5.1), which was higher than California (0.74 persons/ha) and the U.S. overall (0.27 persons/ha) (U.S. Census Bureau, 1990). The population within the study area is expected to continue to grow in the future, primarily due to strong development pressures from the rapidly growing Los Angeles Basin.

Table 5.1. Population, land area, and settlement density for municipalities in the California Mojave Desert, 1990.

| County | City/Town | Area (ha) | Population | Area per capita (ha/person) | Population density (persons/ha) |
|---|---|---|---|---|---|
| San Bernardino | Searles Valley[1] | 3,037 | 2,740 | 1.11 | 0.9 |
| | Lenwood[1] | 667 | 3,190 | 0.21 | 4.78 |
| | Barstow | 5,961 | 21,472 | 0.28 | 3.6 |
| | Nebo Center[1] | 766 | 1,459 | 0.53 | 1.91 |
| | Needles[1] | 7,818 | 5,191 | 1.51 | 0.66 |
| | Adelanto[1] | 9,558 | 8,517 | 1.12 | 0.89 |
| | Apple Valley town | 17,404 | 46,079 | 0.38 | 2.65 |
| | Victorville[1] | 3,591 | 40,674 | 0.09 | 11.33 |
| | Mountain View Acres[1] | 478 | 2,469 | 0.19 | 5.17 |
| | Hesperia | 12,513 | 50,418 | 0.25 | 4.03 |
| | Twentynine Palms Base[1] | 367 | 10,606 | 0.03 | 28.9 |
| | Twentynine Palms | 13,999 | 11,821 | 1.18 | 0.84 |
| | Joshua Tree[1] | 1,574 | 3,898 | 0.4 | 2.48 |

|  |  |  |  |  |  |
|---|---|---|---|---|---|
|  | Yucca Valley[1] | 12,280 | 13,701 | 0.9 | 1.12 |
|  | Morongo Valley[1] | 1,523 | 1,544 | 0.99 | 1.01 |
| Los Angeles | Lancaster | 22,962 | 97,291 | 0.24 | 4.24 |
|  | Quartz Hill[1] | 1,000 | 9,626 | 0.1 | 9.63 |
|  | Lake Los Angeles[1] | 1,275 | 7,977 | 0.16 | 6.26 |
|  | Palmdale[1] | 19,041 | 68,842 | 0.28 | 3.62 |
|  | Desert View Highlands[1] | 122 | 2,154 | 0.06 | 17.66 |
|  | Palmdale East[1] | 117 | 3,052 | 0.04 | 26.09 |
|  | Littlerock[1] | 374 | 1,320 | 0.28 | 3.53 |
| Kern | Ridgecrest | 5,455 | 27,725 | 0.2 | 5.08 |
|  | California | 47,815 | 5,955 | 8.03 | 0.12 |
|  | Mojave[1] | 3,501 | 3,763 | 0.93 | 1.07 |
|  | North Edwards[1] | 1,097 | 1,259 | 0.87 | 1.15 |
|  | Boron[1] | 747 | 2,101 | 0.36 | 2.81 |
|  | Edwards AFB[1] | 3,860 | 7,423 | 0.52 | 1.92 |
|  | Rosamond[1] | 5,214 | 7,430 | 0.7 | 1.43 |
| Inyo | Lone Pine[1] | 482 | 1,818 | 0.27 | 3.77 |
| Riverside[2] |  | -- | -- | -- | -- |
| TOTAL |  | 204,598 | 471,515 | 0.43 | 2.3 |

[1] U.S. Census designated place.
[2] There are no municipalities with the Riverside County portion of the California Mojave Desert.

In order to model landscape change within the region from 1990 to 2020, projected population growth was estimated based upon county-level projections developed by the California State

Department of Finance (1998). Given that the study area does not correspond to county boundaries, the proportion of county population that resided in study area cities for the years 1970, 1980, and 1990 was determined in order to project the proportion of county population that will reside in study area cities for the years 2000, 2010, and 2020. It was further assumed that the near-linear change in proportion as exhibited by the historical data will continue through projection years. Finally, the projected proportions were applied to projected county populations obtained from the California State Department of Finance (1998).

The California Department of Finance uses a baseline cohort-component method to project population by gender, race, ethnicity, and age. The base population used for the projections was the 1990 Census, corrected for undercount. The cohort-component projection method annually traces people born in a given year, applying age-specific mortality and migration assumptions. New cohorts enter the population by applying age-specific fertility assumptions to women of child-bearing age. The mortality component was developed using statewide death records from the Department of Health Services by gender, race/ethnicity and age for 1970, 1980, and 1990, with future mortality patterns expected to follow national trends. The fertility components were developed by examining various fertility rates by race/ethnicity and by county for 1970, 1980, and 1990, and making assumptions regarding the merging of race/ethnic-specific fertility rates across the study period. As for migration, a five-year moving average of migration was calculated representing `typical' migration across the decades 1970-1980 and 1980-1990. Longer-term assumptions regarding a slow decline in migration after the year 2015 were developed in consultation with local government planners and demographers. In the end, an annual average net in-migration to California of 203,000 people is incorporated in the projection (California State Department of Finance, 1998).

According to historical population data, the population of the Mojave has experienced staggering growth over the past several decades **(**Figure 5.1, Appendix C). During the period from 1970 to 1990, the population of incorporated cities within the study area grew by over 350 percent, increasing from nearly 70,000 in 1970 to over 300,000 in 1990. As such, human population represents a key driver of environmental change within the area. If trends continue, the study region's population is projected to increase by nearly 900,000 people during the period 2000-2020, representing a 200 percent increase (Figure 5.1). By excluding Inyo County's population, it is estimated that the total population in the study area will be 680,711 and 1,346,682 residents by 2000 and 2020, respectively, which means a total population growth rate of 98% for the whole area during the 20-year period.

### Modeling Development Probability: Constructing the Development Probability Model

Logistic regression was used to construct a model to predict the probability of future development for each undeveloped hectare of private land in the California Mojave Desert. Logistic regression is a method used for regression analysis of dichotomous data and is applied in many fields, including social work (Proctor, 1992), land use analysis (Nelson and Hellerstein, 1995), human health (Dumas, 1999; Gruskin, 1999), and computer science (Wu, 1999). It is a variant of traditional linear regression in which the dependent variable is dichotomous, and the independent variables are continuous, discrete, or both (Proctor 1992, Cramer, 1991, Hosmer and Lemeshow, 1989; Menard, 1995; Demaris, 1992).

We assumed that six independent variables influence the development (NEWDEV) of land in the study area. These variables have been labeled as: DEVDIST, PRIMDIST, SECDIST, PCTDEV, CITYCAT, and SLOPE, where:

NEWDEV = sites developed between 1970 and 1990
DEVDIST = site distance to existing 1970 developed sites (m)
PRIMDIST = site distance to primary roads (m)
SECDIST = site distance to non-primary roads (m)
PCTDEV = percent of surrounding development (percent)
CITYCAT = within or outside city boundary (“1” or “0”)
SLOPE = site slope (percent).

For example, all else being equal, DEVDIST would be expected to exhibit a negative association with NEWDEV in the study period. A similar inverse relationship was expected for the PRIMDIST, SECDIST, and SLOPE variables. In general, the probability of development for sites close to existing development and infrastructure was expected to be higher than that of sites more distant. Similarly, level sites are expected to be developed before steeper sites, all else being equal.

A positive relationship was expected between NEWDEV and PCTDEV since a higher PCTDEV would indicate a higher proportion of surrounding developed sites. A positive relationship was also expected between NEWDEV and CITYCAT since the development probability was expected to be higher in sites located inside city boundaries as compared to sites located outside.

The logistic model was fit using the Statistical Analysis System (SAS Institute Incorporated, SAS Campus Drive, Cary, North Carolina, USA). The resulting model predicts the probability of development for each undeveloped privately-owned hectare within the 7.4 million hectare study area. These probabilities were then expressed as probability gradient maps. The process required the following steps: (1) defining the basic unit of analysis; (2) using satellite imagery to define values for the dependent variable; and (3) determining values for the independent variables.

*Defining the Basic Unit of Analysis*: The basic unit of analysis (*grain size* or *pixel*) considered in this study was the hectare, which was represented by a single grid-cell of 1 ha size, 100m x 100m. Each cell was given a value which corresponds to the feature or characteristic that is associated with the geographic site, for example developed or undeveloped land. Since the total area under study was 7.4 million ha, the total number of grid-cells was 7.4 million. After the grid-creation process was finished, the next step was to generate values for the dependent variable.

*Using Satellite Imagery to Define Values for the Dependent Variable:* This was accomplished by first identifying land that was converted from undeveloped to developed status (e.g., new development from 1970 to 1990). Two sets of satellite data from1972 and from the early to mid-1990s were acquired from The North American Landscape Characterization Data (NALC) program through the USGS Earth Resources Observation Systems (EROS) Data Center. The objectives of the NALC project are to develop standardized remotely sensed data sets (e.g., NALC duplicates) for change detection analyses. NALC data were created specifically to support landscape change and succession analysis, to develop inventories of terrestrial carbon stocks, to assess carbon cycling dynamics, and to map terrestrial sources of greenhouse gas (e.g., CO, $CO_2$, $CH_3$, $N_2O$, and $O_3$) emissions. NALC satellite data are obtained and referred to as duplicates (e.g., two sets of satellite data acquired in the early 1970s and early to mid-1990s, respectively; NALC triplicates are also available). The NALC data are well suited for analyses of landscape level processes or phenomenon involving time sequences that can be detected in intervals between one and two decades.

NALC duplicates are satellite-based digital imagery from the Landsat Multispectral Scanner (MSS). Original MSS data have a nominal spatial resolution of 79 m but the NALC data are resampled to a nominal spatial resolution of 60 m. The MSS instrument has detectors sensitive in four discrete regions of the electromagnetic spectrum. These discrete bands are: (1) Band 4: 0.5μm - 0.6μm (visible green); (2) Band 5: 0.6μm- 0.7μm (visible red); (3) Band 6: 0.7μm- 0.8μm (near infrared); and (4) Band 7: 0.8μm- 1.1μm (near infrared). These bands are optimal for detecting vegetation and other biotic landscape features as well as abiotic features such as bare soil, water, or impervious surfaces. While the spatial resolution is somewhat coarse relative to other commercially available satellite data (e.g., 1 m panchromatic) the spatial, spectral, and temporal resolutions of MSS data make NALC duplicates ideal for broad scale landscape studies.

Nine scenes of MSS data provide complete coverage of the California Mojave Desert. Because each row and sometimes each path of images were not acquired in the same month or even year, the NALC duplicates for the study area were processed individually rather than conduct a time-consuming atmospheric correction for all scenes. Each scene was first masked to the project study area to exclude regions outside the scope of the project. Each scene was then masked again to include only privately-owned lands, as federally managed public lands are typically not available for development.

The analysis conducted was not a change detection *per se*, but is best considered an analytic interpretation. Each scene for each time period was interpreted for urban or suburban development. Band combinations which accentuated vegetation from watered lawns and other landscaped areas and enhanced anthropogenic features from the natural brightness or darkness of the surrounding unaltered desert landscape were selected.

Spatial pattern was also used to detect anthropogenic features such as houses, outbuilding complexes, and commercial and industrial development. Roads in the California Mojave Desert are typically built on a square grid system; the land surface itself is cleared in regular geometric patterns which are easily discernible from other features such as washes, rock outcrops, or playas. These areas were identified and the perimeters digitized as polygons.

Once the scene analysis was completed, the vectors were converted to raster and assigned a value of “1” for developed areas, and “0” for non-developed areas. These binary arrays were created for each of the 24 NALC scenes and lacked any of the original spectral information. All scenes within each decade were then coordinated together resulting in one binary file for each duplicate decade coded to *developed* or *undeveloped* on a per-pixel basis. These data layers were resampled from 60 m to 100 m for incorporation into further analyses and the larger modeling effort.

Areas newly developed between 1970 and 1990 were obtained by subtracting the developed lands of 1970 from that of 1990 using ARC/INFO. The final result was a data coverage that contained values of “1” for areas developed during the 1970 to 1990, period, and “0” for undeveloped sites. These binary values provided the data for the dichotomous dependent variable in the logistic regression model.

*Determining Values for the Independent Variables*: The next step was to determine the values for the six independent variables for all 1,417,612 one hectare grid cells (i.e., 100 m x 100 m) of private land in the study area. Each of the independent variables was then represented by an individual map or data layer.

The values for the independent variables were obtained from Digital Elevation Model (DEM), Digital Line Graph (DLG), and TIGER coverages prepared by the Mojave Desert Ecosystem Program (MDEP, 1998; later the “MDEI”). The distances from each grid-cell center to 1970 development, primary roads, and non-primary roads were measured with Euclidean distance functions. The Euclidean distance identifies the distance from each cell to the closest source cell (e.g., existing 1970 development, primary roads, and non-primary roads). The shortest distance to existing 1970 development is determined, and the value is assigned to the cell. After applying the Euclidean distance function it was possible to create a map with different bands or gradients for each variable in which each band represented a specific distance between the grid-cells and the variable of interest (e.g., 1970 development, primary roads, and non-primary roads). Percent of surrounding development (PCTDEV) was estimated using square moving analysis windows. This process stops at every cell, counts a predetermined number of developed cells surrounding the center cell (the window), estimates the percent of developed land within the window, and then assigns the value to the cell center of the analysis window. This procedure was applied to each cell, with the number of surrounding cells set at 400 (20 cell x 20 cell square). For cells near the boundary of the study area, the windows did not extend beyond the boundary. The 20 x 20 window size presented the “best” contribution, as determined by $R^2_{adj}$ (see below), to the model as compared to several other window sizes examined (e.g., 3 x 3, 10 x 10, 50 x 50, and 100 x 100). City boundary (CITYCAT) was expressed as a categorical variable. CITYCAT took a value of “1” for each grid cell (i.e., developed and undeveloped private lands) located inside a municipal boundary and 0 otherwise. SLOPE was expressed as percent.

*Model Selection*: A stepwise logistic regression model was then fit to the data. Private lands developed between 1970 and 1990 were correlated with the six independent variables described above. Model goodness-of-fit for the logistic model was assessed using the adjusted coefficient of determination ($R^2_{adj}$) (Nagelkerke, 1991). There are important differences between linear and logistic regression techniques. First, logistic regression differs from linear regression in that the relationship between the dependent and independent variables is sigmoid (i.e., a slanted “S-shaped” function) instead of linear (Proctor 1992). This nonlinear relationship means that a unit change in an independent variable has a variable impact on the dependent variable, depending upon the value of the independent variable (Clearly and Angel, 1984). Second, linear regression will allow estimates below "0" and above "1" (e.g., for dependent dichotomous variables), which makes their interpretation difficult in the case of probabilistic outcomes (Hosmer and Lemeshow, 1989). Third, since the dependent variable in logistic regression is binary, it is not normally distributed. As a result, the sum of squares, significance tests, and the standard error of regression are not true indicators of model fit. Finally, since the dependent variable of the logistic regression is dichotomous, the distribution of residual errors is heteroscedastic, which violates an important assumption of linear regression (Maddala, 1992; Kmenta, 1986).

For linear regression models, the $R^2$ represents the proportion of variance "explained" by the model (Nagelkerke, 1991). It is a measure of the model's ability to predict the dependent variable using the independent variables. Some authors have proposed use of the general linear model $R^2$ (Magee, 1990; Cox and Snell, 1989; Maddala, 1983), but unfortunately, for discrete logistic models, $R^2$ does not achieve a maximum of "1" (Nagelkerke, 1991). Instead, the adjusted $R^2_{adj}$ as defined by Nagelkerke (1991) is preferred. For more information on the properties and interpretation of the $R^2$ and $R^2_{adj}$, see Nagelkerke (1991).

## Private Lands Development Between 1970 And 1990

The California Mojave Desert covers 7.4 million ha, with an estimated 1,542,337 ha in private ownership. The amount of developed private land changed considerably from 1970 to 1990 (Figure 5.2, Appendix C). Only 33,294 ha of private lands had been classified as developed in 1970, representing 2.2% of the private land and only 0.5% of the study area as a whole. By 1990, the total developed land area reached 124,725 ha, covering roughly 8% of private lands and 1.7% of the study area as a whole. This leaves approximately 1.4 million ha of undeveloped private land available for future development.

Subtracting the area of 1970 development from 1990 development reveals that 91,431 ha of private land had been newly developed in that period, an increase of 275%. In general, new development was concentrated around development that existed in 1970, and occurred mostly in the southwestern part of the study area. Most of this development occurred since the early 1980s, when many new residents moved to the area to take advantage of more affordable housing relative to that of the Los Angeles Basin (Northwest Economic Associates, 1994). For example, the population of incorporated cities within the California Mojave increased from 115,000 in 1970, to over 450,000 residents in 1990 -- an increase of over 350% in only 20 years.

## The Development Probability Model

All independent variables were found to be highly significant ($P < 0.001$) predictors for new development, and exhibited the expected direction of the relationship (Table 5.2). Variables associated with existing infrastructure appear to be more important predictors of future development than are natural features. Although all of the independent variables were highly significant, the most important variable in the prediction model as determined by the Wald statistic was PCTDEV, and the least was SLOPE (Table 5.2). Accuracy based on the model data was 87.1%, indicating that the logistic model fit the model data reasonably well. Accuracy of the predictions was further tested through randomization procedures (Manly, 1997) applied to 100 computer-generated sets of data. Mean accuracy was 93.2%, providing further indication that the prediction model fit the model data well.

Table 5.2. Best-fit logistic model predicting future development on undeveloped private lands in the California Mojave Desert.

| Variable | Coefficient | SE | Wald statistic | P | Odds-ratio |
|---|---|---|---|---|---|
| Intercept | -2.208 | 0.014 | 24,473.71 | <0.001 | |
| PCTDEV | 5.436 | 0.048 | 12,790.84 | <0.001 | 229.73 |
| SLOPE | -0.048 | 0.001 | 681.78 | <0.001 | 0.95 |
| DEVDIST | <0.001 | <0.001 | 5,608.72 | <0.001 | 1.00 |
| CITYCAT | 0.929 | 0.009 | 11,133.99 | <0.001 | 2.53 |
| SECODIST | -0.004 | <0.001 | 15,098.40 | <0.001 | 0.99 |
| PRIMDIST | <0.001 | <0.001 | 12,587.80 | <0.001 | 1.00 |

Unfortunately, model fit as determined by the $R^2_{adj}$ was only 32.1%, suggesting that other variables that were not modeled might better explain development patterns from 1970 to 1990. One such variable might be land value. This research intended to include that variable, but data were not available. Another possibility is that the explanatory variables used in the model were not entered in the correct functional form. However, during the model construction process, several functional forms were explored (e.g., linear, quadratic, cubic, exponential, logarithmic, and various combinations thereof). The linear forms presented the best fit of the model as measured by the $R^2_{adj}$.

The logistic prediction model was applied to all remaining undeveloped private land in the study area to estimate the probability of future development for each grid cell (Figure 5.3, Appendix C). As expected, the resulting probability gradient map shows that private undeveloped lands near or surrounded by existing developed areas had the highest probability of being developed in the future. Future development probabilities rapidly decreased as distance to development increased.

## Discussion

Satellite imagery and other geographical data were used to identify land use change and to model the probability of future land use change for 1.5 million ha of private land in the California Mojave Desert. The logistic model developed represents a practical, flexible, and powerful tool for managers, land use planners, developers, and other parties interested in land use planning.

Several concerns regarding the model's specification were identified during the modeling process. First, as described above, the independent variables included in the model and its structure have moderate aggregate predictive power as indicated by the low $R^2adj$. The model could likely be improved by adding additional variables (e.g., land value and proximity to Los Angeles, major employment centers and various amenities), and/or by modifying the ways in which they are measured. For example, instead of introducing single values for each observation, they could be weighted and grouped.

Another model concern is the potential for spatial correlation between the explanatory variables. High spatial correlations (e.g., $r^2 > 0.8$) could lead to multicollinearity problems, which would increase the standard errors of the estimated coefficients and consequently increase the probability of accepting a false hypothesis (Gujarati, 1988; Kmenta, 1986). Also, multicollinearity could cause inconsistency or bias in the coefficients of the estimated model. To check for multicollinearity, Pearson correlations between the explanatory variables were estimated; all were <0.001. However, multicollinearity could still be a problem since these data are spatial, which is not detected by the Pearson correlation. Unfortunately, the detection of spatial autocorrelation is a complicated and relatively new field of study (e.g., Nelson and Hellerstein, 1995), and its detection is beyond the scope of this analysis.

Several broader issues were identified with respect to the modeling process. For example, the land use change detection procedure identified newly developed areas only. As a result, it could not determine whether sites developed prior to 1970 experienced redevelopment and/or intensification of land use between 1970 and 1990. For example, a single family home could be converted to a duplex, or a large lot in a single family zone might be subdivided to accommodate additional homes. The extent to which this occurs would impact the rate of future land development needed to house new residents. Indeed, as population and land values increase in the Mojave, redevelopment and land use intensification would likely accelerate. This process may operate in a nonlinear fashion, and may represent a “threshold” phenomenon of interest to area planners and residents.

In futures modeling, it is important to anticipate various thresholds that may operate across the landscape. Thresholds occur when what one normally considers a linear trend changes to become nonlinear, or when a linear trend changes at a new rate of growth or decline. For example, when a community experiences an economic boom, its growth may increase at greater rates, with increases of from 10% to 15% per year being not uncommon (Little, 1977). Other examples include the response of riparian vegetation to falling water tables, the effect of drought on water availability and hence agricultural land use, and the ecological impacts of exotic plant invasion. Another issue stems from the dynamic nature of the model's explanatory variables. If a secondary road were upgraded to primary status in 1971, it would likely stimulate nearby development, yet the modeling approach would not be able to detect the change in road status. A similar concern could be expressed for most of the model's independent variables.

On a more basic level, the model assumes that the determinants of new development that influenced the location of growth over the 1970 to 1990 period will continue to operate into the future. While this is probably true in general, some specific examples run counter. For example, the growing popularity of isolated, low-density development such as 20-acre “ranchettes” could result in future development patterns not foreseeable under the data and methods used. As a result, this type of development may impact a far greater area than more compact traditional subdivisions. Moreover, while less than 5% of new housing in the California Mojave is found in low-density ranchettes, the ecological impacts could be many times greater than the area suggests.

Finally, as in all landscape studies, the level or scale of analysis may have an impact on probability predictions (Bissonette, 1997). Because it is expected that more accurate results can be obtained at finer resolutions, it should be examined whether the level of analysis affects the conversion of lands from undeveloped to developed status. For example, this research fits a single logistic regression equation to the entire 7.4 million hectare study area. An alternative approach would be to disaggregate the study area into smaller units (e.g., county or city level). Then, a separate development probability model could be developed for each subunit.

# CHAPTER 6

# DESIGNING AND MODELING THE SCENARIOS

Alternative future scenarios represent patterns of possible and plausible land-use changes and impacts that might be expected to occur in the California Mojave Desert. These might result, for example, from an increase in population (and increases greater or lesser than expected), water availability (equal to, lesser and greater than expected), new transportation modes or changes in military missions. Some of the futures might be easily conjectured from the examples of factors just mentioned in the context of future projections of past trends. On the other hand, they might be more complex, stemming from assumptions of changes in patterns of land use that might occur as a result of changes in policy or economics. Once the scenarios were developed, the possible impacts on the biophysical and cultural landscape were evaluated.

The region of the California Mojave Desert has experienced enormous growth over the past several decades. Between 1970 and 1990 the population increased from 117,000 to 470,000, and population projection models (as discussed previously) predict an additional increase of nearly 900,000 people by 2020. Factors associated with development from 1970 to 1990 were also modeled. The factors associated with that regional pattern of development define the growth model used to develop the scenarios. The futures, then, represent the spatial configuration of the landscape as it might appear in the year 2020 with the addition of nearly one million people given the assumptions that comprise the scenarios.

Three separate types of scenarios were developed. The first takes existing trends and data and extrapolates them into the future using reasonable assumptions (e.g., for development possibilities) in conjunction with existing models. These are referred to as “model-based scenarios”. The second class of scenarios combines the same approach used for the model-based scenarios with newly created spatial information that simulates the effects of land use plans, land use policies, or new construction. These scenarios are called “planning-based scenarios”. Other alternative futures analyses (see, for example, Steinitz, et al., 2003) have used design-based scenarios instead of, or in addition to, planning-based scenarios. The third group combined the output from model-based and planning-based scenarios to create scenarios that reflect the interactions between the individual scenarios. These are referred to as “combinatorial scenarios”. An overview of all the scenarios is presented in Table 6.1**.**

## Model-based Scenarios

Two distinct model-based scenarios were created and are referred to as *Trend* and *Plans Build-Out,* The first of these, *Trend,* had four permutations. *Plans Build-Out* had only a single permutation. Both of these scenarios assume that factors affecting current development in the California Mojave Desert will remain constant in the future.

Table 6.1. Overview of scenarios.

| Scenario Name | Description | # of Permutations |
|---|---|---|
| Trend | Models the likely pattern of urban development on private land based upon past trends of development in the region. The four permutations are:<br>1. Standard population projection at current settlement density (3.8 people/ha);<br>2. A fifty percent increase in the standard population projection at current settlement density (3.8 people/ha);<br>3. Standard population projection at a settlement density of 20 people/ha; and<br>4. A fifty percent increase in the standard population projection at a settlement density of 20 people/ha. | 4 |
| Plans Build-Out | Combines all land use plans from local governments in the study area and "build out" or "populates" all currently developable land-use classes. | 1 |
| New Roads | Illustrates potential changes in the pattern of development that might occur with the construction of several new primary roads, and upgrade of secondary to primary. | 4 |
| New City | Illustrates potential changes in the pattern of development that might occur with the creation of a newly incorporated city. | 4 |
| Urban Encroachment Buffer | Establish a 5 km buffer around all military installations and exchange private lands falling with the buffer for a comparable amount of public land outside the buffers. | 4 |
| Flight Path Buffer | Establishes an 8km buffer on either side of flight paths within the R-2508 Complex and exchanges private lands falling with the buffer for a comparable amount of public land outside the buffers. | 4 |

| | | |
|---|---|---|
| High “Index” Swap | Exchanges private land with low development probability and high biodiversity value for public land with high development probability and low biodiversity value. | 4 |
| Inholding Consolidation | Exchanges all inholdings of private land within Status 1 and 2 lands for a comparable amount of public land with a high probability of development. | 4 |
| Combinatorial Scenario | Create a scenario showing the interactions between multiple factors by combing the Trend, New City, Urban Encroachment Buffer, and Inholding Consolidation scenarios. | 4 |

### Trend

The *Trend* scenario models the likely pattern of urban development on private land based on past trends in the region. The scenario utilizes as its foundation the growth scenario developed and discussed in Chapter 5. The growth scenario depicts how development is likely to occur given past trends in development taking into account data on slope, private land, distance to existing development, distance to city boundaries, and distance to primary and secondary roads. The average population density by county populates the model and the product is a surface of probability for development. That probability surface is the mechanism for creating alternative futures. In brief, the research team needed to “populate” the California Mojave Desert over the next 20 years in order to build the various scenarios.

The *Trend* scenario is the basic or initial output from the economic driver. Four permutations were developed. The first projects the likely trend of development (to 2020) using the existing settlement density of approximately 3.8 people/ha and the standard population projections from the socio-demographic driver (Figure 6.1, Appendix D). The second permutation projects development using a settlement density of 20 people per hectare and applies the standard population projection. The third uses the existing settlement density, but the population projection is increased by 50 percent. The fourth and final permutation uses a settlement density of 20 people per hectare, and the population projection is increased by 50 percent. Trend at a density of 3.8 people/ha is referred to as the *Base* scenario. It is the standard against which all other scenarios are compared, and is used to create the difference maps central to the impacts of the futures against [in this case] biodiversity.

From Chapter 5, Figure 5.2 showed the trend of development in the study area between 1970 and 1990. Under the modeling approach developed here, a continuation of past development patterns results in the developed landscape for the year 2020 depicted in Figure 6.1 (i.e., the *Trend* scenario). Under the *Trend* scenario, most new development in 2020 is located in the southwestern portion of the study area near the Los Angeles metropolitan area. Existing Mojave cities most affected are Lancaster, Palmdale, and Victorville. Additional growth occurs south and west of Twentynine Palms, and near the cities of Barstow and Ridgecrest.

Figure 6.1 also shows the impact of existing roads and infrastructure on the location of new development. This is readily seen by the new development in the Barstow area, which closely follows the established highway system. The extensive areas of new development projected to occur adjacent to Edwards Air Force Base may be of concern to base officials and local towns, and probably warrants continued study.

## Plans Build-Out

*Plans Build-Out* portrays the future pattern of land use in accordance with the existing city and county land use plans of the study area. Development proceeds to some time in the future until the opportunities for development in accordance with those plans are used up or “built out”. In this case all city and county plans are combined to have the same zoning classification. To create this scenario the land use plans for Kern, Los Angeles, and San Bernardino counties were assembled. Land use designations were combined into ten classes (Figure 6.2a, Appendix D). It was assumed that the agriculture and open space land-use classes would not be developed. All possible lands currently zoned for development are developed under this scenario. From these data, land-use classes that will most likely be developed were identified and “developed”, and the resultant spatial differences were compared with those under Trend (Figure 6.2b, Appendix D). This scenario can act as a comparative scenario and may be combined with other models in several permutations, such as with a maximum conservation model. Based on planned numbers of residential units per hectare, the model may also be used to determine the spatial extent of future development for a given date in the future.

The *Plans Build-Out* scenario depicts the extent of future development that would occur if all available lands under existing zoning designations were to be fully developed. It is important to note that the large areas developed under *Plans Build-Out* are not envisioned to occur by 2020; instead, the future development depicted in Figure 6.2b should be viewed as independent of both time and populations forecasts. *Plans Build-Out* is sometimes viewed by some as a “worst-case scenario” since, by keeping current zoning designations fixed, it presupposes that communities would not alter future zoning in response to emerging development patterns. While this worst-case view has merit, it must be tempered by the realization that lands currently zoned for agriculture remain in agricultural status in this scenario, a restriction which is likely to under-estimate total development under a *Build-Out* scenario. In a real worse case scenario, plans might be altered allowing for decrease in open-space and increase in building densification (perhaps without appearance regulations).

## Planning-based Scenarios

Although model-based scenarios are useful for evaluating what might happen in the given various development assumptions, societal values are likely to change. Planning for the future is more realistic if these potential value changes can be accommodated. Unlike *Trend* and *Build-Out*, which assume a trajectory through time based on past trends, Planning-based scenarios operate under the assumption that the trajectory of land-use patterns will alter and not remain constant. As such, several scenarios were developed that show how land use patterns might be affected by planning decisions. The first of these planning-based scenarios simulates the urban encroachment on DoD lands, and evaluates two scenarios designed to allow existing DoD installations to continue to meet their training missions while simultaneously allowing for regional growth and development.

### Military Land Exchange

The Department of Defense (DoD) operates 27 military installations in the California Mojave Desert with a total land area of approximately 1.1 million ha (14% of the study area). As mentioned in Chapter 2, there are four major installations representing each branch of the armed forces that comprise the bulk of the DoD's land holdings: the China Lake Naval Weapons Testing Center, Edwards Air Force Base, the National Training Center (Fort Irwin), and the Marine Corps Air Ground Combat Center (Twentynine Palms). The DoD is increasingly concerned about the impact of expanding urban areas (urban encroachment) upon their various installations in the Mojave. Accordingly, two scenarios were created that simulate a land exchange between federal and private land, each of which was designed to diminish the effects of urban encroachment on DoD-managed lands.

*Urban Encroachment Buffer (“Buffered Military”)*: The *Urban Encroachment Buffer* scenario represents a 5 km buffer built around the perimeters of the four largest military installations. Private land falling within this buffered area was converted to public ownership controlled by DoD. Urban areas were buffered to a distance of 8 km, and BLM land located within this buffer was converted to private ownership. BLM land was selected because of its extent and location. The BLM has also historically been the most active participant in federal land exchanges in the region. It was also assumed that public lands near existing cities would have greater value from an economic perspective. Once the exchange had been assumed to have taken place, the growth model was run using the same four permutations as the *Trend* scenario (Figure 6.3a, Appendix D). The urban encroachment buffer is particularly effective at preventing development from encircling Edwards Air Force Base (Figure 6.3b, Appendix D).

Figure 6.3 shows the effect of placing a 5 km buffer around military installations. The buffers are clearly seen in Figure 6.3a**,** particularly around Edwards Air Force Base. Note that existing development adjacent to military bases remains in place; the buffer serves only to displace future development to locations away from the bases. Figure 6.3b is a “difference map” that compares how the *Trend* scenario (Figure 6.1) differs from the *Urban Encroachment Buffer* (Figure 6.3a). Because the rest of the scenarios developed present comparisons of alternative scenarios and “difference” maps, the description here is presented in more depth.

The difference map presented in Figure 6.3b depicts how the *Urban Encroachment Buffer* scenario differs from the *Trend* scenario. For example, the dark blue in Figure 6.3b represents 1990s development, which is common to both the *Trend* and *Encroachment* scenarios. Yellow depicts areas likely to be developed between now and 2020 that are common to both the *Trend* and the *Encroachment* scenarios. Yellow represents areas developed under both scenarios, and are hence unaffected by the restrictions embodied in the *Encroachment* Scenario. Areas shown in light blue or teal depict areas developed under *Trend*, but not developed under the *Encroachment* Scenario. This is clearly seen in Figure 6.3b in the area north and west of Edwards Air Force Base, where the lands within the buffer are shown as teal since they were to have been developed under *Trend*, but are not eligible for development under the *Encroachment* Scenario. Red illustrates where the development that would have taken place under *Trend* (i.e., the teal areas) will be displaced. As a general observation, the development that would have taken place north and west of Edwards Air Force Base (i.e., the teal areas) will have been displaced to the red areas as a result of the *Urban Encroachment Buffer*. Note that while this displaced development (i.e., red areas) is widely scattered throughout the study area, it is still generally found in and around existing development.

*Flight Path Buffer:* A related urban encroachment problem stems from the expansion of urbanization towards areas that lie under or near low-level military flight paths. One of the training areas in the Mojave Desert is the R-2508 Complex, which contains ten low-level flight paths (Figure 6.4a, Appendix D). The military conducts numerous training missions along these routes, and as homes are built within proximity to them, noise complaints will inevitably escalate. In the *Flight Path Buffer* Scenario, all of the flight paths have been buffered by 8 km, which created a 16 km wide corridor for each flight path. The growth model under the new ownership pattern was subsequently computed. Compared with the base *Trend* Scenario, the *Flight Path Buffer* Scenario prevents a substantial amount of development from occurring within the buffer area (Figure 6.4b, Appendix D).

Under the *Flight Path Buffer* scenario, large areas that were to have been developed under the *Trend* Scenario north of Edwards Air Force Base (see the teal areas in Figure 6.4b) are displaced throughout the study area. Once again, development is generally displaced to areas in and around existing development.

## Urban Change

*New Roads*: This scenario was developed by adding several hypothetical roads to the primary roads coverage. Although these roads are only illustrative, it should be noted that this scenario or a similar scenario could easily be created that uses the alignments of actual roads. Once the roads were incorporated into the map, a new development probability map was generated and the region populated at the different population densities. The *New Roads* Scenario contains four permutations using the same criteria as the *Trend* Scenario (Figure 6.5a, Appendix D). The impact of the construction of new roads upon the distribution of development is again reflected in the “difference map,” which depicts spatial areas where differences may or may not arise between the *Trend* and *Build-Out* scenarios (Figure 6.5b, Appendix D).

The *New Roads* Scenario differs from the earlier scenarios in that widely scattered development under the *Trend* Scenario (i.e., isolated teal areas in Figure 6.5b) are displaced and concentrated along the new roadways. This is most easily seen by the high concentration of red along the new roads south of Edwards Air Force Base (Figure 6.5b). This scenario illustrates the large impact that roads and road status (i.e., primary vs. secondary) have on the location of future development.

*New City*: As was the case in the *New Roads* Scenario, the *New City* Scenario was created by adding a newly incorporated city into the California Mojave Desert and generating a new development map populated at 3.8 people/ha. This scenario also has four permutations along the same lines as the *Trend* Scenario, but again only the first permutation (Figure 6.6a, Appendix D) and differences between it and the base *Trend* Scenario (Figure 6.6b, Appendix D) are illustrated.

Under the *New City* Scenario, scattered development under the *Trend* Scenario (i.e., teal areas in Figure 6.6b) are displaced to the newly incorporated municipality (shown as red). The new city designation further stimulates the extensive development predicted to occur in the southwestern portions of the study area.

## Biodiversity Conservation

Another approach to the planning-based scenarios is to plan for biodiversity protection before development occurs instead of attempting to mitigate the impacts subsequent to development. Two scenarios were developed which focused on the conservation of biological diversity, one of which trades land using an index of biological "land value" and another that consolidates private inholdings within publicly owned land, trading those for public lands near existing development.

*High "Index" Swap (or "biodiversity swap"):* Private land with low development probability and high biodiversity value was exchanged for public land with high development probability and low biodiversity value. For the purposes of this scenario, "high biodiversity" was determined by using a composite index derived from the distributions of vertebrate species richness, rarity, and endemism (discussed in Chapter 4). This simple approach highlights a pervasive problem in bio-regional conservation planning: many of the areas that have a high biodiversity value also have a high probability of development and hence are of high economic value. The problem is that if development occurs, or is permitted to occur in areas that have a high biodiversity value, there is virtually no private, high biodiversity land left to be conserved. Conversely, if conservation occurs, there is virtually no way to achieve parity between the amount of private land that is converted to conservation and the amount of public land that is converted to private, developable land. For the purposes of this scenario, which emphasizes conservation planning, conservation took precedence when conflicts occurred. The resulting pattern of ownership was input to the growth model. Four standard permutations and difference maps were also created (Figure 6.7a, Appendix D).

Under the *High Index Swap* Scenario, major regions north and west of Edwards Air Force Base (shown in teal) are displaced to other regions of the study area (Figure 6.7b, Appendix D). The large amount of development displaced from Edwards Air Fore Base results from the existence of threatened and endangered species found in the regions in and around the Base. Note how displaced development (shown in red) is concentrated in and around other developed areas (yellow) and along major roadways.

*Inholding Consolidation ("private land swap")*: The California Mojave Desert contains over 2.7 million ha of National Park land and BLM Wilderness Areas, which is equivalent to about 38% of the study area. However, much of this land (particularly the wilderness areas) consists of fragmented parcels of privately owned land (Figure 6.8a, Appendix D). These parcels are referred to as "inholdings." In this scenario, all of the parcels of private land within Status 1 and 2 lands (i.e., National Parks and BLM Wilderness Areas) were converted to the ownership category of the parcel within which they were located. A comparable amount of public land near existing development was converted to private ownership. The new pattern of ownership was input to the growth model and the difference map generated (Figure 6.8b, Appendix D).

The impact of Inholding Consolidation is difficult to see in Figure 6.8b due to the modeling resolution. In fact, inholdings are almost always small, scattered parcels. The inholdings where development is prohibited are thus small scattered areas shown in teal in Figure 6.9b. While the inholdings themselves are difficult to see, Figure 6.8b does show where development is displaced (red). The main areas receiving the displaced development include Barstow and areas south and west of Twentynine Palms.

## Combinatorial Scenario

The *Combinatorial Scenario* is an example of the possibilities that can be explored with alternative futures modeling. The primary difficulty in modeling the future is that changes tend to be dictated by the interaction of previously adopted policies, newly adopted policies, economic growth (or the lack thereof), and changing societal attitudes. Although not all of these can be modeled, scenarios can be made increasingly more complex through the combination of a variety of new elements. For example, one *Combinatorial Scenario* combines the *Trend*, *New City*, *Urban Encroachment Buffer*, and *Inholding Consolidation* scenarios to create a new scenario and its resultant difference with the base Trend (Figure 6.9a, Appendix D). This combination of interacting factors creates what is probably a more realistic depiction of the changes that will take place in the Mojave Desert over the next twenty years.

In the *Combinatorial Scenario*, most development appears to be displaced from areas north and west of Edwards Air Force Base (see teal areas in Figure 6.9b, Appendix D) to Barstow and areas south of Edwards and China Lake. Additional displacements take place south and west of Twentynine Palms.

# CHAPTER 7

# HABITAT RELATIONSHIP MODELING OF FOCAL SPECIES

The two primary objectives of the project were to develop the alternative futures of the California Mojave Desert and to assess how these alternative futures might affect biodiversity. The impacts of alternative futures on "biodiversity" were considered in several ways. First was how the futures might impact specific groups of species as a function of the futures. This was accomplished as a part of the process of developing and testing the biodiversity "driver" as an impactor on the development of the futures themselves and has been discussed in previous chapters. The second was an evaluation of how the alternative futures might impact biodiversity, that is, groups of species. The third was to assess the impacts on the habitats (as defined by landforms) of species and assess the changes of the respective habitats as a function of the developed futures. Finally, the futures were evaluated as a function of their impact on a number of key species.

## Selecting Focal Species

The California Mojave Desert has a high degree of faunal diversity with approximately 274 resident or breeding vertebrate species. We decided that it would be far more meaningful, not to mention manageable, to select a few species which could be thought of as "focal". Those would be species which were of special interest to biologists, land managers, and others interested in the biodiversity of the Mojave. We knew that Rare, Threatened, and Endangered Species were important to those stakeholders. That group included the flagship species of the region, the Desert Tortoise (*Gopherus agassizii*). A large body of literature is associated with that species. The other focal species to be selected were not so easily selected. To assist in the process of selecting focal species we acquired publications for all 274 resident or breeding vertebrate species, entering descriptive data for 724 articles into a bibliographic database in EndNote (Appendix F) for future retrieval.

A preliminary list of potential species was compiled by selecting all articles that described a species habitat. This resulted in a list of articles which described in comprehensive detail the habitat for approximately 54 species. Ultimately, eleven species were selected based on whether or not habitat descriptions could be translated in to landforms as described by the "Geomorphic Landforms and Surface Composition GIS of the California Mojave Desert" (Mojave Desert Ecosystem Program, 2000, http:// www.mojavedata.gov) and eventually to the LizLand model. Special attention was given to species which were in areas with a high probability of development or were listed, threatened, endangered, or of concern by State or Federal agencies. These eleven species (Table 7.1) were considered to be the "focal" species, species which could be considered representative of the vertebrate biodiversity of the region. This list also includes the Desert Tortoise, the "flagship species" of the Mojave Desert. These species occupy a wide range of habitats (i.e., as defined by landforms). Some, such as *Uma scoparia and Sauromalus ater*, are highly specific, found only on certain landforms, whereas others, such as *Uta stansburiana and Cnemidophorus tigris*, are habitat generalists, found on a wide range of habitats and landforms.

Table 7.1 Focal Species Selected for Assessment

| Scientific Name | Common Name |
|---|---|
| Reptiles | |
| *Callisaurus draconoides* | Zebra-tailed Lizard |
| *Cnemidophorus tigris* | Western Whiptail Lizard |
| *Crotaphytus bicinctores* | Black-collared Lizard |
| *Gopherus agassizii* | Desert Tortoise |
| *Sauromalus ater* | Chuckwalla |
| *Uma scoparia* | Mojave Fringe-toed Lizard |
| *Uta stansburiana* | Side-blotched Lizard |
| Birds and Mammals | |
| *Dipodomys panamintinus* | Panamint Kangaroo Rat |
| *Spermophilus mohavensis* | Mojave Ground Squirrel |
| *Toxostoma bendirei* | Bendire's Thrasher |
| *Toxostoma lecontei* | Le Conte's Thrasher |

**Description of Focal Species**

*Gopherus agassizii*
The Desert Tortoise is the flagship species of the California Mojave Desert. Since this population was listed under the Endangered Species Act as "threatened", it has been the species that has generated the most management concern and hence research activity. Found in washes, canyon bottoms, and oases with sandy or gravelly soils from sea level to 1600 m in elevation. Soils must be friable enough for the digging of burrows and firm enough so that burrows will not collapse.

The Desert Tortoise is an herbivore that may attain a length of 22 to 37 cm in carapace length making it the largest reptile in the Mojave Desert. It is well adapted to life in the desert, foraging in the spring (March to June) to build up stores of fat and water for the rest of the year. There are many plants in the desert which the Desert Tortoise eats including cactus, annual forbs, grasses, and wildflowers. Desert Tortoises live in burrows where they may spend 95% of their lives, and where they estivate in summer when it is very hot. In the fall, when it is cooler, the Desert Tortoise will again emerge and eat dried grasses and drink after a thunderstorm, although when there is no water available they are able to absorb the water from their bladders. In the winter (October to March) they return to their burrows to hibernate. Some burrows have been passed down through generations of tortoises. The maximum age of the Desert Tortoise is typically 80 years, but they may live to reach 100 years old. (http://www.projectlinks.org/dtortoise/ , http://www.nps.gov/moja/planning/tort.htm)

*Crotaphytus bicinctores* formally *C. insularis bicinctores*
The taxonomy of this species was not well defined until recent work by McGuire (1996) where the species *bicinctores* was adopted. It has been commonly referred to as the Black-collared Lizard or the Great Basin Collared Lizard. The Collared Lizard is distinguished by a conspicuous black and white collar across the back of the neck. It is a robust lizard with a broad head, short snout and long laterally flattened tail. It is found throughout the Mojave Desert and elsewhere in the west from sea level to 2300 m.

It occurs in rocky habitats with scant vegetation, such as inselbergs, lava flows, and spatially heterogeneous rocky erosional highlands avoiding sandy landforms, canyons, and rocky plains (Stebbins, 1985). The Black-collared Lizard is occasionally seen inhabiting open less rocky habitats. Their ability to inhabit such areas may allow this species to disperse cross suboptimal habitats to isolated mountain ranges (McGuire, 1996).

*Sauromalus ater* (formerly *S. obesus*)
*Sauromalus ater* is the scientific name presently given to Chuckwallas living in the Southwestern Deserts. All of the former subspecies of *S. obesus* are now included in the single species, *S. ater*. The Chuckwalla is a large (13 -20 cm), flat, dark-bodied lizard with folds of skin on its neck and sides. Chuckwallas are restricted to rocky habitats such as lava flows, inselbergs, and erosional highlands. It is strictly herbivorous and will venture from its rocky dwelling to obtain preferred forage (Berry, 1974; Hollingsworth, 1998). They are well known for their defensive strategy of seeking shelter in rock crevices and gulping air to swell their bodies thereby prevent predators from dislodging them from the crevice. This lizard is widely distributed throughout the Mojave Desert in appropriate habitats from sea level to 1900 m (Stebbins, 1985).

*Callisaurus draconoides*
The Zebra-tailed Lizard is a medium-sized (6.2 -10 cm) thin lizard with a long flattened tail. This lizard preys on other lizards and insects. Coloration is usually yellow to tan with two dark bars extending up from the belly onto the lower sides just behind the front legs. The underside is white with black bars on the underside of the tail (Stebbins, 1985). Zebra-tailed Lizards are the fastest lizards in the desert specializing in movement on firm substrates, and are considered a bipedal specialist. Consequently, *Callisaurus draconoides* has several specializations for high-speed bipedal locomotion, including long hind limbs, a long tail, and long distal elements (Irschick and Jayne, 1999). They have an odd habit of curling their tail over their back, thus revealing the striping (zebra-tailed), and then waving it slowly from side to side. Zebra-tailed Lizards prefer areas of hard packed soils (washes and desert pavement) with little vegetation (McMahon, 1997; Stebbins, 1985) preferring a “race track” like environment (Heaton and Kiester, In Review). The Zebra-tailed Lizard is common and widely distributed throughout the Mojave in appropriate habitat.

*Uma scoparia*
The Mojave Fringe-toed Lizard is a medium size (6.9-11.2 cm) omnivorous lizard, feeding on dried seeds, flowers, grasses, leaves, insects, and scorpions (Miller and Stebbins, 1964;

Stebbins 1985). The Mojave Fringe-toed Lizard is restricted to fine, loose, windblown sand of dunes, sandy plains, river banks, and washes with scant vegetation between 90 m and 910 m above sea level (Stebbins, 1985). Highly adapted for life in fine, loose sand fringe-toed lizards have ear flaps, a countersunk lower jaw, valves that close the nostrils and, of course, elongated fringed toes. The lizard's flat body and shovel-shaped nose enables it "swim" in the sand. The fringes on the bottom of the elongated toes enable them to attain the remarkable bipedal speed of 7 meters per second over the sand (Norris, 1963). Sand dune ecosystems, including areas of source sand and sand corridors, are necessary for the long-term survival of aeolian sand specialists, such as, Fringe-toed Lizards (Barrows, 1996).

*Uta stansburiana*
The Side-blotched Lizard is small (4.0-6.0 cm), brown in color, with conspicuous dorsolateral stripes (rows of dots) and conspicuous bluish-black blotches on each side behind the forelimbs.

The Side-blotched Lizard is widespread and one of the most abundant lizards in the Mojave Desert. It is found in most habitats below 2700m elevation excluding sand sheets and wind blown sand (Stebbins, 1985). It prefers the spatially heterogeneous rocky landforms over the sandy landforms.

The dorsal ground color of Side-blotched Lizards is generally a light shade of gray or tan that is sprinkled with both light and dark colored spots. Some of these spots may be light blue on both sexes, and males often have orange sides and neck, particularly during the breeding season. The ventral coloration of Side-blotched Lizards is more subdued, being a light cream or white. The most obvious marking is the namesake of these lizards, and is the dark bluish-black spot that is present on the sides behind the forelimbs. These spots are more distinct in males, but females and juveniles generally have the marking to some degree. The Side-blotched Lizard eats insects (frequently *Hymenoptera, Coleoptera, Hemiptera, and Orthoptera*), spiders, scorpions, mites, and ticks. Adult males sometimes cannibalize young. In Idaho, diet may include flies, ants, and caterpillars.

*Cnemidophorus tigris*
The Western Whiptail is 5.9-11.2 cm long with eight light-colored stripes that are often very indistinct, with crossbars in adults suggesting a checkered appearance; dark markings on dorsum with yellow, tan or brown background; throat pale with black spots; long tail; enlarged, square scales on venter; dorsal scales fine and granular; tongue is forked and flicked continually (Stebbins, 1985).

The Western Whiptail is found in all Mojave Desert habitats below 2200m elevation except wind blown sand. However, it prefers the sandy landforms, alluvial plains and sandy washes over the rocky landforms, alluvial deposits and rocky washes (Heaton and Kiester, In Review). It avoids thick grass and dense shrubs. Whiptails forage actively on the ground near the base of vegetation taking a wide variety of ground-dwelling invertebrates including grasshoppers, beetles, ants, termites, insect larvae, and spiders. Individuals often probe cracks and crevices and dig in loose soil as they forage. Whiptails will also eat smaller lizards (Stebbins, 1985).

*Toxostoma bendirei*
Bendire’s Thrasher is a light grayish brown bird with yellow eyes and faint streaking on the sides of the neck and breast (McMahon, 1997). Distribution within the California Mojave Desert is disjunct and sparse ranging from 600m to 1800m in elevation. Bendire’s Thrasher breeds in the Mojave but is not a permanent resident, preferring to winter in Mexico. The largest breeding population probably occurs in and around the East Mojave Preserve. These thrashers avoid dense vegetation and riparian woodland preferring desert scrub with Joshua trees, Spanish bayonet, Mojave yucca, cholla cactus, or other succulents (Grinnell and Miller, 1944; Garrett and Dunn, 1981). Unlike other thrashers, that almost never fly, this bird flies from bush to bush. Most of its feeding is done on the ground where it forages for invertebrates, seeds and small fruits. Breading pairs are monogamous. Cup-shaped nests of twigs and grasses are typically constructed in small trees, cactus, or thorny shrubs. Pairs typically have two broods each season (Ehrlich et al., 1988). Bendire’s Thrasher is a California Species of Special Concern.

*Toxostoma lecontei*
Le Conte’s Thrasher is a light sand colored bird with dark eyes and a dark tail found throughout the California Mojave Desert in appropriate habitat below 1600m (McMahon, 1997; Sheppard, 1996). It is a permanent resident in the Mojave. Typical habitat consists of areas of low relief including sparsely vegetated desert flats, alluvial fans, and gently rolling hills where substrates are sandy and often alkaline. Two plant groups often associated with Le Conte’s Thrasher are the saltbushes (*Atriplex* sp.) and chollas (*Opuntia* sp.). These birds avoid areas devoid of dense vegetation, tall creosote bush, south facing slopes, and cultivated areas (Sheppard, 1970). Nests are placed in cacti or dense thorny shrubs including saltbush, ocotillo, and Desert thorn.

*Spermophilus mohavensis*
Primarily a solitary species, the Mojave Ground Squirrel is a small (152-165 mm) short tailed, cinnamon-grey squirrel without conspicuous markings. When food is scarce, from August to March, this squirrel will estivate in a burrow until conditions improve. While running it holds its tail over it back exposing the white underside. It is restricted to about 20,000 km$^2$ of the western Mojave Desert and prefers sandy or sand and gravel soils between 500 and 1600m above sea level (Burt, 1936; Best, 1995). The Mojave Ground Squirrel is listed by the State of California as threatened. Management plans and conservation strategies are under development including a Mojave Ground Squirrel Conservation Area. Destruction and degradation of habitat are cited as the primary threats to this species (Laabs, 1998).

*Dipodomys panamintinus*
Panamint Kangaroo Rats are medium to large kangaroo rats, 12 to 13cm long. More than half of its length is tail. They have fur-lined cheek pouches that open on either side of the mouth (Burt and Grossenheider, 1980). Panamint Kangaroo Rats avoid cliffs and desert pavement preferring coarse sand, gravelly desert flats, and alkaline or salt encrusted soils. They are often associated with yucca, juniper, and pinion trees which cover the upper slopes of alluvial fans, (Intress and Best, 1990). There are five subspecies of Panamint Kangaroo Rat found between 900 and 2800m in elevation. At least four subspecies are found in the California Mojave Desert (*D. p. mohavensis, D. p. panamintinus, D. p. argusensis,* and *D. p. caudatus*). *D. p.*

*caudatus* is completely isolated from other populations in eastern California and southern Nevada. *D. p. panamintinus* and *D. p. argusensis* probably do not have contact with other subspecies either. Isolated populations, primarily of *D. d. panamintinus*, in the western Mojave may be affected by development. As such, this subspecies may be particularly at risk.

## Defining Species Ranges

Current species range models were examined from California Wildlife Relationship System (CFGWHR 1999) and Gap Analysis of Mainland California (CalGAP; Davis et al., 1999; http://www.biogeog.ucbs.edu/projects/gap/gap.html). CalGap models were incomplete. We noted that CalGAP habitat models for many Mojave Desert species contained abrupt truncations at political and/or jurisdiction boundaries. Therefore, they were only used for guidance in developing habitat ranges. Species ranges, as ArcInfo (ESRI, Environmental Systems Research Institute, Inc., Redlands, CA) vector covers, were obtained from California Wildlife Habitat Relationship System Ver. 7.0, California Department of Fish and Game (1999) (http://dfg/ca/gov/whdab/cwhr/whrintro.html). Elevation limits were determined for each species from either CWHRS or from appropriate published literature (Stebbins, 1985). Minimum elevation limits were rounded down to the nearest 100m and maximum elevation limits were rounded up to the nearest 100m. Habitat below the minimum and above the maximum elevations were removed from the covers.

All cover manipulations were completed using ArcInfo 8 (ESRI). When more current data became available new ranges were developed or existing maps were modified to reflect new data (Table 7.2). Point and transect data from published literature were useful for confirming species occurrence or modify species ranges. For seven of the focal species, CWHR maps were adequate with only elevation limits removed. For these seven species it was accepted that they may occur throughout the California Mojave Desert and were restricted only by elevation or habitat type. The four remaining maps were modified or replaced by supporting new data.

## Habitat Landform Relationships

Traditionally, vertebrate habitat-association models have been based primarily on vegetation. These models have been successful at predicting avian habitat and have been effective, although somewhat less successful in predicting mammalian habitat. Vegetation-based models have not been as effective in defining reptile habitat, especially in arid environments. Since reptiles are more responsive to differences in macro and micro landforms than to vegetation, it might be hypothesized that the habitats of terrestrial vertebrates as a whole might be defined by landforms. Indeed, Mouat (1974) showed that vegetation in the semiarid environments of southeast Arizona could be defined by terrain variables. A new concept of habitat (especially reptile habitat) in the California Mojave Desert was developed based upon macro and micro landform characteristics. In turn, this model was used to describe the habitat for a number of non-reptilian vertebrates.

Table 7.2: Sources for Focal Species Habitat Modeling

| | Range | Elevation | Habitat Discription |
|---|---|---|---|
| *Gopherus agassizii* | CWHRS[1] | 0-1600m (BLM field data)[6] | Lukenbach 1982, Schamberger and Turner 1986 |
| *Sauromalus ater* | CWHRS[1] | 0-1900m (Stebbins1985) | Johnson 1965, Berry 1974, Espinoza *et al.*, 1998 |
| *Callisaurus draconoides* | CWHRS[1] | 0-1600m (Stebbins1985) | Heaton et. al, in review |
| *Uma scoparia* | CalGAP[2] | 0-1000m (Stebbins1985) | CWHRS, Stebbins 1985 |
| *Crotaphytus bicinctores* | CWHRS[1] | 0-2300m (Stebbins1985) | McGuire 1996 |
| *Uta stansburiana* | CWHRS[1] | < 2700m (Stebbins1985) | Heaton et. al, in review |
| *Cnemidophorus tigris* | CWHRS[1] | < 2200m (Stebbins1985) | Heaton et. al, in review |
| *Toxostoma bendirei* | Composit[3] | 600-1800m (England and Laudenslayer 1989) | England and Laudenslayer 1989, 1993 |
| *Toxostoma lecontei* | CWHRS[1] | < 1600m (Sheppard 1970) | Sheppard 1970, 1996 |
| *Spermophilus mohavensis* | BLM[4] | 500-1600m (CWHRS) | Burt 1936, Bartholomew and Hudson 1961, Best 1995 |
| *Dipodomys panamintinus* | Composite[5] | 900-2800m (Recht 1995, Morafka and Prigge 1998, 1999, CWHRS) | Itress and Best 1990 |

[1] California Wildlife Habitat Relationship System ,Ver. 7.0 (Contact Monica Parisi, CWHR Program Coordinator, http://dfg.ca.gov/whdab/cwhr/whrinfo.html) map modified to reflect elevation limits

[2] *Uma scoparia* - no range boundaries were defined; dune fields and sand sheets were identified within or near boundaries of the CalGAP map resulting in extending the range westward to include the large dune fields north and south of Edwards AFB.

[3] *Toxostoma bendirei* - CWHRS model combined with BLM West Mojave Plan distribution and locations buffered by 10 km.

[4] *Spermophilus mohavensis* - map provided by BLM West Mojave Plan

[5] *Dipodomys panamintinus* - range developed from CWHRS, CalGAP, new data (Recht, 1995; Morafka and Prigge, 1998, 1999) and suitable habitat within these areas.

[6] California Desert District, Bureau of Land Management, Riverside, CA. Contact: Nanette_Pratini@ca.blm.ca

The fact that vegetation was not used to define habitat is not meant to denigrate its importance as a critical contributor to habitat. The importance of vegetation composition in controlling the distribution of some desert reptiles is considerable, especially at the local and/or micro habitat scales. For example, species such as *Xantusis vigilis* are closely tied to Joshua Trees (*Yucca brevifolia*) and other *Yucca* sp. But even if a reliable and accurate vegetation composition map of the entire Mojave Desert were available, the fact remains that the type "Creosote Bush Scrub, with *Larrea tridentata* and *Ambrosia dumosa*", occupies 70% of the Mojave Desert" (Rowlands, 1995). Such widespread distribution of vegetation types encompasses numerous habitat types. In addition, what little variability that does exist is difficult to detect using ecosystem wide research and monitoring tools such as remote sensing. We believe that in most instances lizard and other species in the Mojave Desert are more likely responding to changes in micro and macro landform geomorphology than to coarse resolution vegetation composition. The second reason why reptiles and amphibians are often excluded from consideration in habitat evaluation and management in arid environments is that these coarse resolution vegetation composition maps conflict with management needs. In the California Mojave Desert, the management needs of individual stakeholders cannot be met with maps that place most management units in a single vegetation class (such as the "Creosote Bush Scrub" vegetation type).

Landforms are alternative correlates to predicting animal presence/absence, especially in arid ecosystems and have been previously considered to define vertebrate species ranges (Forman & Godron, 1986). They affect abiotic conditions, the flow of organisms, propagules, energy and material, and the frequency and spatial pattern of disturbance regimes as well as constraining the very geomorphic processes that created them (Swanson et al., 1988). The term "geomorphic habitats" was coined in reference to cliffs, caves, talus, lava flows, sand dunes and playas formed by geomorphic processes in both the Great Basin of Southeastern Oregon (Maser et al., 1979b) and the Blue Mountains of Oregon and Washington (Maser et al., 1979a). Within all ecosystems, landforms and landform processes affect plant and animal distributions both temporally and spatially. Landforms affect fauna by determining the geographic distribution of habitats and by forming special habitats (Swanson, 1979). For example, in the arid southwest, fine scale micro-topographic relief provides shelter from the sweltering heat of summer and the freezing nocturnal temperatures of winter, while the high spatial and temporal variability of rainfall in the arid southwest is due in large part to the regional topography.

## The LizLand Habitat Model

As a result of the habitat/landform analysis described above, we proposed that habitat, especially reptile habitat (Figure 7.1, Appendix G) for arid environments should rely not only on spatial heterogeneity or micro habitat (i.e., micro landform), but macro landform characteristics as well. We linked the micro habitat requirements of individual species to macro landforms via their mutual micro habitat characterizations. Finally, we integrated this concept of habitat with "geomorphic landforms" (MDEP, 2000), surface composition, and hydrologic data into a spatially explicit habitat model: *LizLand*. Conceptually, LizLand is centered on landforms but it also considers the contribution of vegetation composition and structure to the location of each species. At the time of the development of the model and, subsequently, the analysis of species *vis a vis* the alternative futures, a reliable, accurate, and consistent spatial representation of Mojave Desert vegetation did not exist. As a result, the LizLand GIS model is based solely upon the characterization of the macro landform and its link to lizard habitat (Appendix H). When an adequate map of Mojave Desert vegetation becomes available, it can be incorporated into the model as needed. By focusing the characterization of habitat on landforms instead of vegetation we address the unique biological requirements of desert vertebrates including reptiles, and by linking large scale macro landforms to lizard habitat via micro landform characterizations, we address the issue of management scale and ecosystem research.

## Applying the LizLand Model

The LizLand model was initially developed for the focal reptile species, *Callisaurus draconoides*, *Cnemidophorus tigris*, and *Uma scoparia*. Later, *Uta stansburiana* and *Sauromalus ater* (until recently *Sauromalus obesus*), which retain some form of local, state, or federal listing, were added for further testing and evaluation. The LizLand model was developed for the entire California Mojave Desert, with initial results focusing on the Marine Corps Air Ground Combat Center (MCAGCC). LizLand was compared to and contrasted with the California Mojave Desert GAP model not only to emphasize accuracy but also to assess implications of its use to wildlife management.

The Marine Corps Air Ground Combat Center (MCAGCC) and Joshua Tree National Park comprised the study area for the development of the LizLand model. Four separate basins were selected and a number of transects were laid out for each basin. Observations along transects included the type of lizard, percent vegetation cover ("total cover", "crown cover" or cover at > 0.5m height, and "surface cover" or cover at < 0.5m height), and surface particle size of six size classes ranging from "sand" (<2.0mm) to "boulder" (> 600mm). A "rockiness index", a function of the largest four particle size classes (boulder, stone, cobble, and gravel) was found to be highly correlated with landform.

Statistical analyses were performed in SPSS 10.0.0 and S-PLUS 4.5 Professional Release 2, both for Windows, $P<0.05$ for all tests. Simple descriptive statistics were calculated for species and micro landform cover characteristics, and Multivariate Analysis of Variance (MANOVA) was used to test for differences. Because samples were unbalanced and Levene's Test of Equality confirmed heterogeneity of variance, the Games-Howell *post-hoc* pair wise method of multiple comparisons was calculated. In addition, individual species distributions across macro landforms and the distribution of all species within a single landform were tested using Pearson's chi-square analysis.

Canonical Discriminant Function Analysis (DFA) (Huberty, 1994; Manly, 1994) compared the micro landform characteristics between sites, within each macro landform used by a species and not used by that species, and compared the macro landforms to one another. Structure coefficients were interpreted to assign meaningful labels to the correlations between the variables and the discriminant functions, in lieu of the standardized discriminant function coefficients. For cross-validation, the *a priori* probabilities were set proportional to the number of each species observed per landform for the used versus unused site comparisons and were set to equal for the macro landform comparison. Observations removed from the original data set in order to standardize transect sample length were used to cross-validate the DFA classification. The cross-validated classification probabilities were based upon the Mahalanobis distance, a measure of distance between two points in space defined by two or more correlated variables

Results were presented only for 801 individual lizard observations (n = 251 *C. tigris*; n = 401 *C. draconoides*; n = 149 *U. stansburiana*). Results from MANOVA indicated that the mean values for the five cover variables (shrub, ground vegetation, total vegetation, pebble and sand) and the rockiness index ($R_{i)}$, were significantly different between the four landform types. Both sandy washes and rocky washes had higher average shrub and lower average ground cover. Not surprisingly, alluvial deposits and rocky washes had higher average $R_i$ values and lower average sand cover than either sandy washes or alluvial plains. In addition, the mean values of these same variables were significantly different between the focal lizard species observations sites. *Callisaurus draconoides* observation sites had the lowest average total vegetation cover and ground cover and the highest average pebble cover. *Cnemidophorus tigris* observation sites had the highest average total vegetation, shrub and ground cover and *U. stansburiana* observation sites averaged lower sand cover and higher $R_i$ values than either *C. draconoides* or *C. tigris* sites.

For the landform model, three canonical discriminant functions were calculated, accounting for 74.0, 22.6 and 3.4% of the variance. Landforms characterized by high sand and low rockiness were associated with function one, and best separated sandy washes from alluvial deposits. Function two characterized landforms with high shrub and rockiness and low ground vegetation cover and best separated rocky washes from alluvial plains. Function three characterized landforms with high sand and total vegetation cover and low pebble cover and best separated sandy washes and alluvial deposit from rocky washes.

*Post-hoc* classification probabilities based upon the Mahalanobis distance correctly classified 75.6% of the original cases and 74.1% of the cross-validated cases. In order of correct classification of the cross-validated cases were sandy washes (92%), alluvial plains (67%) and alluvial deposits (64%). Omission errors for the cross-validated cases ranged from 34% (alluvial deposits) to 8% (sandy wash). The combined low classification statistics suggest that the Canonical Discriminant Function Analysis had difficulty differentiating the macro landforms using the micro landform characteristics. The classification analysis seemed capable of distinguishing the sandy landforms (sandy washes and alluvial plains) from the rocky alluvial deposits, but not alluvial deposits from sandy landforms. In addition, the analysis appeared able to distinguish sandy washes from the patches (alluvial plains and alluvial deposits) but not the patches from sandy washes.

For the species model, two canonical discriminant functions were calculated, accounting for 82.1% and 17.9% of the variance respectively. Function one was characterized by low rockiness and high sand cover and best separated *C. draconoides* observation sites from *U. stansburiana*. Function two was characterized by low total vegetation cover, shrub cover, ground vegetation cover and high pebble cover and best separated *C. draconoides* and *U. stansburiana* from *C. tigris* observation sites.

A statistically significant correlation existed between macro and micro landforms and lizard presence/absence for all three species. Micro landform characterizations comprise the link between macro landforms and lizard habitat. This link is supported by life history information and the unique biological requirements of each species. LizLand is the integration of this concept of habitat with geomorphic landforms, surface composition, and hydrologic data into a spatially explicit habitat model.

Developing the LizLand spatial model was based upon primary and secondary data, as well as qualitative and quantitative data. The digital LizLand base map was composed of landform and surface composition (MDEP, 2000) and USGS 1:100,000 Digital Line Graph (DLG) hydrology data (USGS, 1989). The original MDEP (2000) data consisted of 32 geomorphic landform categories, which were collapsed into 12 relevant habitat classes based upon landform (i.e. macro landforms), surface composition and relative rockiness. Relative rockiness is a micro landform characterization that was subjective and derived from author knowledge, field work and literature (Mabbutt, 1977; Cooke, 1993; Dokka, 1998). The DLG linear hydrology data were buffered 50m on either side to create a 100m wide polygon hydrology data set. The polygon hydrology data were intersected with the 12 habitat classes and then collapsed into two categories: rocky wash or sandy wash. A DLG derived wash was considered rocky if it intersected one of the following habitat classes: Erosional Highlands, Inselbergs, Desert Pavement, Rocky or Rocky Washes. A wash was considered sandy if it intersected Sand and Gravel, Sandy Wash, Sand Sheet, Wind Blown Sand or Playa. Finally, the 12 habitat classes derived from the MDEP (2000) data were merged with the two category (either rocky or sandy wash) hydrology data set to form a single data layer which became the base map.

For each lizard species, assignment of suitability to any one habitat class was based upon quantitative data (primary field work) and "weight of evidence" qualitative data (existing literature, expert opinion and author knowledge). In both cases we searched for a link between species habitat preferences and macro landforms via their micro landform characterizations. Assignment to a LizLand habitat class using field data was based upon the following general rules for mean number of lizards observed by landform: Suitable Habitat = greater than 50%; Moderate Habitat = 10-50%; Sub-marginal Habitat = less than 10%; Unsuitable Habitat = no observations. Elevation constraints were applied for each species based upon known elevation limits (Stebbins, 1985). Habitat outside the elevation range of each species was assigned to Unsuitable Habitat.

Model accuracy assessments were performed using independent data sets from MCAGCC. The geo-referenced location data were recorded to the nearest 1m as reported by Culter et al. (1999), and to the nearest 100m to 1000m as reported by Minnich et al. (1993). Data for all species were plotted against their respective LizLand models. For *C. draconoides* and *U. stansburiana*, model accuracy was calculated for three groups of collapsed LizLand habitat classes: 1) habitable/uninhabitable (i.e. Suitable, Moderate, and Sub-Marginal versus Unsuitable), 2) top/bottom (i.e. Suitable and Moderate versus Sub-Marginal and Unsuitable) and 3) best/rest (Suitable versus Moderate, Sub-Marginal and Unsuitable). For *U. scoparia*, *S. ater*, and *C. tigris*, the two middle habitat classes were combined into a single class called Moderate to Sub-Marginal Habitat. This resulted in just two groups: 1) habitable/uninhabitable and 2) the best/rest. Contingency tables of primary field data and independent data for each species were used to calculate LizLand percent model accuracy, and omission and commission errors.

The LizLand geo-spatial model is presented in Figure 7.2 (Appendix G). LizLand habitat models were run for all eleven focal species across the entire area. Table 7.3 illustrates the LizLand model predictions for those focal species. The Table lists just nine landform/habitat types as three were not suitable for any of the species. Habitat specific species, such as *Uma scoparia*, are shown to occupy a small number of potential habitats, while habitat generalists, such as *Cnemidophorus tigris* and *Uta stansburiana*, are shown to occupy many.

Though California GAP (CA-GAP) classifies 29 different habitat types in the Mojave Desert, Desert Scrub (dominated by creosote bush) accounts for 78% of the total; add Alkaline Scrub and these two classes make up 89% of the total land area. Barren and Pinyon Juniper each total 2%, seven classes each represent 1% and the remaining 18 cover a total of less than 1%. For MCAGCC (the area initially used for accuracy assessment) only four CA-GAP habitat types exist (Figure 7.3a, Appendix G): Desert Scrub (93%), Alkaline Scrub (4%), Barren (2%) (which in the case of MCAGCC represents three separate lava flows) and Urban (1%). A single map, with three separate legends, is used to represent the CA-GAP habitat model for each of the three focal species (Figure 7.3b, Appendix G).

According to the CA-GAP analysis, 93% (Desert Scrub) of MCAGCC is considered >50% high or medium habitat suitability for all five species and no more than 3% of MCAGCC is considered unsuitable for any one species. Under such cartographic generality it is no wonder that accuracy assessment for all species, based upon field work and the independent Culter et al. (1999) and Minnich et al. (1993) data sets, was 100% and omission and commission errors were 0%. According to the criteria established by Marcot et al., (1983) for validating wildlife-habitat relationship models, the CA-GAP lizard models are neither precise nor accurate.

Unlike CA-GAP, LizLand reflects observed biological processes and lizard interactions. It met the 80% or higher accuracy assessment target range set by GAP (Csuti & Crist, 2000) for all five species across both primary field data and independent data observations in distinguishing habitable/uninhabitable habitat. Success by species was variable for the remaining two categories, top/bottom and best/rest.

Table 7.3: Predicted Landform/Habitat Type Suitability and Predicted Occurrence for 11 Focal Species in the California Mojave Desert.

| Landform/Habitat Type[1] | *Gopherus agassizii* | *Sauromalus ater* | *Callisaurus draconoides* | *Uma scoparia* | *Uta stansburiana* | *Cnemidophorus tigris* | *Crotaphytus bicinctores* | *Toxostoma bendirei* | *Toxostoma lecontei* | *Spermophilus mohavensis* | *Dipodomys panamintinus* |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Rocky | | $X^{S}$ | $X^{M}$ | | $X^{S}$ | $X^{M}$ | X | | | | |
| Rocky Wash | X | $X^{M}$ | $X^{M}$ | | $X^{M}$ | $X^{M}$ | X | X | X | X | X |
| Desert Pavement | X | $X^{M}$ | $X^{M}$ | | $X^{S}$ | $X^{M}$ | X | | | | |
| Inselberg | | $X^{S}$ | | | $X^{S}$ | $X^{M}$ | X | | | | |
| Erosional Highland | | $X^{S}$ | | | $X^{S}$ | $X^{M}$ | X | | | | |
| Sand and Gravel | X | | $X^{Sub}$ | | $X^{Sub}$ | $X^{S}$ | | X | X | X | X |
| Sandy Wash | X | | $X^{S}$ | | $X^{M}$ | $X^{M}$ | | X | X | X | X |
| Sand Sheet | | | $X^{Sub}$ | $X^{S}$ | | $X^{S}$ | | X | X | X | X |
| Wind Blown Sand | | | | $X^{S}$ | | | | | | X | |

[1] None of these species is predicted to occur in Reservoir, Disturbed, or Playa habitats and therefore, these habitats are not diplayed.
X = predicted occurrence, habitat quality not determined., $X^{S}$ = suitable habitat, $X^{M}$ = moderately suitable habitat, $X^{Sub}$ = sub-marginal habitat, blank = not predicted to occur.

LizLand provides fewer unique habitat classes then CA-GAP, 12 instead of 29, but distribution of these 12 classes is more relevant to lizard habitat. No single class accounts for more than 34% of the cover of the Mojave Desert (Figure 7.4 in Appendix G illustrates the distribution of LizLand classes across the California Mojave Desert as well as MCAGCC) and the top two classes account for just 61% compared to 89% for CA-GAP. Only one LizLand class contains 1% or less of the area compared to 18 of 29, or 62% (combining for a total of 1% of the total area), of the CA-GAP classes. The spatial distribution of LizLand habitat for the initial focal species on MCAGCC is shown in Figure 7.5 (Appendix G). LizLand reduced the amount of potentially necessary manageable land (i.e. habitat) within MCAGCC by ~36% in the case of *C. draconoides*, *U. stansburiana*, and *S. ater* and ~63% in the case of *C. tigris* and *U. scoparia*. This is significant for two reasons. First, LizLand reduces the probability that MCAGCC will set aside more land to protect/preserve habitat then is warranted, thus removing it from training and testing. Second, more detailed information provides MCAGCC and other land managers with a better and more accurate picture of the value of their land from a habitat perspective. In this position, all are better able to negotiate (and mitigate) issues related to biodiversity with surrounding land managers and interested stakeholders, all of which must comply with local, state and federal laws related to rare, sensitive, threatened or endangered species.

As a result of the integration across both spatial and managerial scales, LizLand provides species presence/absence information that is sufficiently precise and robust enough to provide useful data to land managers for the five species presented here. At broad spatial scales, LizLand models the unique macro landform characteristics of the Mojave Desert. Lizard habitat preferences were linked to these macro landforms via their mutual micro landform characterizations. Future managerial decisions could be based upon information from broad (macro landforms) or local scales (micro landforms), or some combination of the two. For example, LizLand broad spatial scale analysis of *U. scoparia* habitat leads to the identification of roughly 87,000 hectares of MCAGCC as habitable habitat. At present, an unaccountable cartographic error exists in the delineation of fine wind blown sand and other sand dune areas important to *U. scoparia*. In the event of a state or federal threatened or endangered listing, finer scale analysis of potential habitat within MCAGCC would be necessary. A simple set of on-the-ground criteria, such as a decision support tree detailing appropriate actions to be taken by commanding officers and military personal in the field to assess a training sites habitat potential, could be established and used within the approximate 87,000 hectares of potential habitable habitat. If implemented under adaptive management principles future military activities in the area could be designed around past assessments. These site specific decision tools would minimize the within and between macro landform variability and uncertainty found at the broader scale, and further enhance habitat analysis reliability.

The LizLand model was developed as an alternative tool to CA-GAP for developing wildlife-habitat relationship models. Its success was initially based upon five lizard species, for which primary and secondary data were collected and analyzed. CA-GAP greatly over generalized the habitat of those five species, producing what looked more like range maps than habitat suitability maps. As a result, MCAGCC and surrounding land managers were left with a much greater perceived amount of "associated" habitat. The consequence for MCAGCC, as well as the remaining large DoD military installations in the California Mojave Desert (U.S. Army National Training Center at Ft Irwin, Edwards Air Force Base and China Lake Naval Air

Weapons Station), is pressure to set aside more land than is warranted, thus removing it from training and testing. Similarly, the consequences of such a high level of cartographic generality make it more difficult for the NPS and BLM to accomplish their mission of protecting species. This difficulty is due to the fact that they may inadvertently choose the wrong location in a large polygon of supposedly uniform habitat. The more difficult it is for the NPS and BLM to accomplish their mandated goal of species protection and preservation, among their other mandates, the more difficult it is for the DoD to accomplish its goal of national security.

For the five species initially studied, LizLand provided a useful tool for MCAGCC. As such, it was felt that it would be useful for the remaining portions of the California Mojave Desert. LizLand underwent continued development, refinement and application for the other vertebrate species and taxa within the area. Subsequently, it was applied to the other six focal species as was shown previously in Table 7.3.

# CHAPTER 8

# RESULTS:

## EVALUATING THE SCENARIOS AGAINST HABITAT AND FOCAL SPECIES

While thirty three scenarios were originally developed (in the original scenario development, there were two assumptions on housing density and two on population increase; for the subsequent impact assessment, housing density was kept at the present rate and the population forecast was the state's projection), nine were selected to assess impacts on biodiversity (i.e., the eleven focal species). The assumptions on population increase were restricted to that increase suggested by the State of California and housing density was left at current levels (a lesser impact on habitat would result if the future population increase were distributed at a greater density). In addition to those nine alternative futures, "Predevelopment" condition (essentially the same as habitat) and "present" condition (defined as the pattern of development as it was distributed in the study area in 1990) were also evaluated.

The principal impact of the future scenarios on biodiversity is the consequent encroachment of the development patterns of those futures on habitat. Habitat has been defined, through the development of the LizLand model, as functions derived from a set of landforms (or geomorphology) of the region, mapped and labeled by Dokka (MDEP, 2000) originally into 32 classes, subsequently collapsed into twelve classes (a more thorough discussion of the development of the LizLand model is presented in Chapter 7). Table 8.1depicts the amount of landform (translated to "habitat" via LizLand) developed as a result of land converted from undeveloped to developed status as a result of assumptions made for each scenario. As would be expected, the Plans Buildout scenario has the greatest amount of land converted, with nearly 550,000 hectares developed (from a 1990 development of about 125,000 hectares). Not surprisingly, the amount of developed land varies significantly with landform with unconsolidated parent materials (aeolian or "windblown" and alluvial) being developed more than landforms having consolidated parent materials (such as rocky hillsides). This is partly due to the ease of building on unconsolidated parent materials and also due to the coincidence of more landforms comprised of unconsolidated than consolidated parent materials occurring in the western Mojave. The western Mojave also has much more private land than in the eastern Mojave. For most of the future scenarios, approximately 5% to 10% of unconsolidated landforms were developed and less than 3% of consolidated landforms. Table 8.1 clearly shows the proportion of habitats converted to development due to the nature of their associated parent material (i.e., the unconsolidated aeolian and alluvial landforms versus the consolidated pediments, inselbergs and rocky hillslope landforms).

Landform was converted to habitat via the LizLand model. Table 8.2 shows habitat loss for the eleven focal species due to the resultant impacts of the selected scenarios (The distribution of habitat for a species in the conditions of "Predevelopment" and "Development as of 1990" were also included). A first inspection of the Table seems to indicate that a relatively low percentage of the Mojave landscape will be converted to development, even for the *Plans Buildout* scenario, which shows, for example, that for the worst-case situation, the Mojave Fringe-toed Lizard (*Uma scoparia*) will see a 22.5% decrease in its habitat. Yet the habitat decrease percentage is for the entire area of the California Mojave Desert, and with most of the land in public ownership, this loss means that nearly all of the habitat of the Mojave Fringe-Toed Lizard occurring on private land will be lost. Nearly half of that species' habitat is lost for most of the scenarios, with only the *Biodiversity* and the *Military Buffer* Swaps having significantly less habitat loss. This species clearly is benefited by the *Biodiversity Swap* which was essentially intended to protect the greatest number of species, but not necessarily threatened and endangered species, or species of concern. The *Biodiversity Swap* Scenario protected wind blown sand habitats, which is also prime habitat for the *Uma*. The *Uma* (among the species studied) also has, by far, the greatest variance in habitat loss resulting from the effects of the various scenarios. This would indicate that the nature of the scenario would make a difference on the future distribution of habitat of the species.

The assessment of impacts stemming from changes in patterns of development from the present (1990 condition) to the various futures on biodiversity is evaluated and illustrated for six species. These include the Mojave Fringe-Toed Lizard (*Uma scoparia*), the Desert Tortoise (*Gopherus agassizii*), the Side-blotched Lizard (*Uta stansburiana*), the Bendire's Thrasher (*Toxostoma benderi*), the Mojave Ground Squirrel (*Spermophilus mohavensis*) and the Panamint Kangaroo Rat (*Dipodomys panamintinus*). The impacts of the remaining five species can be seen by inspection of the tables (for example Table 8.2) and are also described briefly in the text. In addition, each of those six species has its habitat illustrated for five conditions: Present (1990 condition), Trend, Plans Build-out, New City, and Biodiversity Swap. Other futures might have greater or lesser impact on a species' habitat but evaluating habitat change is more readily understood with somewhat fewer graphics.

Figure 8.1 (Appendix I) shows the distribution of habitat of *Uma* in 1990. There was little conflict between development and the distribution of this species. Some habitat had been lost east of Barstow and in the vicinity of Twentynine Palms. The loss of habitat due to most of the future scenarios is marked, as shown in Figures 8.2 to 8.5 (Appendix I). Most of the habitat on private land west and north of Edwards Air Force Base is consumed by development. Additional habitat is loss east of Barstow and in Twentynine Palms. In the Build-out scenario, nearly all of the habitat is lost on private land. The Biodiversity Swap future (Figure 8.5) conserves a large patch of habitat west of Edwards AFB, east of Barstow and in the vicinity of Twentynine Palms.

Table 8.1. Amount and Percent of LizLand Habitat Types Developed for Selected Scenarios.

| | Scenario | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 1990 Development | | Trend | | Plans Build-out | | New City | | New Roads | |
| Habitat Type | Hectares | % Developed | Hectares | % Developed | Hectares | % Developed | Hectares | % Developed | Hectares | % Developed |
| Sand and Gravel[1] | 1868672 | | 1708315 | | 1531756 | | 1706508 | | 1704566 | |
| | 98209 | 5.0 | 160357 | 8.6 | 336916.0 | 18.0 | 162164 | 8.7 | 164106 | 8.8 |
| Rocky | 1015528 | | 1009548 | | 1002136.0 | | 1009894 | | 1009972 | |
| | 6917 | 0.7 | 5980 | 0.6 | 13392.0 | 1.3 | 5634 | 0.6 | 5556 | 0.5 |
| Sandy Wash | 463119 | | 443460 | | 416945.0 | | 442806 | | 444123 | |
| | 7452 | 1.6 | 19659 | 4.2 | 46174.0 | 10.0 | 20313 | 4.4 | 18996 | 4.1 |
| Desert Pavement | 579245 | | 566709 | | 540198.0 | | 566620 | | 567981 | |
| | 3419 | 0.6 | 12536 | 2.2 | 39047.0 | 6.7 | 12625 | 2.2 | 11264 | 1.9 |
| Erosional Highland | 2436722 | | 2429743 | | 2404777.0 | | 2430165 | | 2430094 | |
| | 2852 | 0.1 | 6979 | 0.3 | 31945.0 | 1.3 | 6557 | 0.3 | 6628 | 0.3 |
| Wind Blown Sand | 109268 | | 97234 | | 84377.0 | | 97500 | | 97117 | |
| | 2086 | 1.9 | 12034 | 11.0 | 24891.0 | 22.8 | 11768 | 10.8 | 12151 | 11.1 |
| Playa | 163596 | | 162722 | | 159314.0 | | 162809 | | 162710 | |
| | 158 | 0.1 | 874 | 0.5 | 4282.0 | 2.6 | 787 | 0.5 | 886 | 0.5 |
| Reservoir | 1082 | | 1023 | | 878.0 | | 1025 | | 1026 | |
| | 35 | 3.1 | 59 | 5.5 | 204.0 | 18.9 | 57 | 5.3 | 56 | 5.2 |
| Disturbed | 5377 | | 4805 | | 3201.0 | | 4861 | | 4873 | |
| | 309 | 5.4 | 572 | 10.6 | 2176.0 | 40.5 | 516 | 9.6 | 504 | 9.4 |
| Rocky Wash | 294328 | | 291228 | | 284619.0 | | 291446 | | 291569 | |
| | 1081 | 0.4 | 3100 | 1.1 | 9709.0 | 3.3 | 2882 | 1.0 | 2759 | 0.9 |
| Inselberg | 177816 | | 174701 | | 162165.0 | | 174949 | | 174686 | |
| | 1244 | 0.7 | 3115 | 1.8 | 15651.0 | 8.8 | 2867 | 1.6 | 3130 | 1.8 |
| Sand Sheet | 148185 | | 140395 | | 125661.0 | | 140943 | | 140855 | |
| | 961 | 0.6 | 7790 | 5.3 | 22524.0 | 15.2 | 7242 | 4.9 | 7330 | 4.9 |
| Total Undeveloped | 7262938 | | 7029883 | | 6716027 | | 7029526 | | 7029572 | |
| Total Developed | 124723 | 1.7 | 233055 | 3.2 | 546911 | 7.5 | 233412 | 3.2 | 233366 | 3.2 |
| Total Mojave | 7387661 | | 7262938 | | 7262938 | | 7262938 | | 7262938 | |
| Mean | | 1.7 | | 4.3 | | 12.4 | | 4.1 | | 4.1 |
| Var | | 3.4 | | 15.5 | | 132.4 | | 14.3 | | 14.7 |

[1] Number of hectares remaining undeveloped. Value below equals number of hectares developed.

Table 8.1 (cont.). Amount and Percent of LizLand Habitat Types Developed for Selected Scenarios.

| | Scenario | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Exchange 1 | | Exchange 2 | | Exchange 3 | | Exchange 4 | | | |
| Habitat Type | Hectares | % Developed | Hectares | % Developed | Hectares | % Developed | Hectares | % Developed | Mean | Var |
| Sand and Gravel[1] | 1717990 | | 1714073 | | 1714073 | | 1714073 | | | |
| | 150682 | 8.1 | 154599 | 8.3 | 154599 | 8.3 | 154599 | 8.3 | 9.1 | 12.4 |
| Rocky | 1005243 | | 1005248 | | 1005248 | | 1005248 | | | |
| | 10285 | 1.0 | 10280 | 1.0 | 10280 | 1.0 | 10280 | 1.0 | 0.9 | 0.1 |
| Sandy Wash | 444936 | | 442162 | | 442162 | | 442162 | | | |
| | 18183 | 3.9 | 20957 | 4.5 | 20957 | 4.5 | 20957 | 4.5 | 4.6 | 4.9 |
| Desert Pavement | 560426 | | 563351 | | 563351 | | 563351 | | | |
| | 18819 | 3.2 | 15894 | 2.7 | 15894 | 2.7 | 15894 | 2.7 | 2.8 | 2.7 |
| Erosional Highland | 2419386 | | 2428056 | | 2428056 | | 2428056 | | | |
| | 17336 | 0.7 | 8666 | 0.4 | 8666 | 0.4 | 8666 | 0.4 | 0.5 | 0.1 |
| Wind Blown Sand | 109098 | | 103458 | | 103458 | | 103458 | | | |
| | 170 | 0.2 | 5810 | 5.3 | 5810 | 5.3 | 5810 | 5.3 | 8.2 | 45.6 |
| Playa | 162886 | | 161091 | | 161091 | | 161091 | | | |
| | 710 | 0.4 | 2505 | 1.5 | 2505 | 1.5 | 2505 | 1.5 | | 0.7 |
| Reservoir | 1020 | | 1005 | | 1005 | | 1005 | | | |
| | 62 | 5.7 | 77 | 7.1 | 77 | 7.1 | 77 | 7.1 | 7.2 | 20.8 |
| Disturbed | 5297 | | 5054 | | 5054 | | 5054 | | | |
| | 80 | 1.5 | 323 | 6.0 | 323 | 6.0 | 323 | 6.0 | 10.7 | 133.7 |
| Rocky Wash | 287453 | | 289940 | | 289940 | | 289940 | | | |
| | 6875 | 2.3 | 4388 | 1.5 | 4388 | 1.5 | 4388 | 1.5 | 1.5 | 0.7 |
| Inselberg | 172546 | | 174849 | | 174849 | | 174849 | | | |
| | 5270 | 3.0 | 2967 | 1.7 | 2967 | 1.7 | 2967 | 1.7 | 2.5 | 5.9 |
| Sand Sheet | 143210 | | 141638 | | 141638 | | 141638 | | | |
| | 4975 | 3.4 | 6547 | 4.4 | 6547 | 4.4 | 6547 | 4.4 | 5.2 | 15.8 |
| Total Undeveloped | 7029491 | | 7029925 | | 7029925 | | 7029925 | | | |
| Total Developed | 233447 | 3.2 | 233013 | 3.2 | 233013 | 3.2 | 233013 | 3.2 | | |
| Total Mojave | 7262938 | | 7262938 | | 7262938 | | 7262938 | | | |
| Mean | | 2.8 | | 3.7 | | 3.6 | | 3.7 | | |
| Var | | 5.5 | | 6.8 | | 6.8 | | 6.8 | | |

[1] Number of hectares remaining undeveloped. Value below equals number of hectares developed.

Table 8.2.  Habitat loss for 11 focal species and selected scenarios.

| | Species | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | *Gopherus agassizii* | | *Sauromalus ater* | | *Callisaurus draconoides* | | *Uma scoparia* | |
| Scenario | Hectares | % Loss | Hectares | % Loss | Hectares | % Loss | Hectares | % Loss |
| Predevelopment | 3229454 | | 4372812 | | 4403068 | | 212662 | |
| Development 1990 | 3119392 | 3.4 | 4356983 | 0.4 | 4285028 | 2.7 | 209630 | 1.4 |
| Trend | 2924378 | 6.3 | 4325223 | 0.7 | 4075501 | 4.9 | 190000 | 9.4 |
| Plans Build Out | 2689483 | 13.8 | 4246845 | 2.5 | 3817284 | 10.9 | 162433 | 22.5 |
| New City | 2922301 | 6.3 | 4324140 | 0.8 | 4074059 | 4.9 | 190812 | 9.0 |
| Open Space | 2926641 | 6.2 | 4327620 | 0.7 | 4076300 | 4.9 | 187681 | 10.5 |
| New Roads | 2922809 | 6.3 | 4327620 | 0.7 | 4074901 | 4.9 | 190318 | 9.2 |
| Biodiversity Swap | 2925863 | 6.2 | 4298330 | 1.3 | 4075144 | 4.9 | 204611 | 2.4 |
| Buffered Military | 2924154 | 6.3 | 4314751 | 1.0 | 4072256 | 5.0 | 197369 | 5.8 |
| Private Land Swap | 2925371 | 6.2 | 4322879 | 0.8 | 4076557 | 4.9 | 190060 | 9.3 |
| Flight Path Buffer | 2925371 | 6.2 | 4313859 | 1.0 | 4078408 | 4.8 | 189612 | 9.5 |
| Mean | | 6.7 | | 1.0 | | 5.3 | | 8.9 |
| VAR | | 6.3 | | 0.3 | | 4.0 | | 29.6 |

Table 8.2 (cont.). Habitat loss for 11 focal species and selected scenarios.

| | Species | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | *Crotaphytus bicinctores* | | *Uta stansburiana* | | *Cnemidophorus tigris* | | *Toxostoma bendirei* | |
| Scenario | Hectares | % Loss | Hectares | % Loss | Hectares | % Loss | Hectares | % Loss |
| Predevelopment | 4476129 | | 6932298 | | 7106164 | | 214486 | |
| Development 1990 | 4460616 | 0.3 | 6811238 | 1.7 | 6984026 | 1.7 | 207659 | 3.2 |
| Trend | 4428907 | 0.7 | 6600230 | 3.1 | 6764505 | 3.1 | 204928 | 1.3 |
| Plans Build Out | 4350887 | 2.5 | 6320700 | 7.2 | 6468637 | 7.4 | 199954 | 3.7 |
| New City | 4430052 | 0.7 | 6599162 | 3.1 | 6763738 | 3.2 | 205211 | 1.2 |
| Open Space | 4427852 | 0.7 | 6602994 | 3.1 | 6765943 | 3.1 | 204666 | 1.4 |
| New Roads | 4431280 | 0.7 | 6599416 | 3.1 | 6764251 | 3.1 | 205313 | 1.1 |
| Biodiversity Swap | 4402034 | 1.3 | 6584938 | 3.3 | 6751596 | 3.3 | 203624 | 1.9 |
| Buffered Military | 4418425 | 0.9 | 6594178 | 3.2 | 6759718 | 3.2 | 204222 | 1.7 |
| Private Land Swap | 4426569 | 0.8 | 6600025 | 3.1 | 6764255 | 3.1 | 204572 | 1.5 |
| Flight Path Buffer | 4417469 | 1.0 | 6599769 | 3.1 | 6764264 | 3.1 | 203517 | 2.0 |
| Mean | | 1.0 | | 3.4 | | 3.4 | | 1.9 |
| VAR | | 0.3 | | 1.8 | | 1.9 | | 0.7 |

Table 8.2 (cont.). Habitat loss for 11 focal species and selected scenarios.

| | Species | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | *Toxostoma lecontei* | | *Spermophilus mohavensis* | | *Dipodomys panamintinus* | | | |
| Scenario | Hectares | % Loss | Hectares | % Loss | Hectares | % Loss | Mean | Var |
| Predevelopment | 4771193 | | 1246318 | | 676060 | | | |
| Development 1990 | 4660936 | 2.3 | 1179164 | 5.4 | 644011 | 4.7 | 2.5 | 2.6 |
| Trend | 4462978 | 4.2 | 1064033 | 9.8 | 599020 | 7.0 | 4.6 | 10.3 |
| Plans Build Out | 4215997 | 9.5 | 939602 | 20.3 | 534650 | 17.0 | 10.7 | 48.9 |
| New City | 4461703 | 4.3 | 1060785 | 10.0 | 589487 | 8.5 | 4.7 | 11.3 |
| Open Space | 4466374 | 4.2 | 1074887 | 8.8 | 594899 | 7.6 | 4.7 | 10.9 |
| New Roads | 4461042 | 4.3 | 1054579 | 10.6 | 601579 | 6.6 | 4.6 | 11.1 |
| Biodiversity Swap | 4462871 | 4.2 | 1075142 | 8.8 | 583510 | 9.4 | 4.3 | 7.9 |
| Buffered Military | 4466718 | 4.2 | 1091072 | 7.5 | 597274 | 7.3 | 4.2 | 5.7 |
| Private Land Swap | 4463953 | 4.2 | 1066742 | 9.5 | 601039 | 6.7 | 4.4 | 10.7 |
| Flight Path Buffer | 4469460 | 4.1 | 1095153 | 7.1 | 590814 | 8.3 | 4.6 | 8.5 |
| Mean | | 4.6 | | 9.8 | | 8.3 | | |
| VAR | | 3.1 | | 14.5 | | 9.8 | | |

The Desert Tortoise (*Gopherus agassizii*), on the other hand, has an almost identical loss of habitat regardless of scenario. Habitat loss is either 6.2% or 6.3% with the scenarios and maximizes at 13.8% with the *Plans Build-Out* Scenario. Figures 8.7 to 8.10 (Appendix I) illustrate the habitat of the Desert Tortoise as a function of the type of future. Figure 8.6 (Appendix I) illustrates its habitat distribution at present (1990). An inspection of the three alternative futures to trend shows little difference in habitat loss. In the *Plans Build-Out* Scenario, approximately half of the private land within the western Mojave is converted to development, possibly placing an additional burden on the two nearby military bases (Edwards AFB and MCAGCC) to protect the already threatened species.

As the table illustrates, similar results also occur for the Zebra-tailed Lizard (*Callisaurus draconoides*), the Side-blotched Lizard (*Uta stansburiana*), the Western Whiptail Lizard (*Cnemidophorus tigris*), and Le Conte's Thrasher (*Toxostoma lecontei*). For each of these species, the amount of habitat lost is virtually the same for all of the scenarios. The Side-blotched and Western Whiptail Lizards each lose 3.1% or 3.2% of their habitat, the Le Conte's Thrasher about 4.2% of its habitat, and the Zebra-tailed Lizard nearly 5% of its habitat. These essentially uniform habitat losses attest to the species' lack of preference for specific habitat types (Figure 8.11 in Appendix I illustrates the habitat preferred by the *Uta* and its distribution at present) or spatial location within the Mojave, occurring more or less uniformly throughout the region. For these species, then, the nature of the scenario makes little difference on the future distribution of their habitat. Figures 8.12 to 8.15 (Appendix I) illustrate this observation for the Side-blotched Lizard (*Uta stansburiana*). In fact, most of the habitat lost, even in *Plans Build-Out*, is less desirable, or sub-marginal habitat. The future with the greatest impact is the Biodiversity Swap. That future places the most desirable habitat in the path of development.

In addition to the specialist species previously discussed (the Mojave Fringe-Toed Lizard, *Uma scoparia*), the remaining five species also have a rather varied pattern of habitat loss with changes in scenarios, as results depicted in Table 8.2 illustrate. The widely distributed Chuckwalla (*Sauromalus ater*) and Black-collared Lizard (*Crotophytus bicinctores*) also have their largest habitat losses with the *Biodiversity Swap* Scenario; although at 1.3%, they are not that significant. They only lose from 0.7% to 1.0% with the other scenarios. The sparsely distributed (with only about 200,000 hectares of habitat in the Mojave) Bendire's Thrasher (*Toxostoma benderei*) loses little habitat, 1.1% to 2.0% but some of the few remaining populations might become extinct. Figures 8.16 to 8.20 (Appendix I) illustrate present conditions and habitat loss scenarios for the four futures for the Bendire's Thrasher. Most of this thrasher's habitat occurs on public land in the eastern and southern parts of the study area. A substantial amount of the two small areas of suitable habitat west of Twentynine Palms and southeast of Victorville is lost in the development scenarios.

Both of the moderately distributed rodent species, the Mojave Ground Squirrel (*Spermophilus mohavensis*) and the Panamint Kangaroo Rat (*Dipodomys panamintinus*), have significant reductions in habitat with the scenarios. The ground squirrel loses over 20% of its habitat with the *Plans Build Out*, and over 10% with the *New City* and *New Roads* Scenarios. It loses less habitat with the other scenarios with a low of 7.1% loss with the *Flight Path Buffer* Scenario. Figure 8.21 (Appendix I) illustrates that the location of habitat within the context of present development (1990) for the Mojave Ground Squirrel occurs primarily within the western part of the study area and, as a result, occurs heavily on private lands. Thus, with the trend of development from 1990 through to the *Plans Build-Out* future (Figures 8.22 and 8.23 Appendix I), nearly the entire habitat south of Edwards AFB is converted to development. Edwards AFB might become a major factor in its management as development proceeds. The other two futures (Figures 8.24 and 8.25, Appendix I) show little difference in the association of development with ground squirrel habitat. The Panamint Kangaroo Rat loses 17% of its habitat in *Plans Build Out* (Figure 8.28) and Figures 8.26 and 8.27 (Appendix I) illustrate the development trend from 1990 through to Build-Out. The species loses from 6.6% to 9.4% of its habitat with the other futures (cf. Table 8.2). More significantly, however, is the tremendous loss of habitat of the subspecies *D. p. mohavensis*. While precise boundaries for this subspecies are not definite, it is generally thought to be confined to the western part of the study area, somewhat north and east and definitely west and south of Edwards Air Force Base. Most of the habitat of this subspecies will be lost in *Plans Build Out*, and a substantial amount of habitat is lost in all of the other future scenarios. Figures 8.27 to 8.30 (Appendix I) show the loss of habitat with the *Trend*, *Plans Build-Out* and other futures. Prime habitat for the subspecies occurs on the large bajada and associated landforms south and southeast of Edwards Air Force Base between Palmdale and Victorville. In *Plans Build Out*, nearly all of this area is developed. In the other scenarios, much of it is converted to urban-related land uses. The other subspecies of *Dipodomys panamintinus* are little affected by future development patterns.

# CHAPTER 9

# SUMMARY AND CONCLUSIONS

The overall objective of this study was to evaluate the effects of development on biodiversity in the Mojave Desert (within California) at the present time (1990) and to model its potential future impact for the year 2020. The study area, where 77% of the land is managed by the federal government (Table 1.1) is an ecologically diverse and inherently fragile ecosystem, contains some of the largest military installations in the country, is experiencing rapid population growth and is faced with a number of environmental issues and land use conflict situations.

A landform-based habitat suitability model was developed and used to assess habitat of selected species. Biodiversity was modeled using four indices - richness, diversity, rarity and endemism – individually, and in combination based on wildlife habitat relationships. Socio/demographic and economic drivers were based on projected population growth and six independent variables influencing development of land in the study area, to generate a development probability model.

Three techniques for developing alternative future scenarios were devised – model based, planning based and combined – resulting in a total of 33 scenarios, nine of which were used for further analysis. Of these, the scenarios that showed development displaced from areas north and west of Edwards Air Force Base to Barstow and areas south of Edwards and China Lake, and south and west of Twentynine Palms were deemed the most realistic from the perspective of minimizing impact on biodiversity while maintaining military mission interests.

The Mojave Desert in California has a high species diversity with approximately 274 resident or breeding vertebrate species, among them the Desert Tortoise (*Gopherus agassizii*) which is listed as “threatened” under the Endangered Species Act. Of these 274, eleven were selected as focal species, see Table 7.1. Habitat-landform relationships were investigated, and a spatially explicit habitat model, LizLand, was initially tested on three lizard species and subsequently used to generate habitat suitability maps for all 11 focal species. LizLand reflects observed biological processes and was compared and contrasted with the California Mojave Desert GAP model, which did not show equal precision or accuracy for the lizard habitat (cf. Figure 7.4).

The impact of different development scenarios upon biodiversity was assessed by converting landform into habitat using the LizLand model, the habitat needs of each of the 11 focal species was considered and the implications for land ownership or management explored. Nine scenarios, plus predevelopment (as a baseline) and present (1990) were assessed, showing that approximately 50% of privately owned land in the western Mojave would be used for development under the plans build-out scenario (Table 8.1). Superficially it appears that there is not an overwhelming impact on habitat associated with this potential development, with the greatest loss being 22.5% for the Mojave Fringe-toed Lizard (*Uma scoparia*). However, the effect of such development would be to restrict this species almost entirely to publicly owned land, thus placing some responsibility for the survival of this lizard upon Federal agencies including the military. See Table 8.2 and Figure 8.1.

Results indicate that habitat loss with the project's designed and modeled alternative futures is a function of land ownership as only land which is privately held can be developed given the assumptions which we used to develop those alternative futures. This does not mean that public land can be considered as permanently excluded from future development. It is possible that land management agencies may be given the authority and opportunity to exchange public lands with, for example, low biodiversity values for private lands with high biodiversity values. Other exchanges may also be permitted. Our exchanges do not result in an increase in private land but rather private land which can still be developed. For most of the species, changing patterns of development will not deleteriously affect their distribution and probably not their viability. Most of the habitat of these species is protected as a result of their occurrence on public lands. Only a few species and one subspecies are threatened by the prospect of future development. Nevertheless, increased pressure on public land management agencies to manage, and protect species diversity is a likely outcome of increased development on military lands.

The relationship between land ownership and landforms recognizes that landforms are distributed in a manner not governed by ownership (Figure 9.1). It appears, however, that the landforms which are more suitable for development, flat lands especially, are more likely to be in private ownership than rocky, and steep landforms. As such, the distribution of habitat types is somewhat dependent on ownership. Those species which are generalists, such as the Desert Tortoise (*Gopherus agassizii*) and the Zebra-tailed Lizard (*Callisaurus draconoides*) will be more or less evenly distributed throughout the Mojave, while specialists such as the Mojave Fringe-toed Lizard (*Uma scoparia*) will be found on specific habitats. Where those habitats intersect urban development, those species will suffer a greater risk of habitat destruction and elimination. The burden that the military might shoulder with respect to biodiversity protection depends to some degree on the proportion of habitat of a particular species on military lands. Table 9.1 shows the proportion of habitat of the focal species occurring on military land. Table 1.1 shows that approximately 14% of the area of the California Mojave is in Military ownership. Eight of the eleven species we studied also have close to14% (12% to 15%) of their potential habitat on military lands. Only three other species have a greater or lesser percentage of their potential habitat on military lands (Mojave Fringe-toed Lizard, Mojave Ground Squirrel, and Bendire's Thrasher). The species with no habitat on DoD lands (Bendire's Thrasher) may have a risk of habitat loss, but it will be outside the direct concern of the military. Therefore, in some cases, existing DoD lands will not have to be protected to conserve habitat. The military might, however, wish to engage in land swaps where it might swap land that has little training value and little testing value as well as with high habitat value for private land with higher biodiversity value regardless of training value. Concomitantly, those species which have considerable habitat both on high value DoD training and testing land and on land subject to development might be at very high risk for habitat loss. The DoD might find itself needing to negotiate land conservation with both the private sector and other land holding agencies. The intersection of alternative futures with land ownership might shed light on those areas of concern. Species, whose habitat occurs primarily on private developable land

and on portions of military land which are used primarily for training and testing activities, raise red flags from a biodiversity conservation perspective and should be given additional attention by the military.

Table 9.1 Percent of Focal Species Habitat Found on Military Lands

| Species | | Habitat (ha) | | |
|---|---|---|---|---|
| Scientific Name | Common Name | Military | Total | Percent |
| *Gopherus agassizii* | Desert Tortoise | 449,554 | 3,313,861 | 14 |
| *Callisaurus draconoides* | Zebra-tailed Lizard | 624,054 | 4,403,068 | 14 |
| *Cnemidophorus tigris* | Western Whiptail Lizard | 1,014,709 | 7,062,427 | 14 |
| *Crotaphytus bicinctores* | Black-collared Lizard | 646,118 | 4,517,253 | 14 |
| *Sauromalus ater* | Chuckwalla | 625,140 | 4,415,022 | 14 |
| *Uma scoparia* | Mojave Fringe-toed Lizard | 45,805 | 212,748 | 22 |
| *Uta stansburiana* | Side-blotched Lizard | 986,640 | 6,987,007 | 14 |
| *Dipodomys panamintinus* | Panamint Kangaroo Rat | 83,941 | 676,318 | 12 |
| *Spermophilus mohavensis* | Mojave Ground Squirrel | 377,948 | 1,246,394 | 30 |
| *Toxostoma bendirei* | Bendire’s Thrasher | 0 | 214,631 | 0 |
| *Toxostoma lecontei* | Le Conte’s Thrasher | 707,146 | 4,812,686 | 15 |

While the research was conducted specifically in the Mojave ecoregion, the understanding gained and approaches developed should be more broadly applicable. In particular, our research will contribute to improved understanding of the effects of human disturbance on biodiversity in arid landscapes in general. The analytical framework and user-friendly interface can be adopted to address land-use conflicts and the regional management of biodiversity in other environments.

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# Appendix A

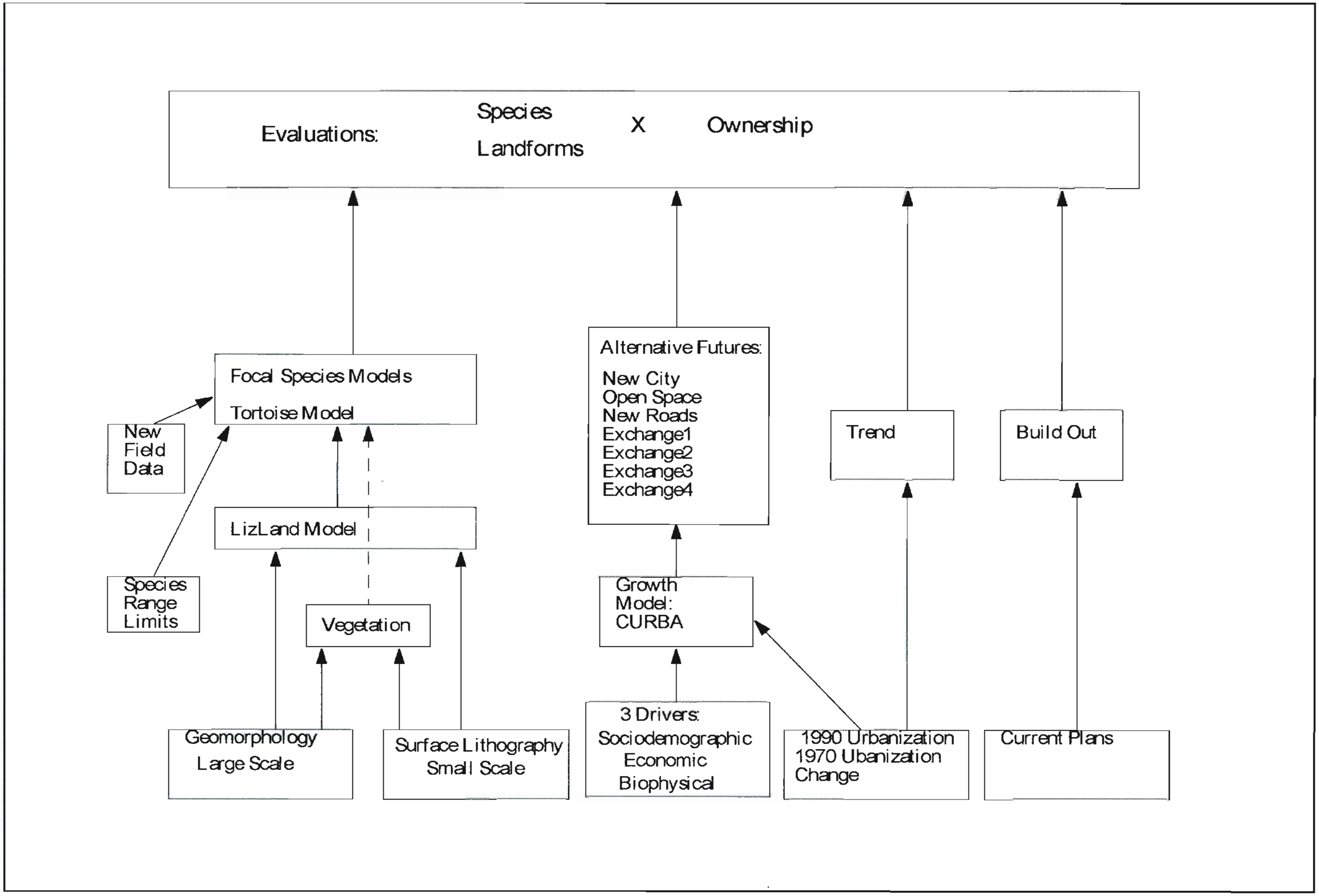


Figure 1.1. Conceptual model for the project, showing factors affecting biodiversity on the left and those contributing toward alternative future scenario models on the right. The figure reads from bottom to top.

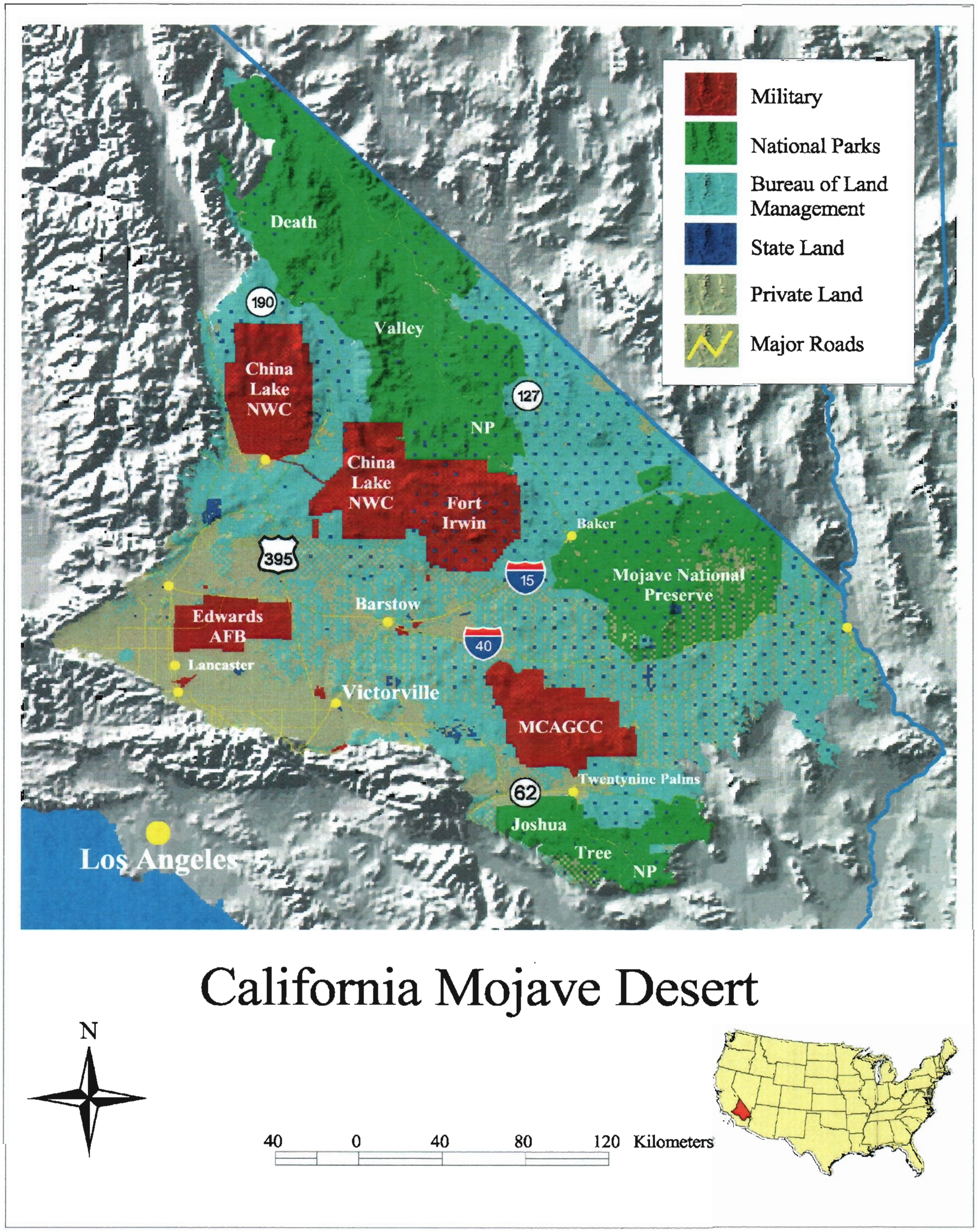


Figure 2.1. Location of the study area.

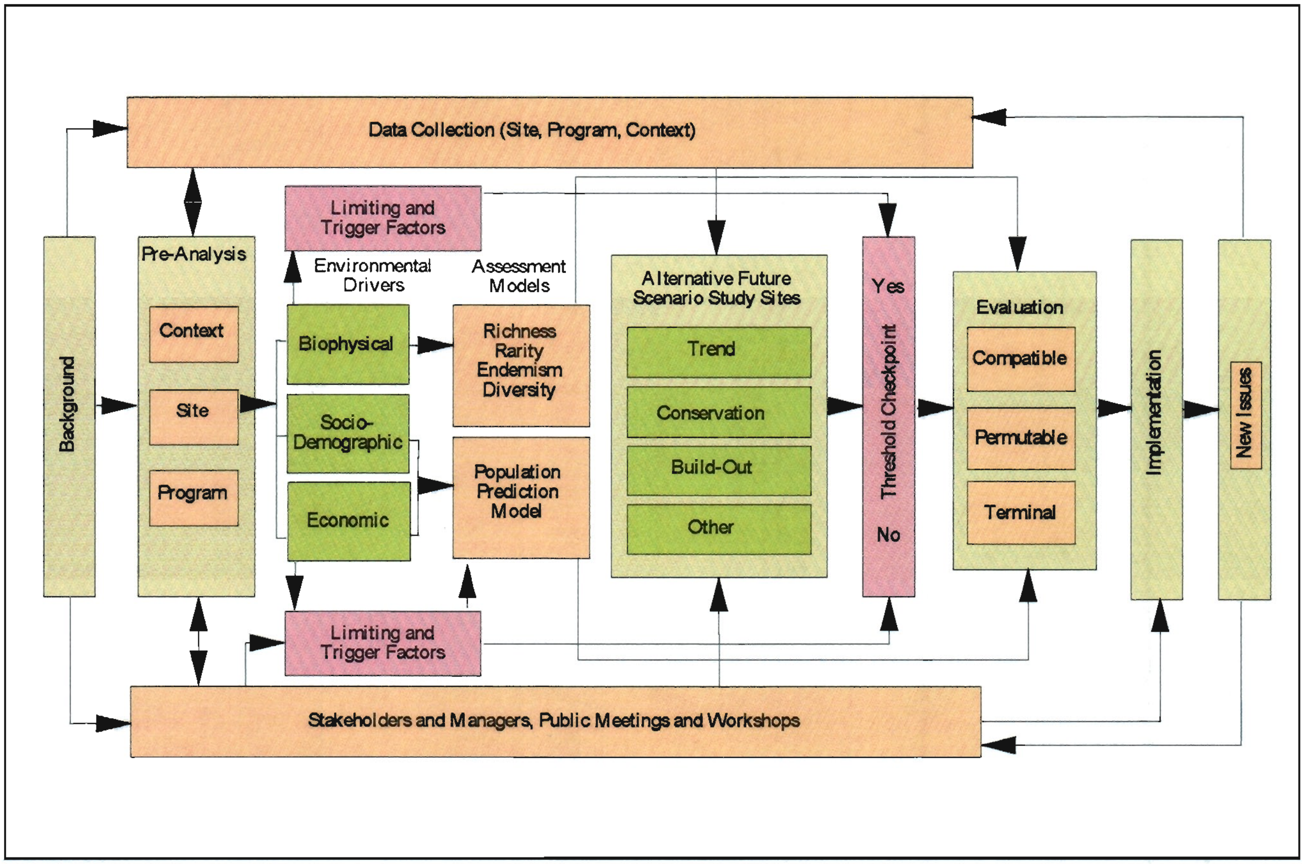


Figure 3.1. Alternative Futures conceptual model.

# Appendix B

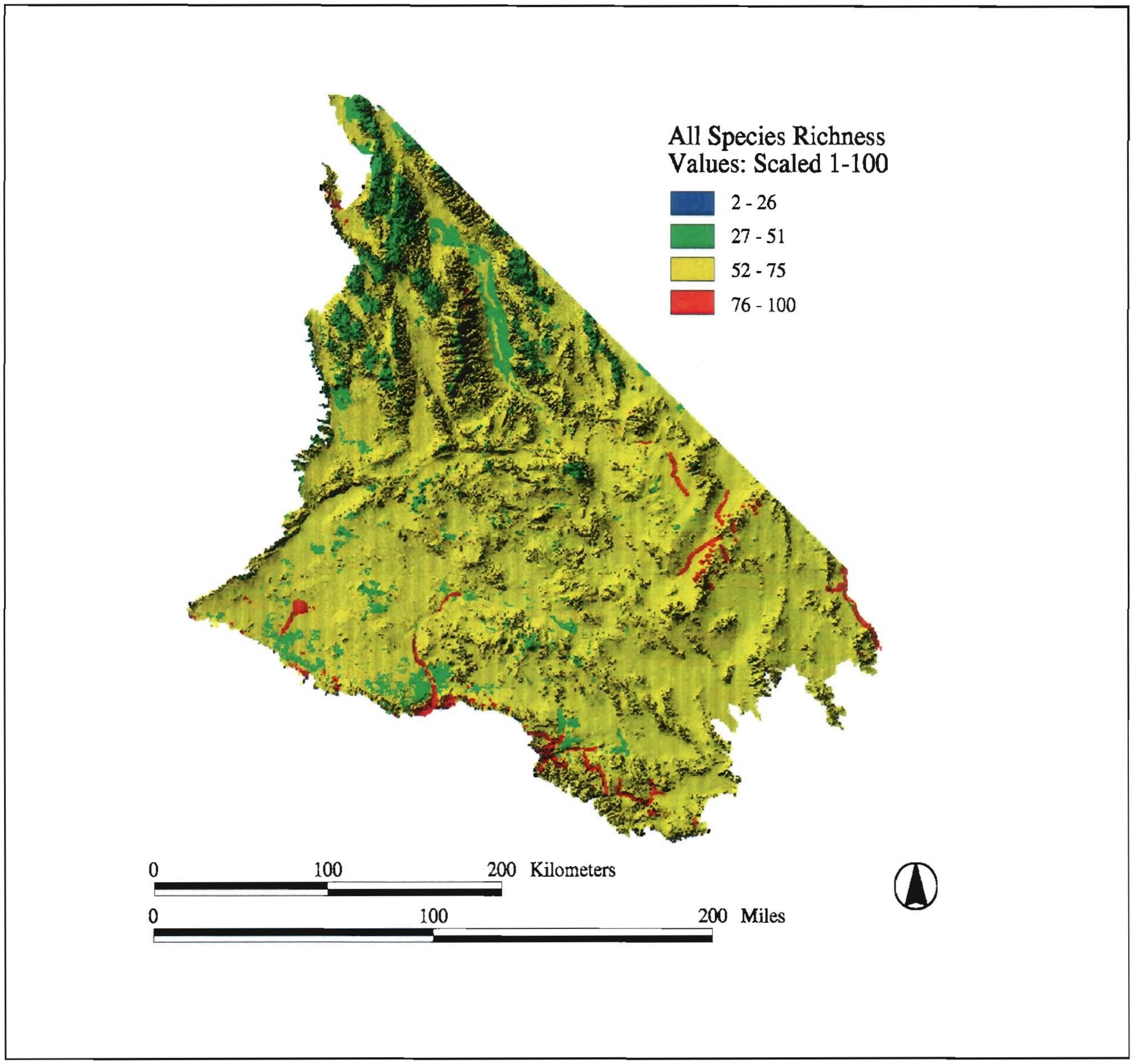


Figure 4.1. Species richness.

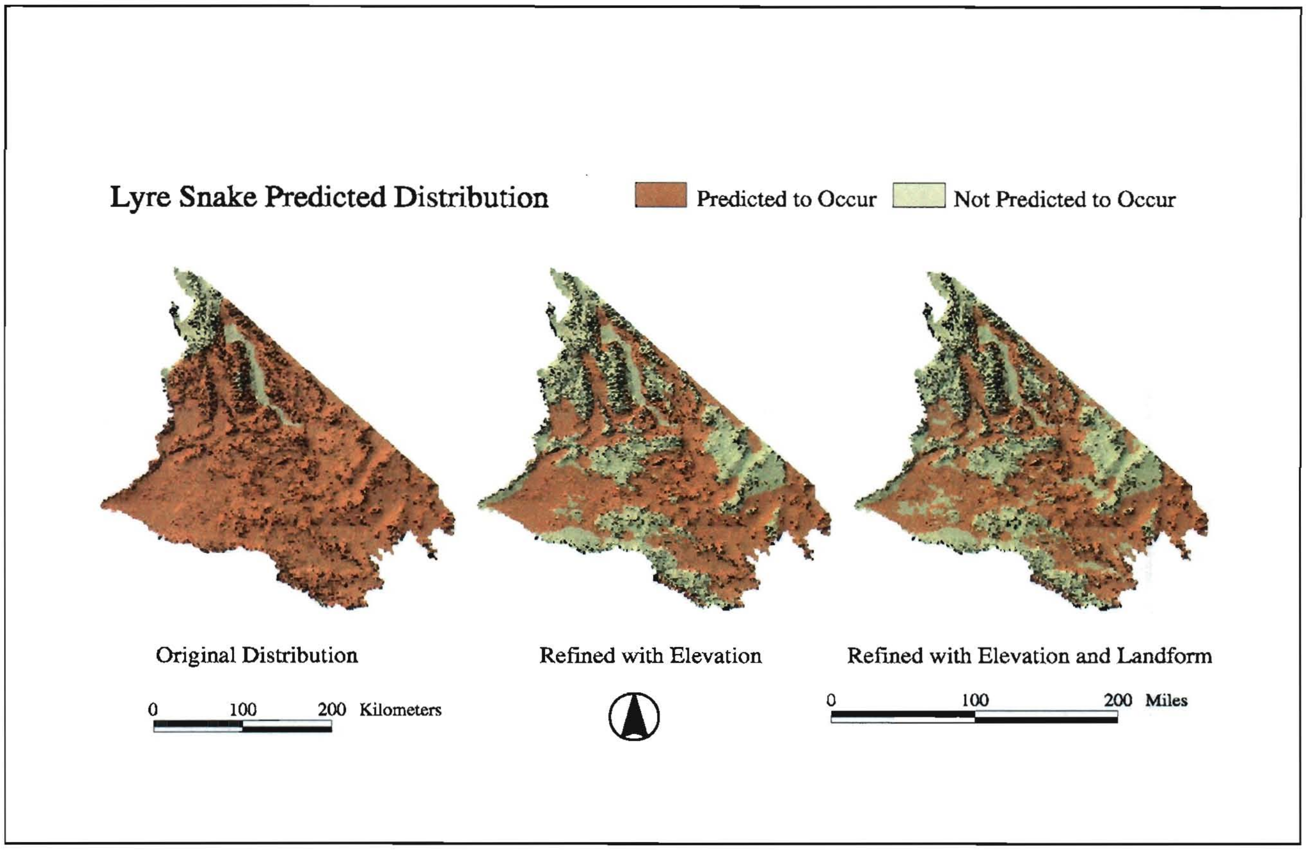


Figure 4.2. Lyre Snake predicted distribution.

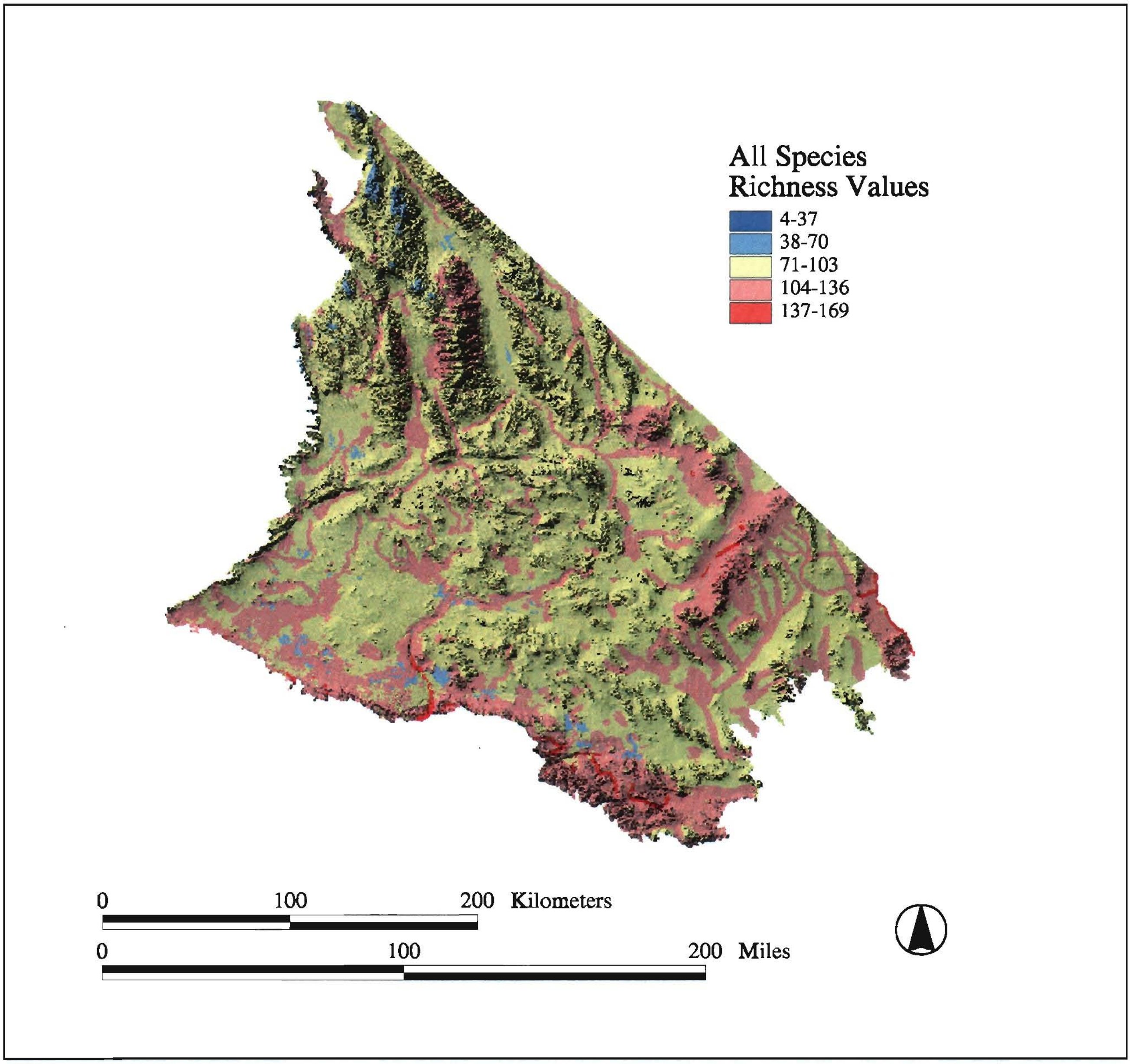


Figure 4.3. Total species richness.

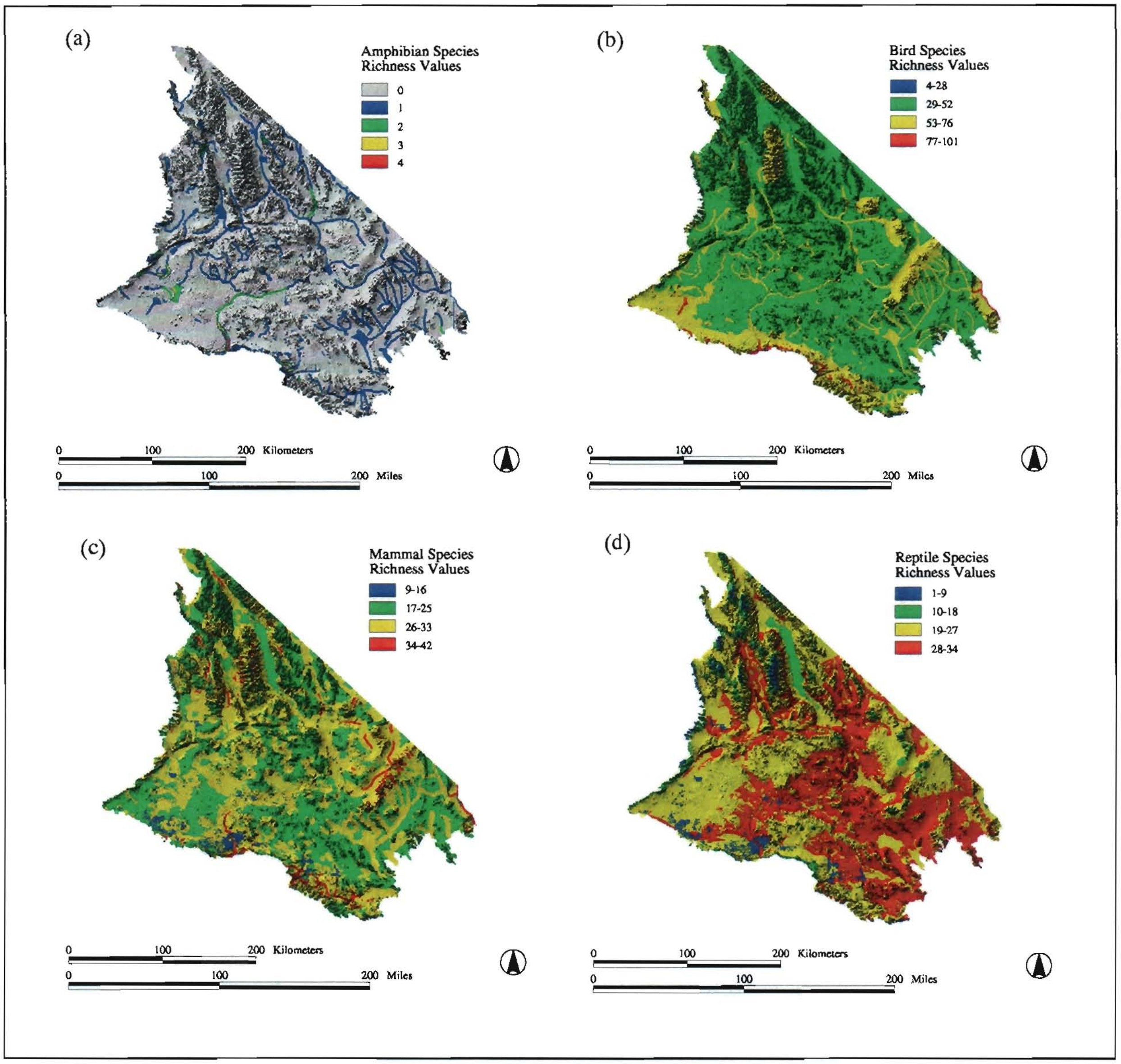


Figure 4.4. Species richness according to taxa.

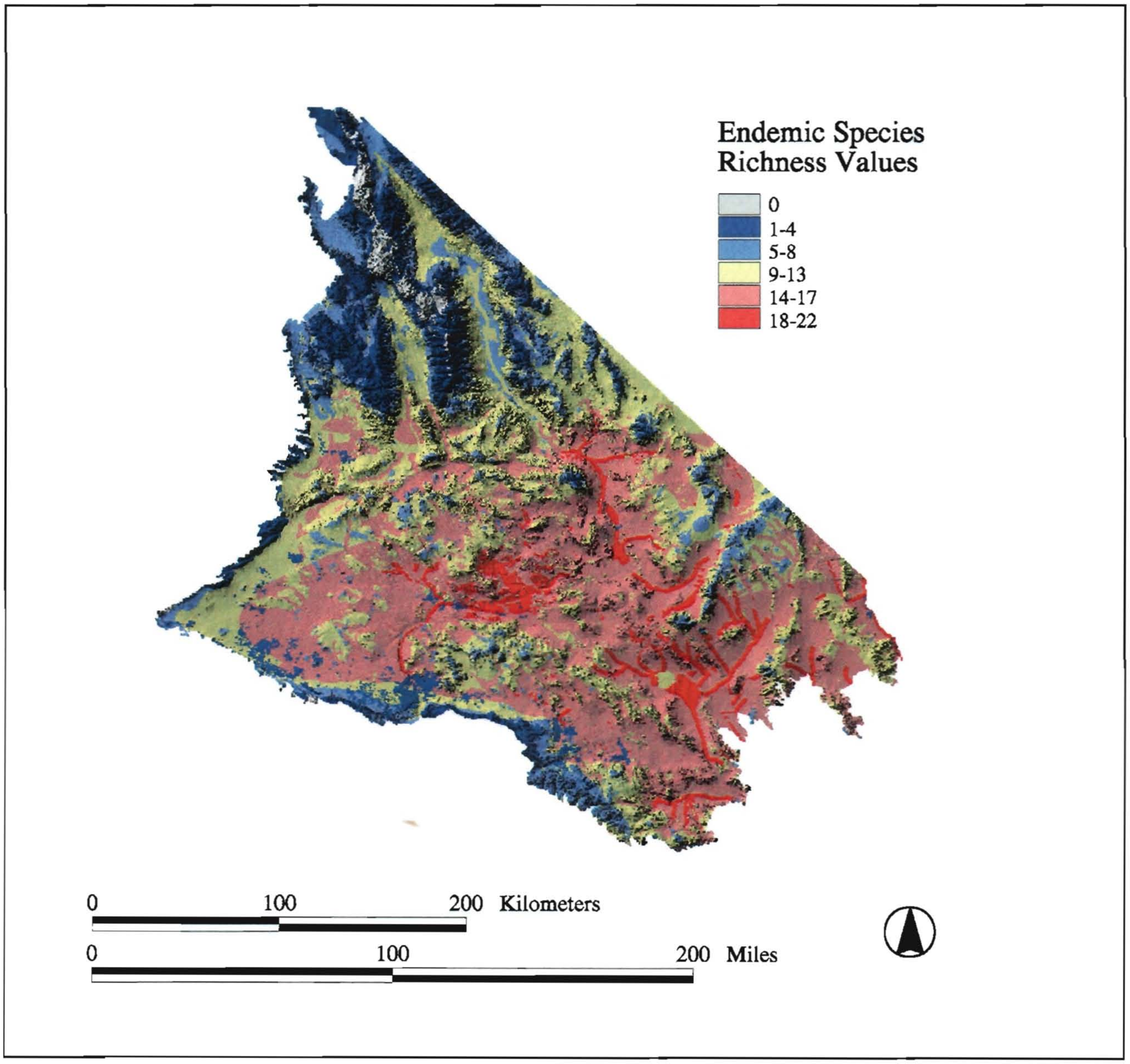


Figure 4.5. Endemic species richness.

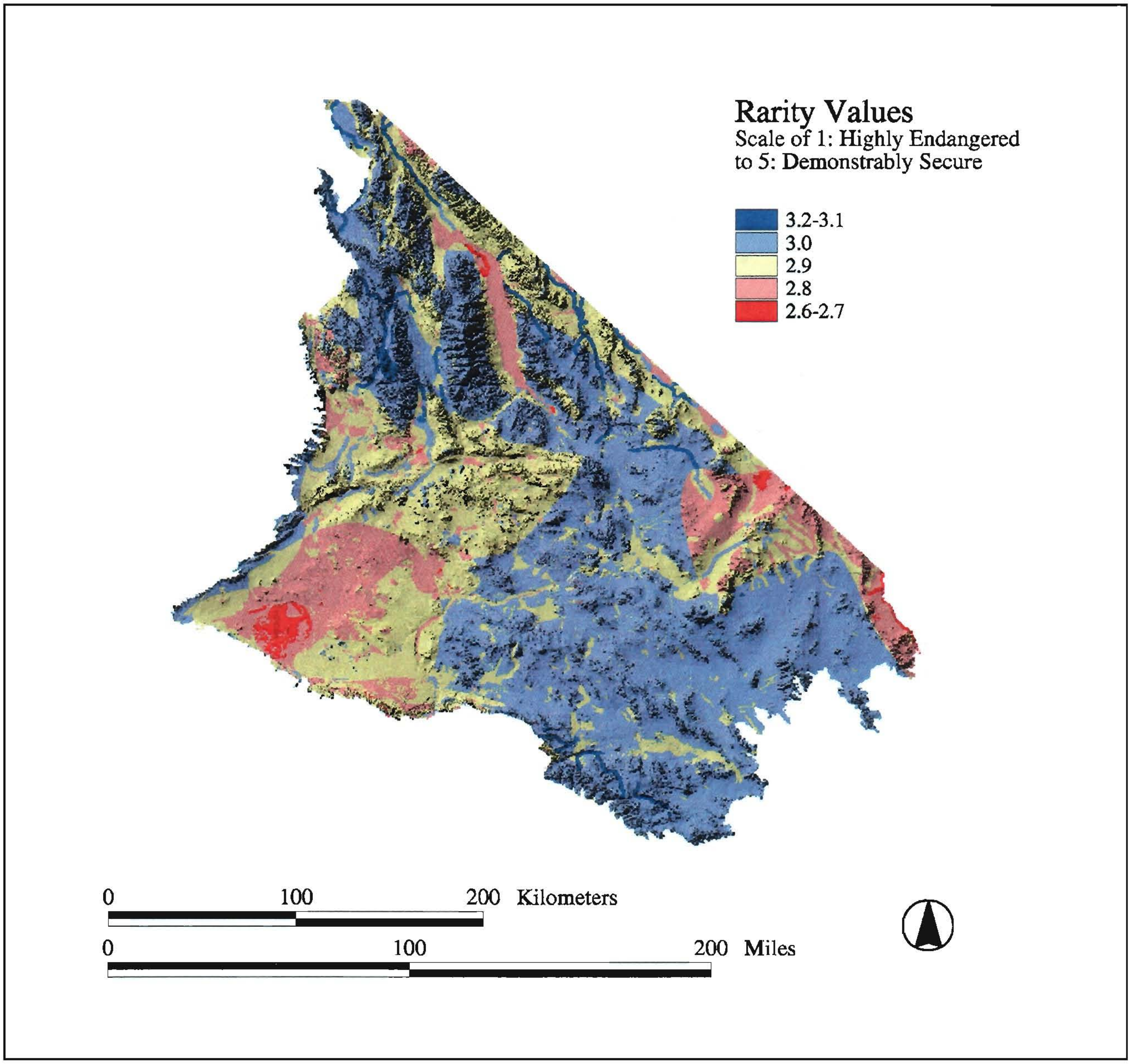


Figure 4.6. Levels of rarity, with areas in red indicating highest endangerment.

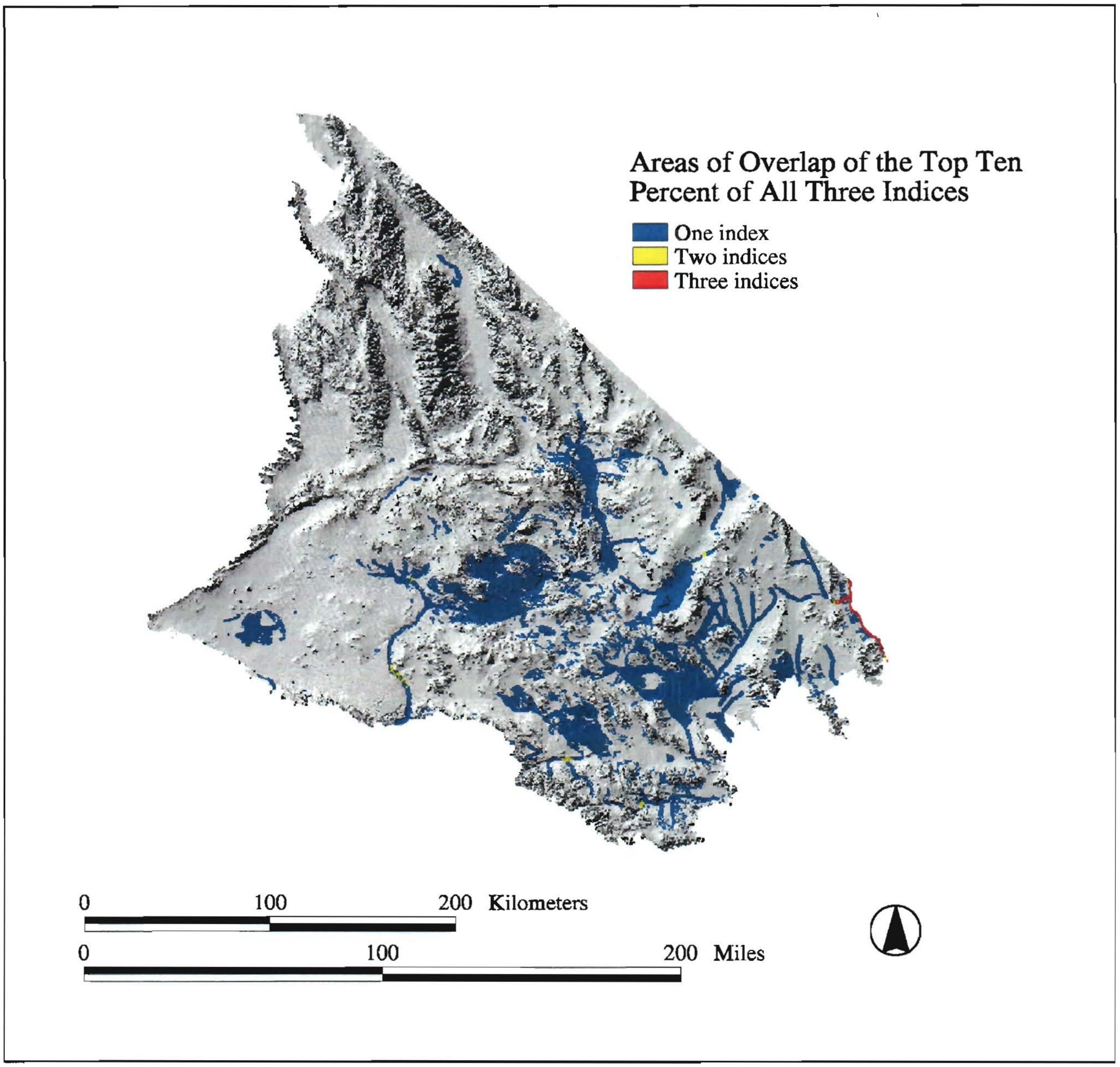


Figure 4.7. Areas where the three indices overlap: all species richness, endemic species richness and rarity.

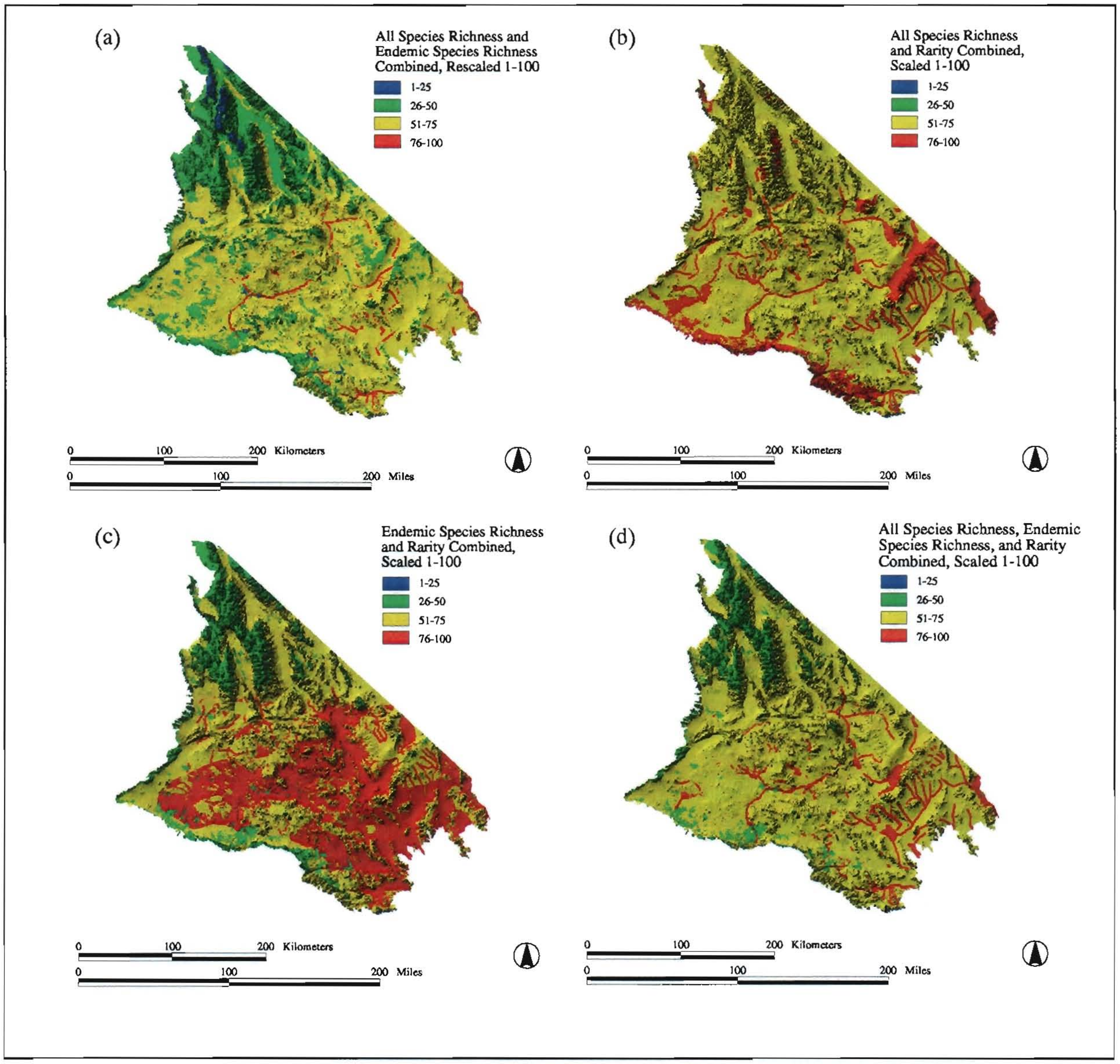


Figure 4.8. Index combinations.

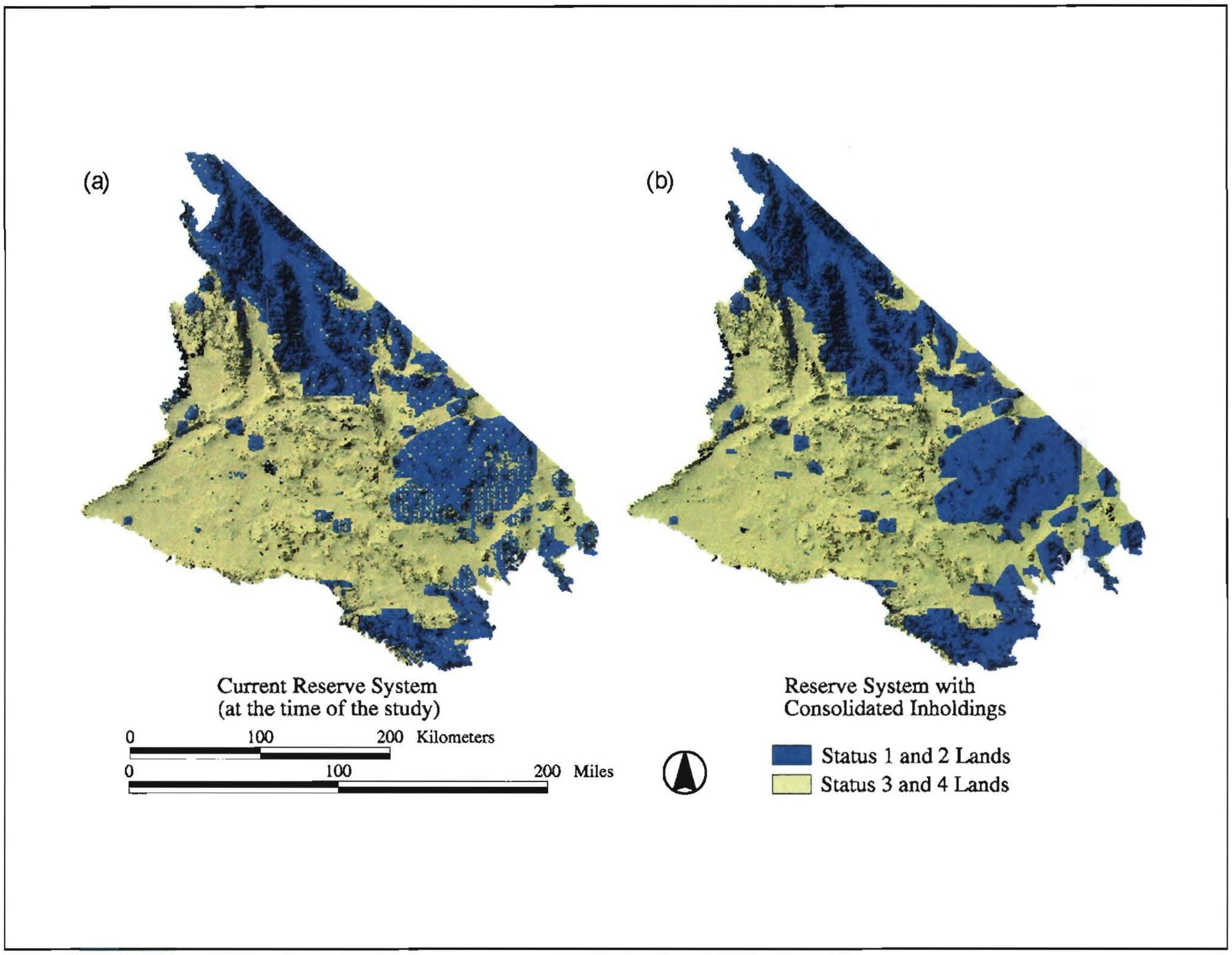


Figure 4.9. Current reserve system (a); and reserve system with consolidated inholdings (b).

# Appendix C

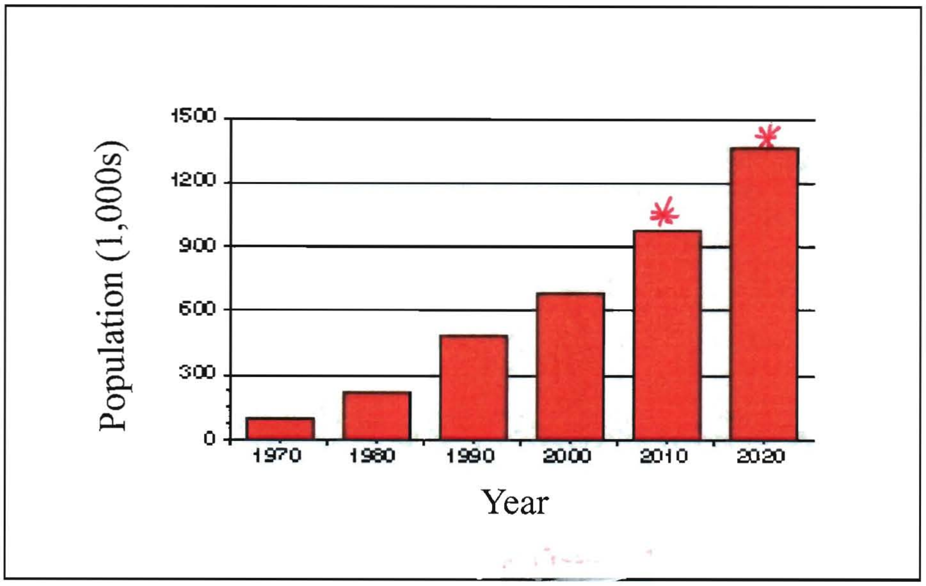
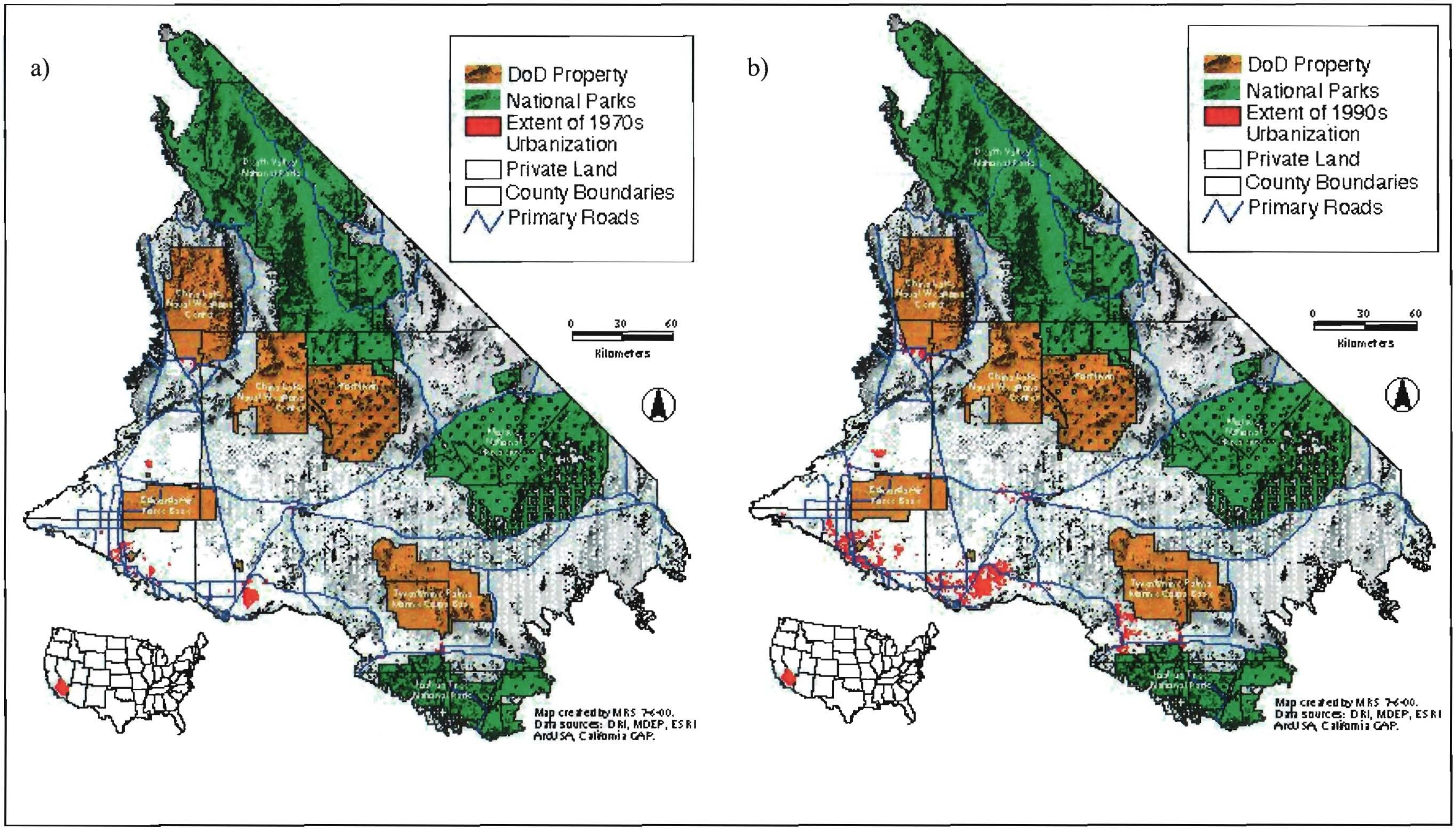


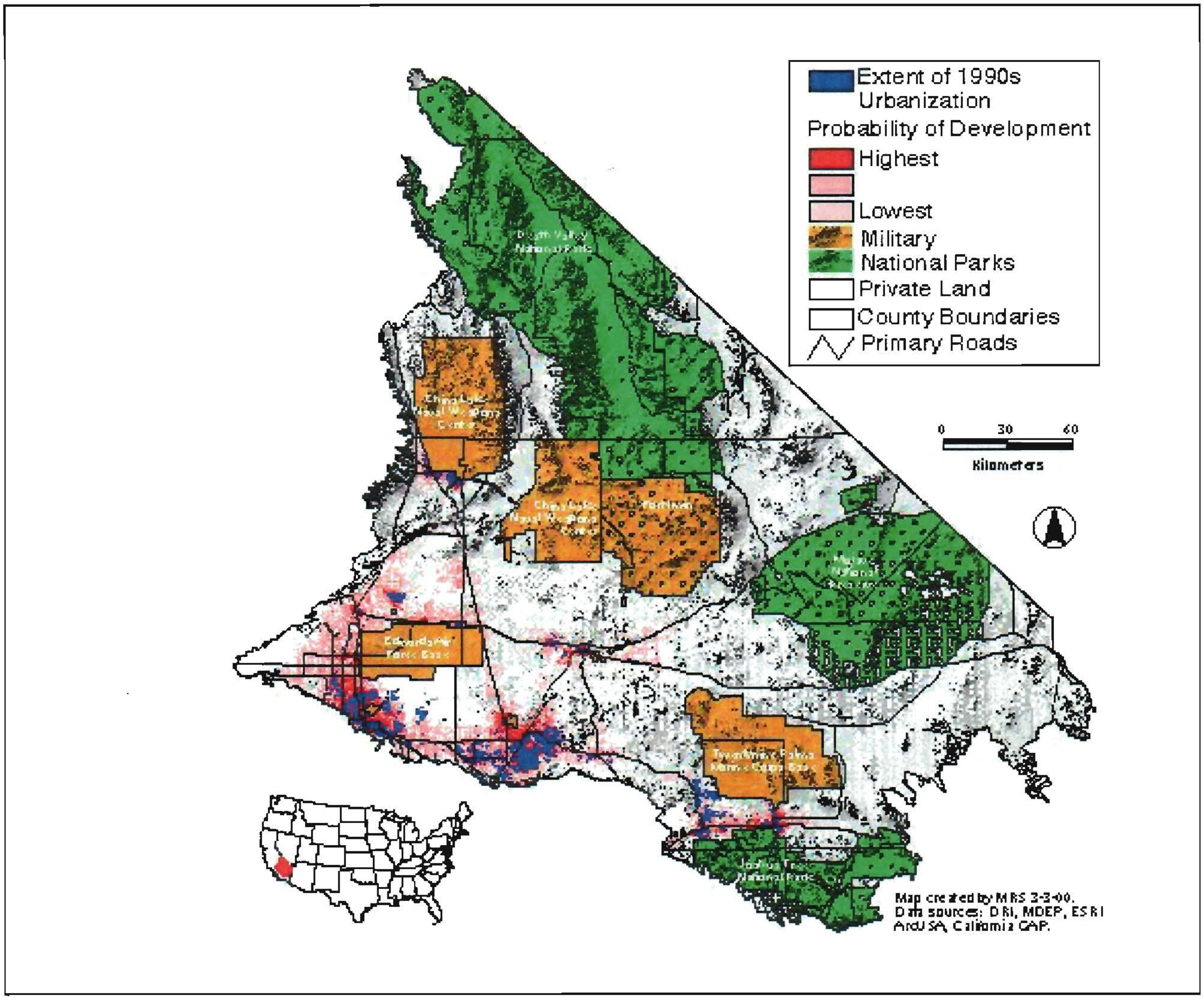
Figure 5.1. Population change in the California Mojave Desert.



Map created by MRS 7-6-00.
Data sources: DRI, MDEP, ESRI ArcUSA, California GAP.

Map created by MRS 7-6-00.
Data sources: DRI, MDEP, ESRI ArcUSA, California GAP.

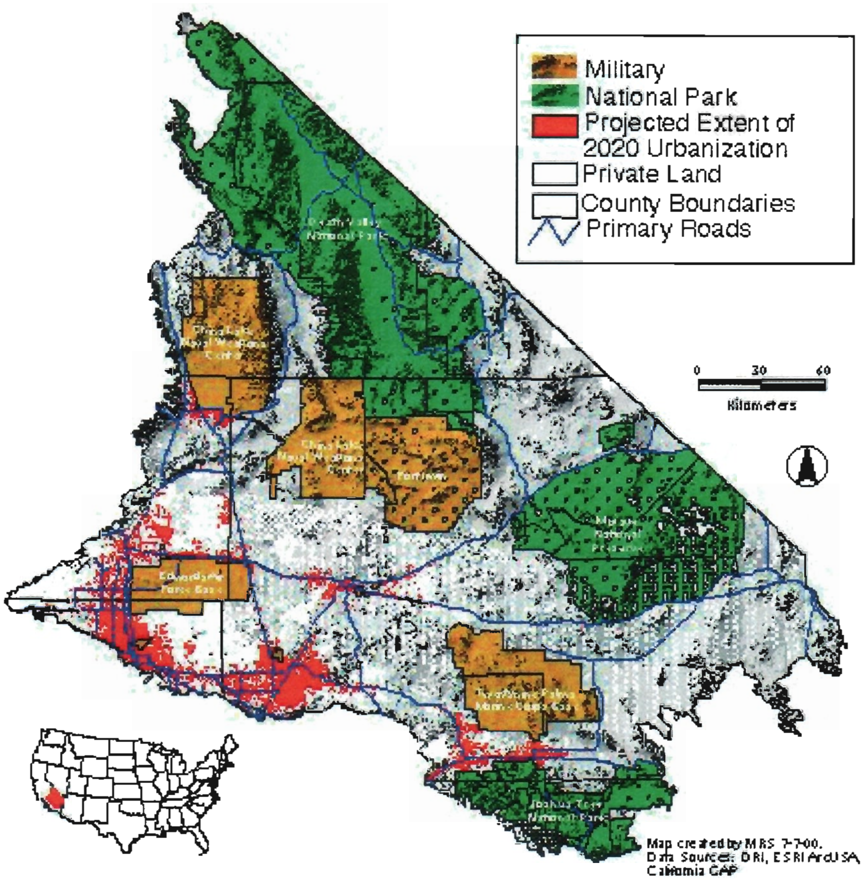
Figure 5.2. Development on private lands in 1970 (a); and 1990 (b).



Map created by MRS 3-3-00.
Data sources: DRI, MDEP, ESRI
ArcUSA, California GAP.

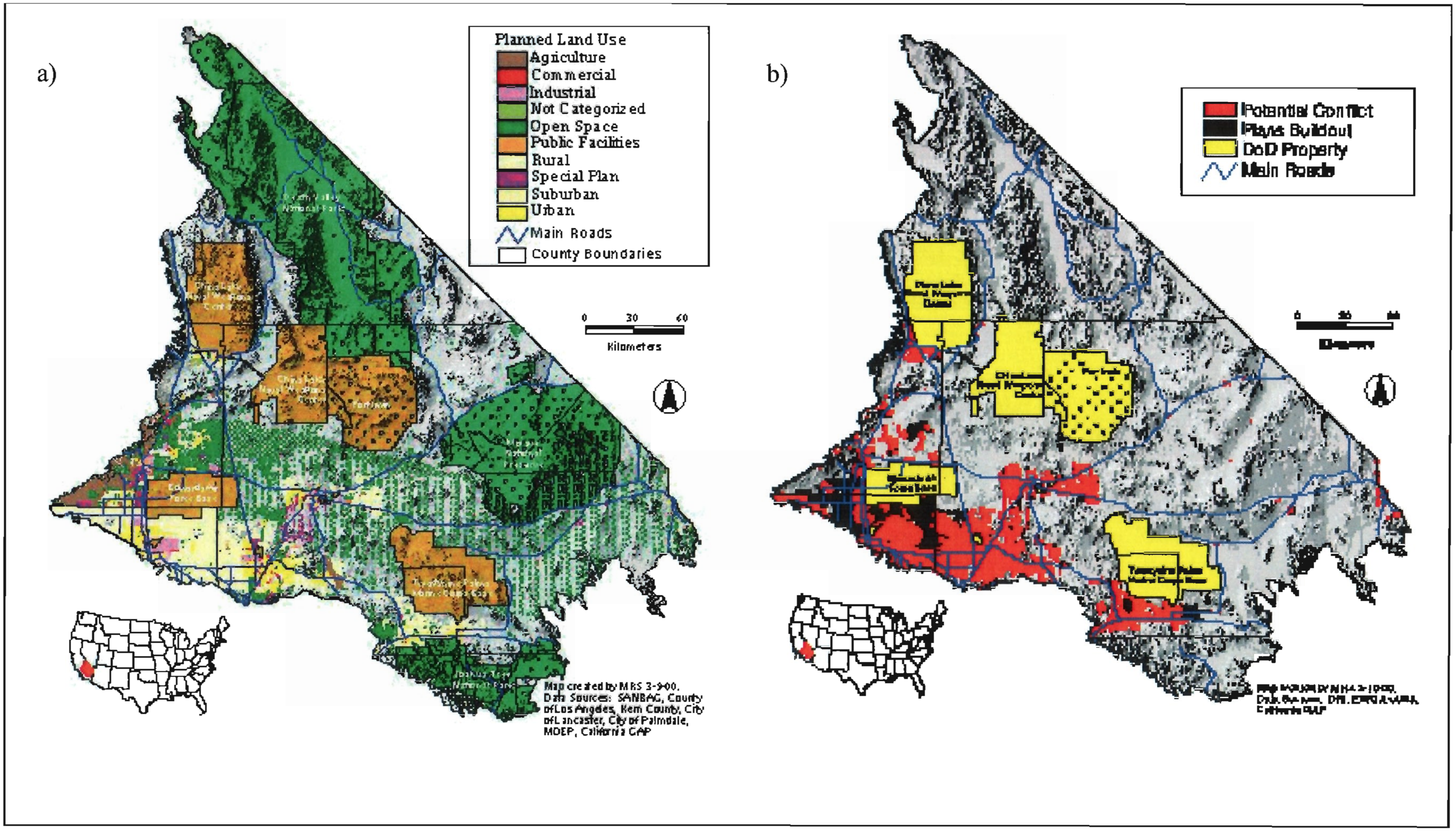
Figure 5.3. Probability of future development.

# Appendix D



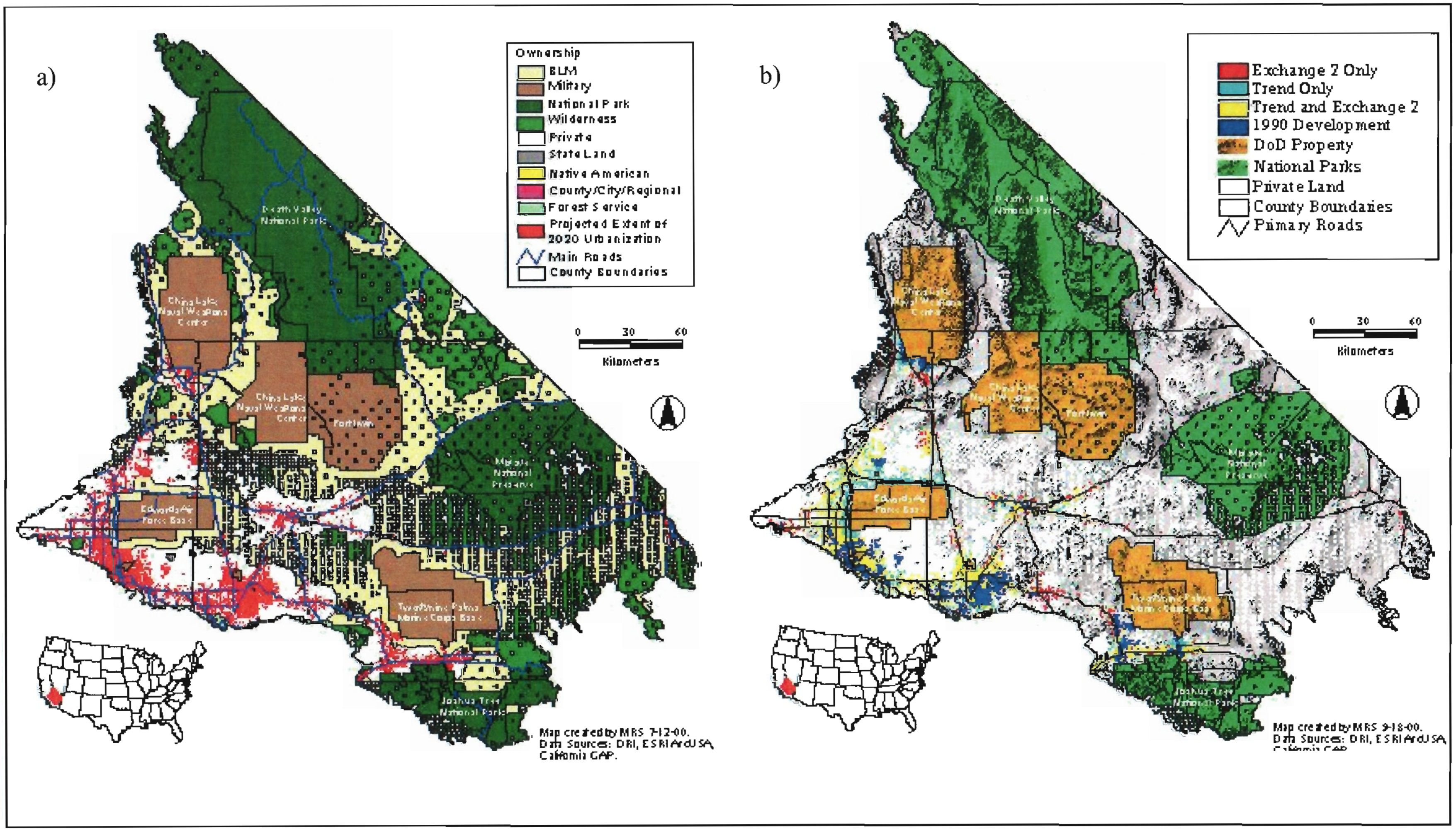
Map created by MRS 7-7-00.
Data Sources: DRI, ESRI ArcUSA, California GAP

Figure 6.1. Projected extent of 2020 urbanization ("Trend" scenario).



Map created by MRS 3-9-00. Data Sources: SANBAG, County of Los Angeles, Kern County, City of Lancaster, City of Palmdale, MOEP, California GAP

Figure 6.2. Development associated with Plans Build-out (a); and compared with Trend (b).



Map created by MRS 7-12-00.
Data Sources: DRI, ESRI ArcUSA, California GAP.

Map created by MRS 9-18-00.
Data Sources: DRI, ESRI ArcUSA, California GAP.

Figure 6.3. Future development associated with the Urban Encroachment Buffer (Exchange 2) scenario (a); and compared with Trend (b).

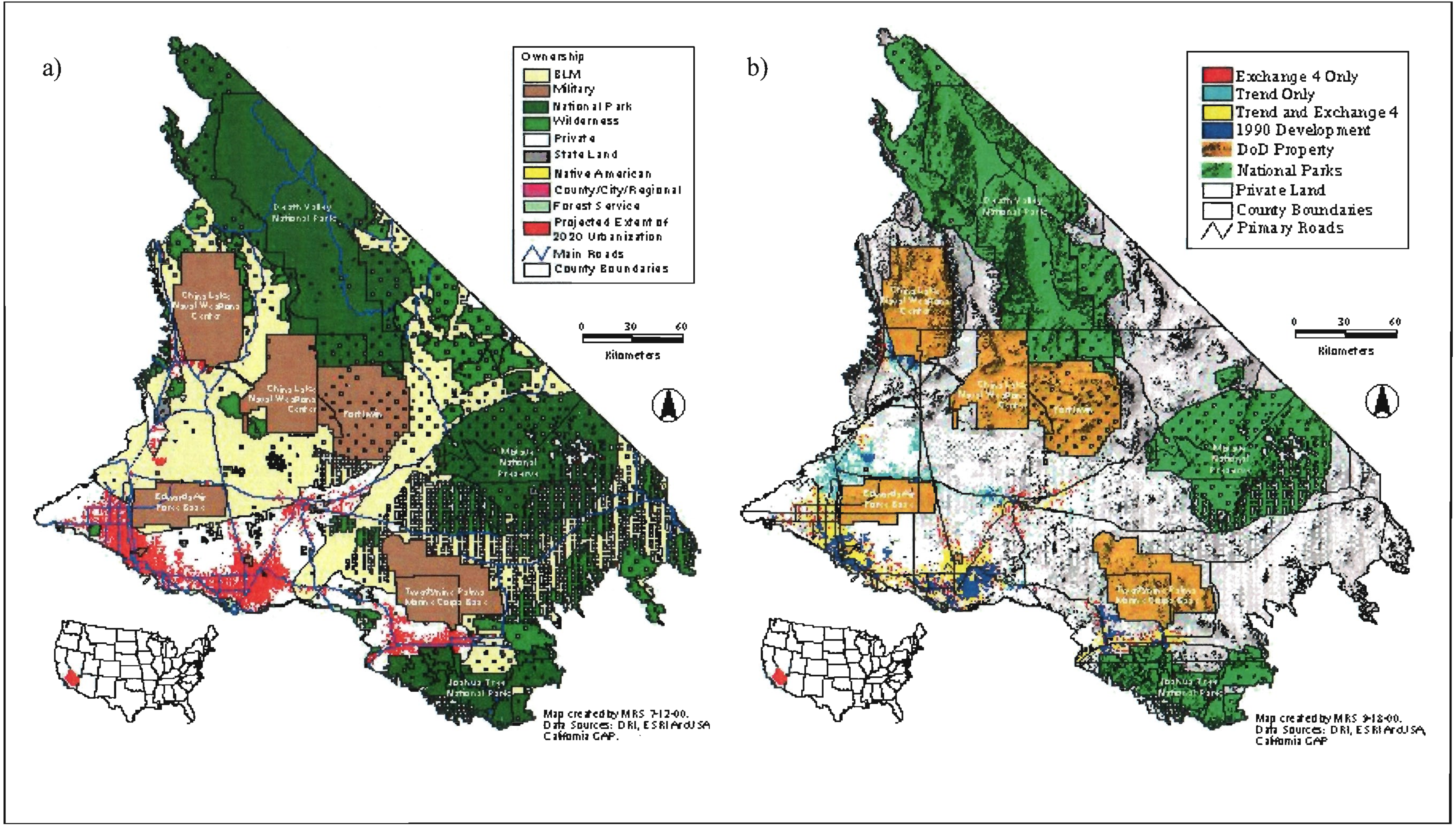


Figure 6.4. Future development associated with the Flight Path Buffer (Exchange 4) scenario (a); and compared with Trend (b).

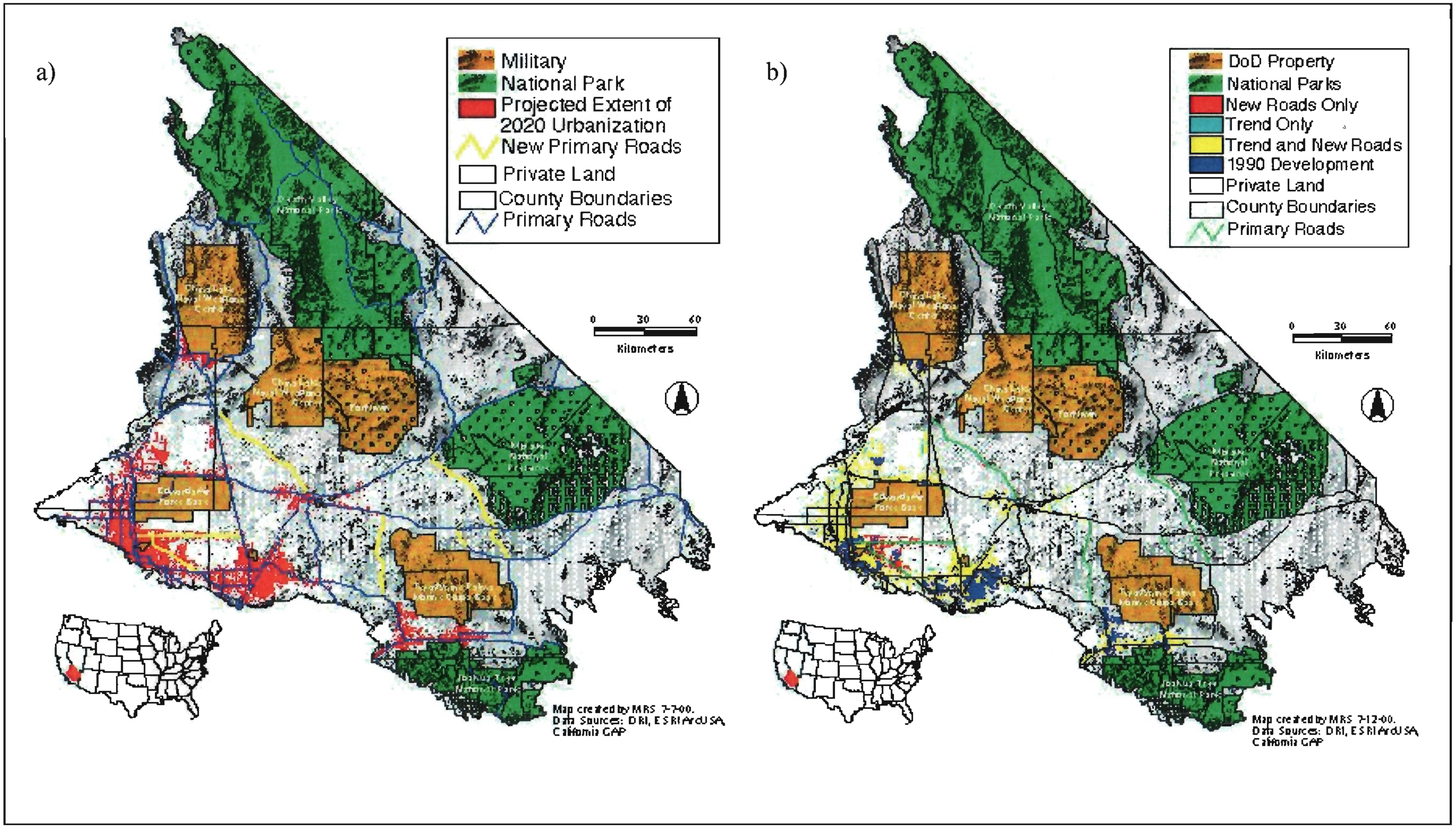


Figure 6.5. Future development associated with the New Roads scenario (a); and compared with Trend (b).

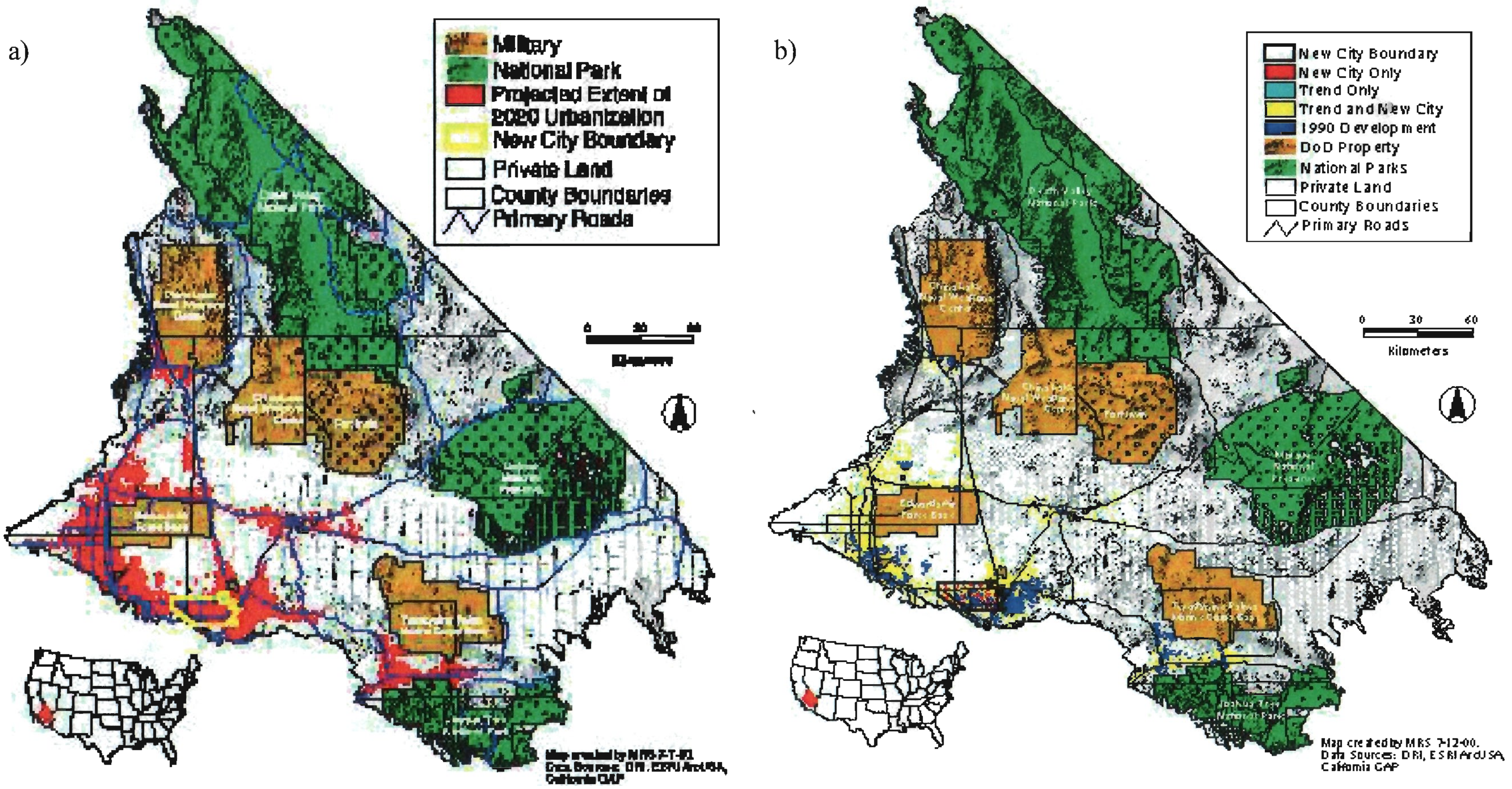


Figure 6.6. Future development associated with the New City scenario (a); and compared with Trend (b).

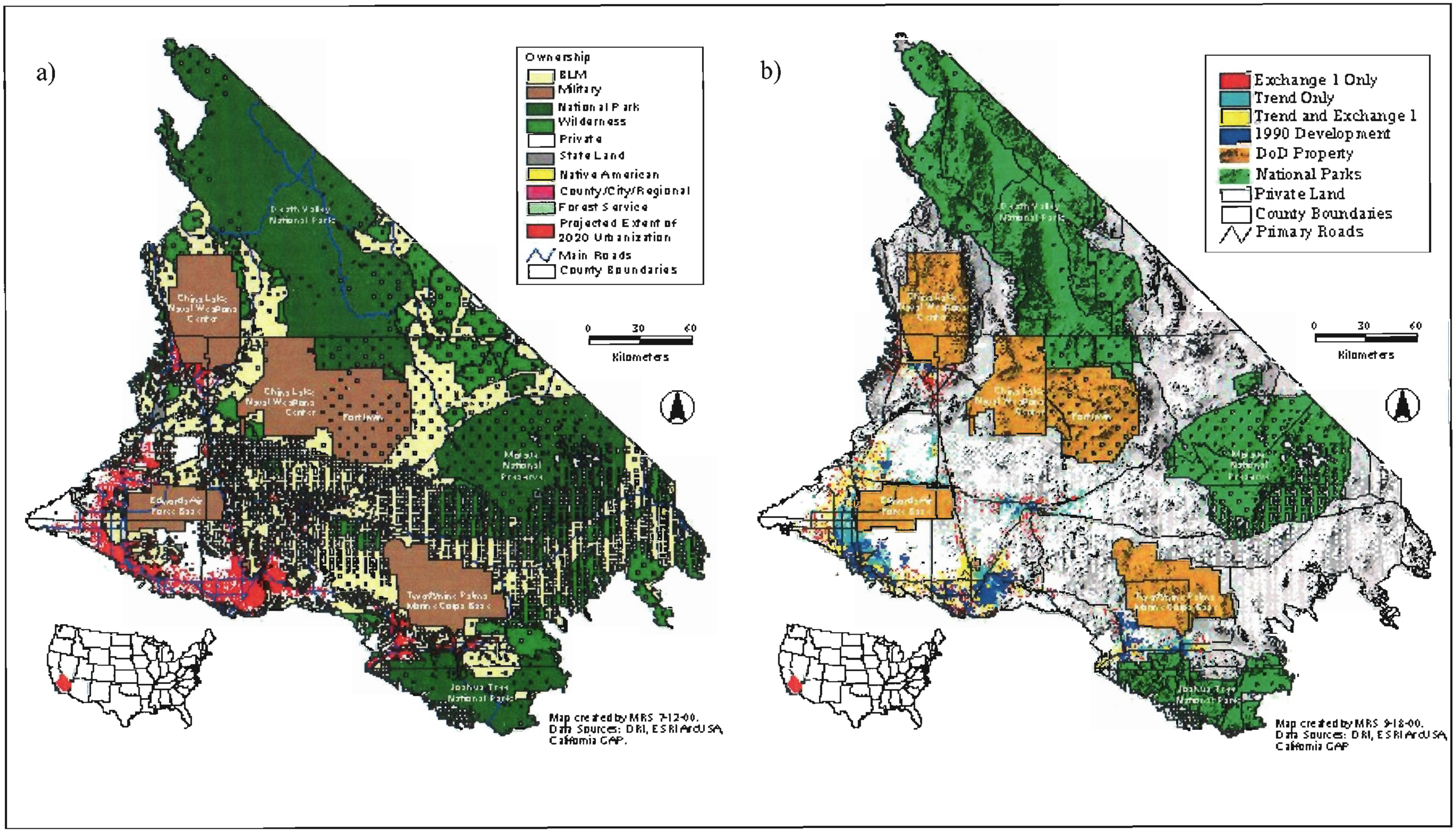
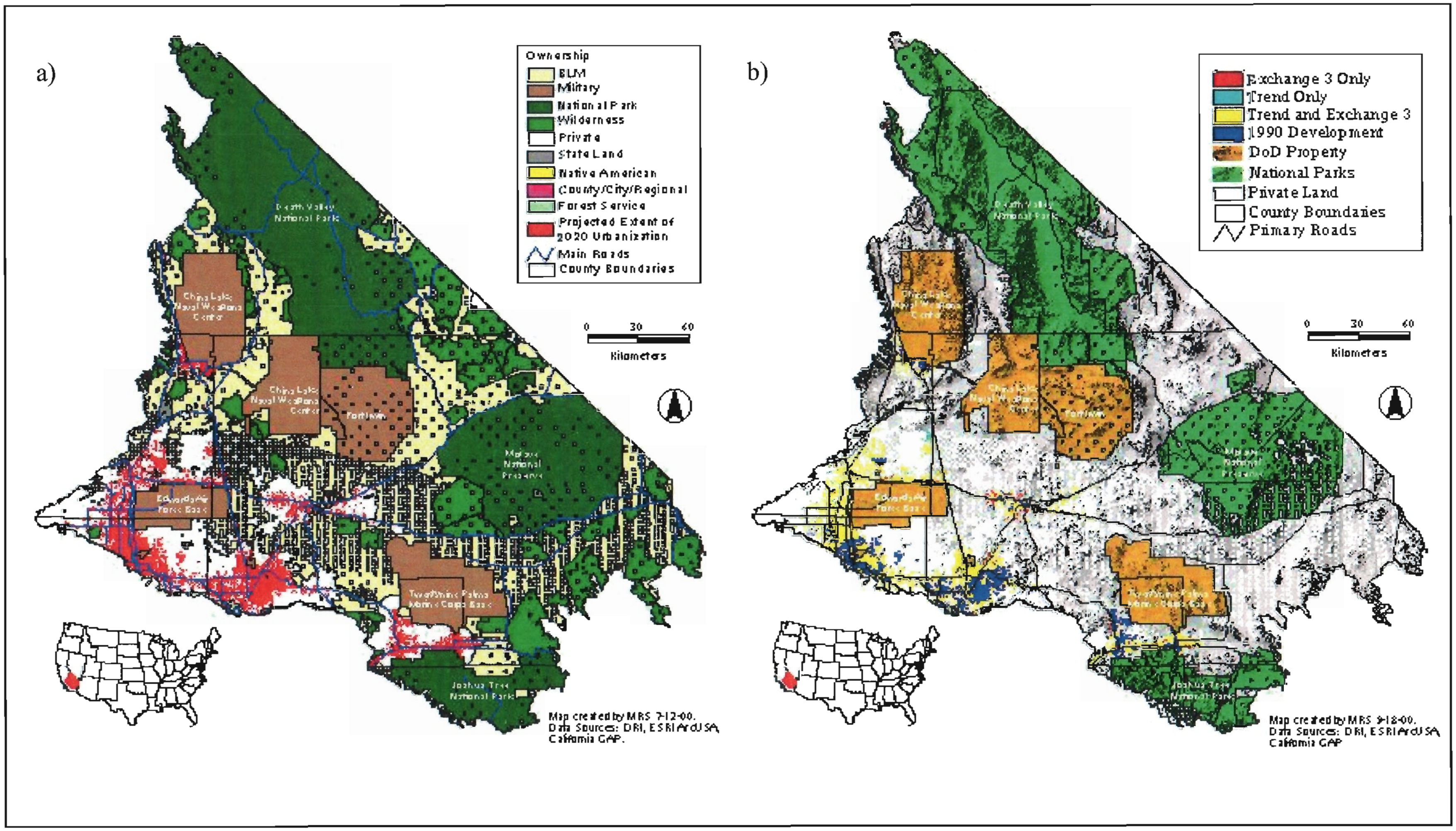


Figure 6.7. Future development associated with the Biodiversity Swap (Exchange 1) scenario (a); and compared with Trend (b).



Map created by MRS 7-12-00.
Data Sources: DRI, ESRI ArcUSA, California GAP.

Map created by MRS 9-18-00.
Data Sources: DRI, ESRI ArcUSA, California GAP

Figure 6.8. Future development associated with the Private Land Swap (Exchange 3) scenario (a); and compared with Trend (b).

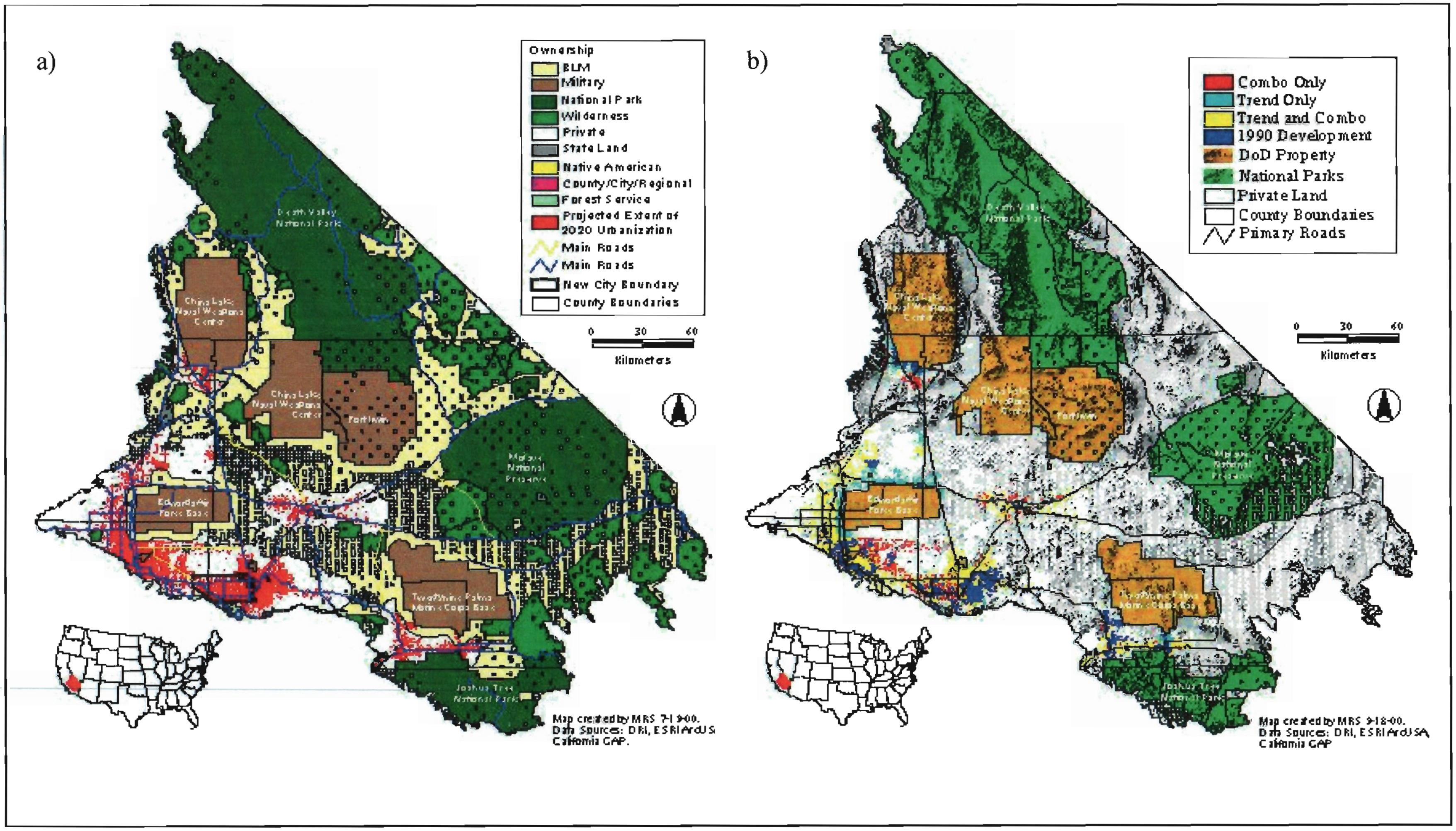


Figure 6.9. Future development associated with a scenario that combines the Trend, New City, Urban Encroachment Buffer and the Private Lands Swap scenarios (a); and compared with Trend (b).

# Appendix E

# Appendix E: California Mojave Desert Breeding Terrestrial Vertebrate (n=274)[1]

| CWHRS[2] # | Scientific name | Common Name |
|---|---|---|
| | Amphibian (n=7) | |
| A027 | *Scaphiopus couchii* | Couch's Spadefoot |
| A029 | *Scaphiopus intermontanus* | Great Basin Spadefoot |
| A032 | *Bufo boreas* | Western Toad |
| A035 | *Bufo microscaphus* | Southwestern Toad |
| A036 | *Bufo punctatus* | Red-spotted Toad |
| A038 | *Hyla cadaverina* | California Treefrog |
| A039 | *Hyla regilla* | Pacific Chorus Frog |
| | Reptiles (n=44) | |
| R004 | *Clemmys marmorata* | Western Pond Turtle |
| R005 | *Gopherus agassizii* | Desert Tortoise |
| R008 | *Coleonyx variegatus* | Western Banded Gecko |
| R010 | *Dipsosaurus dorsalis* | Desert Iguana |
| R011 | *Sauromalus obesus* | Chuckwalla |
| R012 | *Callisaurus draconoides* | Zebra-tail Lizard |
| R015 | *Uma scoparia* | Mojave Fringe-toed Lizard |
| R017 | *Crotaphytus bicinctores* | Black-collared Lizard |
| R018 | *Gambelia wislizenii* | Longnose Leopard Lizard |
| R020 | *Sceloporus magister* | Desert Spiny Lizard |
| R022 | *Sceloporus occidentalis* | Western Fence Lizard |
| R023 | *Sceloporus graciosus* | Sagebrush Lizard |
| R024 | *Uta stansburiana* | Side-blotched Lizard |
| R025 | *Urosaurus graciosus* | Brush Lizard |
| R029 | *Phrynosoma coronatum* | Coast Horned Lizard |
| R030 | *Phrynosoma platyrhinos* | Desert Horned Lizard |
| R034 | *Xantusia vigilis* | Desert Night Lizard |
| R037 | *Eumeces gilberti* | Gilbert's Skink |
| R039 | *Cnemidophorus tigris* | Western Whiptail |
| R040 | *Gerrhonotus multicarinata* | Southern Alligator Lizard |
| R041 | *Gerrhonotus panamintina* | Panamint Alligator Lizard |
| R044 | *Heloderma suspectum* | Gila Monster |
| R045 | *Leptotyphlops humilis* | Western Blind Snake |
| R047 | *Lichanura trivirgata* | Rosy Boa |
| R048 | *Diadophis punctatus* | Ringneck Snake |
| R050 | *Phyllorhynchus decurtatus* | Spotted Leafnose Snake |
| R052 | *Masticophis flagellum* | Coachwhip |
| R054 | *Masticophis taeniatus* | Striped Whipsnake |

|  |  |  |
|---|---|---|
| R055 | *Salvadora hexalepis* | Western Patchnose Snake |
| R056 | *Arizona elegans* | Glossy Snake |
| R057 | *Pituophis melanoleucus* | Gopher Snake |
| R058 | *Lampropeltis getula* | Common Kingsnake |
| R060 | *Rhinocheilus lecontei* | Longnose Snake |
| R066 | *Sonora semiannulata* | Ground Snake |
| R067 | *Chionactis occipitalis* | Western Shovelnose Snake |
| R068 | *Tantilla planiceps* | Western Blackhead Snake |
| R069 | *Tantilla hobartsmithi* | Southwestern Blackhead Snake |
| R070 | *Trimorphodon biscutatus* | Lyre Snake |
| R071 | *Hypsiglena torquata* | Night Snake |
| R072 | *Crotalus atrox* | Western Diamondback Rattlesnake |
| R074 | *Crotalus mitchelli* | Speckled Rattlesnake |
| R075 | *Crotalus cerastes* | Sidewinder |
| R076 | *Crotalus viridis* | Western Rattlesnake |
| R077 | *Crotalus scutulatus* | Mojave Rattlesnake |
|  | <u>Birds (n=153)</u> |  |
| B006 | *Podilymbus podiceps* | Pied-billed Grebe |
| B009 | *Podiceps nigricollis* | Eared Grebe |
| B050 | *Ixobrychus exilis* | Least Bittern |
| B058 | *Butorides virescens* | Green Heron |
| B059 | *Nycticorax nycticorax* | Black-crowned Night-heron |
| B079 | *Anas platyrhynchos* | Mallard |
| B080 | *Anas acuta* | Northern Pintail |
| B083 | *Anas cyanoptera* | Cinnamon Teal |
| B084 | *Anas clypeata* | Northern Shoveler |
| B085 | *Anas strepera* | Gadwall |
| B090 | *Aythya americana* | Redhead |
| B107 | *Oxyura jamaicensis* | Ruddy Duck |
| B108 | *Cathartes aura* | Turkey Vulture |
| B111 | *Elanus caeruleus* | Black-shouldered Kite |
| B114 | *Circus cyaneus* | Northern Harrier |
| B116 | *Accipiter cooperii* | Cooper's Hawk |
| B123 | *Buteo jamaicensis* | Red-tailed Hawk |
| B126 | *Aquila chrysaetos* | Golden Eagle |
| B127 | *Falco sparverius* | American Kestrel |
| B131 | *Falco mexicanus* | Prairie Falcon |
| B139 | *Callipepla gambelii* | Gambel's Quail |
| B140 | *Callipepla californica* | California Quail |
| B141 | *Oreortyx pictus* | Mountain Quail |
| B145 | *Rallus limicola* | Virginia Rail |
| B146 | *Porzana carolina* | Sora |
| B149 | *Fulica americana* | American Coot |
| B154 | *Charadrius alexandrinus* | Snowy Plover |
| B158 | *Charadrius vociferus* | Killdeer |

| | | |
|---|---|---|
| B163 | *Himantopus mexicanus* | Black-necked Stilt |
| B164 | *Recurvirostra americana* | American Avocet |
| B214 | *Larus delawarensis* | Ring-billed Gull |
| B215 | *Larus californicus* | California Gull |
| B254 | *Zenaida asiatica* | White-winged Dove |
| B255 | *Zenaida macroura* | Mourning Dove |
| B257 | *Columbina passerina* | Common Ground-dove |
| B259 | *Coccyzus americanus* | Yellow-billed Cuckoo |
| B260 | *Geococcyx californianus* | Greater Roadrunner |
| B262 | *Tyto alba* | Common Barn Owl |
| B263 | *Otus flammeolus* | Flammulated Owl |
| B264 | *Otus kennicottii* | Western Screech Owl |
| B265 | *Bubo virginianus* | Great Horned Owl |
| B267 | *Glaucidium gnoma* | Northern Pygmy Owl |
| B269 | *Athene cunicularia* | Burrowing Owl |
| B272 | *Asio otus* | Long-eared Owl |
| B273 | *Asio flammeus* | Short-eared Owl |
| B275 | *Chordeiles acutipennis* | Lesser Nighthawk |
| B277 | *Phalaenoptilus nuttallii* | Common Poorwill |
| B278 | *Caprimulgus vociferus* | Whip-poor-will |
| B282 | *Aeronautes saxatalis* | White-throated Swift |
| B286 | *Archilochus alexandri* | Black-chinned Hummingbird |
| B287 | *Calypte anna* | Anna's Hummingbird |
| B288 | *Calypte costae* | Costa's Hummingbird |
| B289 | *Stellula calliope* | Calliope Hummingbird |
| B290 | *Selasphorus platycercus* | Broad-tailed Hummingbird |
| B301 | *Picoides scalaris* | Ladder-backed Woodpecker |
| B304 | *Picoides villosus* | Hairy Woodpecker |
| B307 | *Colaptes auratus* | Northern Flicker |
| B311 | *Contopus sordioulus* | Western Wood-pewee |
| B318 | *Empidonax oberholseri* | Dusky Flycatcher |
| B319 | *Empidonax wrightii* | Gray Flycatcher |
| B321 | *Sayornis nigricans* | Black Phoebe |
| B323 | *Sayornis saya* | Say's Phoebe |
| B324 | *Pyrocephalus rubinus* | Vermillion Flycatcher |
| B326 | *Myiarchus cinerascens* | Ash-throated Flycatcher |
| B328 | *Myiarchus tyrannulus* | Brown-crested Flycatcher |
| B331 | *Tyrannus vociferans* | Cassin's Kingbird |
| B333 | *Tyrannus verticalis* | Western Kingbird |
| B337 | *Eremophila alpestris* | Horned Lark |
| B340 | *Tachycineta thalassina* | Violet-green Swallow |
| B341 | *Stelgidopteryx serripennis* | Northern Rough-winged Swallow |
| B343 | *Hirundo pyrrhonota* | Cliff Swallow |
| B344 | *Hirundo rustica* | Barn Swallow |
| B346 | *Cyanocitta stelleri* | Steller's Jay |

| | | |
|---|---|---|
| B348 | *Aphelocoma coerulescens* | Scrub Jay |
| B349 | *Gymnorhinus cyanocephalus* | Pinyon Jay |
| B350 | *Nucifraga columbiana* | Clark's Nutcracker |
| B354 | *Corvus corax* | Common Raven |
| B356 | *Parus gambeli* | Mountain Chickadee |
| B359 | *Auriparus flaviceps* | Verdin |
| B360 | *Psaltriparus minimus* | Bushtit |
| B361 | *Sitta canadensis* | Red-breasted Nuthatch |
| B362 | *Sitta carolinensis* | White-breasted Nuthatch |
| B364 | *Certhia americana* | Brown Creeper |
| B365 | *Campylorhynchos brunneicapillus* | Cactus Wren |
| B366 | *Salpinctes obsoletus* | Rock Wren |
| B367 | *Catherpes mexicanus* | Canyon Wren |
| B368 | *Thryomanes bewickii* | Bewick's Wren |
| B369 | *Troglodytes aedon* | House Wren |
| B370 | *Troglodytes troglodytes* | Winter Wren |
| B372 | *Cistothorus palustris* | Marsh Wren |
| B375 | *Regulus satrapa* | Golden-crowned Kinglet |
| B376 | *Regulus calendula* | Ruby-crowned Kinglet |
| B377 | *Polioptila caerulea* | Blue-gray Gnatcatcher |
| B378 | *Polioptila melanura* | Black-tailed Gnatcatcher |
| B380 | *Sialia mexicana* | Western Bluebird |
| B381 | *Sialia currucoides* | Mountain Bluebird |
| B382 | *Myadestes townsendi* | Townsend's Solitaire |
| B386 | *Catharus guttatus* | Hermit Thrush |
| B389 | *Turdus migratorius* | American Robin |
| B393 | *Mimus polyglottos* | Northern Mockingbird |
| B394 | *Oreoscoptes montanus* | Sage Thrasher |
| B396 | *Toxostoma bendirei* | Bendire's Thrasher |
| B398 | *Toxostoma redivivum* | California Thrasher |
| B399 | *Toxostoma dorsale* | Crissal Thrasher |
| B400 | *Toxostoma lecontei* | Le Conte's Thrasher |
| B408 | *Phainopepla nitens* | Phainopepla |
| B410 | *Lanius ludovicianus* | Loggerhead Shrike |
| B413 | *Vireo bellii* | Bell's Vireo |
| B414 | *Vireo vicinior* | Gray Vireo |
| B418 | *Vireo gilvus* | Warbling Vireo |
| B425 | *Vermivora celata* | Orange-crowned Warbler |
| B427 | *Vermivora virginiae* | Virginia's Warbler |
| B428 | *Vermivora luciae* | Lucy's Warbler |
| B430 | *Dendroica petechia* | Yellow Warbler |
| B435 | *Dendroica coronata* | Yellow-rumped Warbler |
| B436 | *Dendroica nigrescens* | Black-throated Gray Warbler |
| B461 | *Geothlypis trichas* | Common Yellowthroat |
| B467 | *Icteria virens* | Yellow-breasted Chat |

| | | |
|---|---|---|
| B469 | *Piranga rubra* | Summer Tanager |
| B471 | *Piranga ludoviciana* | Western Tanager |
| B475 | *Pheucticus melanocephalus* | Black-headed Grosbeak |
| B476 | *Guiraca caerulea* | Blue Grosbeak |
| B477 | *Passerina amoena* | Lazuli Bunting |
| B482 | *Pipilo chlorurus* | Green-tailed Towhee |
| B483 | *Pipilo maculatus* | Spotted Towhee |
| B484 | *Pipilo crissalis* | California Towhee |
| B487 | *Aimophila ruficeps* | Rufous-crowned Sparrow |
| B489 | *Spizella passerina* | Chipping Sparrow |
| B491 | *Spizella breweri* | Brewer's Sparrow |
| B493 | *Spizella atrogularis* | Black-chinned Sparrow |
| B495 | *Chondestes grammacus* | Lark Sparrow |
| B496 | *Amphispiza bilineata* | Black-throated Sparrow |
| B497 | *Amphispiza belli* | Sage Sparrow |
| B505 | *Melospiza melodia* | Song Sparrow |
| B512 | *Junco hyemalis* | Dark-eyed Junco |
| B519 | *Agelaius phoeniceus* | Red-winged Blackbird |
| B520 | *Agelaius tricolor* | Tricolored Blackbird |
| B521 | *Sturnella neglecta* | Western Meadowlark |
| B522 | *Xanthocephalus xanthocephalus* | Yellow-headed Blackbird |
| B524 | *Euphagus cyanocephalus* | Brewer's Blackbird |
| B525 | *Quiscalus mexicanus* | Great-tailed Grackle |
| B528 | *Molothrus ater* | Brown-headed Cowbird |
| B530 | *Icterus cucullatus* | Hooded Oriole |
| B532 | *Bullock's Oriole* | Icterus bullockii |
| B533 | *Icterus parisorum* | Scott's Oriole |
| B537 | *Carpodacus cassinii* | Cassin's Finch |
| B538 | *Carpodacus mexicanus* | House Finch |
| B538 | *Loxia curvirostra* | Red Crossbill |
| B543 | *Carduelis psaltria* | Lesser Goldfinch |
| B548 | *Aechmophorus clarkii* | Clark's Greebe |
| B549 | *Colaptes chrysoides* | Gilded Flicker |
| B552 | *Baeolophus griseus* | Juniper Titmouse |
| B554 | *Vireo plumbeus* | Plumbeous Vireo |
| | Mammals (n=61) | |
| M014 | *Notiosorex crawfordi* | Desert Shrew |
| M019 | *Macrotus californicus* | California Leaf-nosed Bat |
| M021 | *Myotis lucifugus* | Little Brown Myotis |
| M026 | *Myotis thysanodes* | Fringed Myotis |
| M027 | *Myotis volans* | Long-legged Myotis |
| M028 | *Myotis californicus* | California Myotis |
| M029 | *Myotis ciliolabrum (leibii)* | Western Small-footed Myotis |
| M031 | *Pipistrellus hesperus* | Western Pipistrelle |
| M032 | *Eptesicus fuscus* | Big Brown Bat |

| | | |
|---|---|---|
| M034 | *Lasiurus cinereus* | Hoary Bat |
| M035 | *Lasiurus xanthinus* | Western Yellow Bat |
| M036 | *Euderma maculatum* | Spotted Bat |
| M037 | *Corynorhinus townsendii* | Townsend's Big-eared Bat |
| M038 | *Antrozous pallidus* | Pallid Bat |
| M039 | *Tadarida brasiliensis* | Brazilian Free-tailed Bat |
| M | *Idionycteris phyllotis* | Allen's (mexican) Big-eared Bat |
| M047 | *Sylvilagus audubonii* | Audobon's (desert) Cottontail |
| M051 | *Lepus californicus* | Black-tailed (hare) Jackrabbit |
| M064 | *Tamias panamintinus* | Panamint Chipmunk |
| M067 | *Ammospermophilus leucurus* | White-tailed Antelope Squirrel |
| M071 | *Spermophilus variegatus* | Rock Squirrel |
| M072 | *Spermophilus beecheyi* | California Ground Squirrel |
| M073 | *Spermophilus mohavensis* | Mohave Ground Squirrel |
| M074 | *Spermophilus tereticaudus* | Round-tailed Ground Squirrel |
| M081 | *Thomomys bottae* | Botta's Pocket Gopher |
| M086 | *Perognathus longimembris* | Little Pocket Mouse |
| M088 | *Perognathus parvus* | Great Basin Pocket Mouse |
| M091 | *Chaetodipus formosus* | Long-tailed Pocket Mouse |
| M093 | *Chaetodipus penicillatus* | Desert Pocket Mouse |
| M094 | *Chaetodipus fallax* | San Diego Pocket Mouse |
| M096 | *Chaetodipus spinatus* | Spiny Pocket Mouse |
| M100 | *Dipodomys microps* | Chisel-toothed Kangaroo Rat |
| M107 | *Dipodomys panamintinus* | Panamint Kangaroo Rat |
| M109 | *Dipodomys deserti* | Desert Kangaroo Rat |
| M110 | *Dipodomys merriami* | Merriam's Kangaroo Rat |
| M113 | *Reithrodontomys megalotis* | Western Harvest Mouse |
| M115 | *Peromyscus eremicus* | Cactus Mouse |
| M117 | *Peromyscus maniculatus* | Deer Mouse |
| M118 | *Peromyscus crinitus* | Canyon Mouse |
| M119 | *Peromyscus boylii* | Brush Mouse |
| M120 | *Peromyscus truei* | Pinyon Mouse |
| M122 | *Onychomys torridus* | Southern Grasshopper Mouse |
| M126 | *Neotoma lepida* | Desert Woodrat |
| M127 | *Neotoma fuscipes* | Dusky Woodrat |
| M128 | *Neotoma cinerea* | Bushy-tailed Woodrat |
| M134 | *Microtus californicus* | California Vole |
| M138 | *Lemmiscus curtatus* | Sagebrush Vole |
| M139 | *Ondatra zibethicus* | Muskrat |
| M145 | *Erethizon dorsatum* | Common Porcupine |
| M146 | *Canis latrans* | Coyote |
| M148 | *Vulpes macrotis* | Kit Fox |
| M149 | *Urocyon cinereoargenteus* | Common Gray Fox |
| M152 | *Bassariscus astutus* | Ringtail |
| M153 | *Procyon lotor* | Common Raccoon |

| | | |
|---|---|---|
| M160 | *Taxidea taxus* | American Badger |
| M161 | *Spilogale gracilis* | Western Spotted Skunk |
| M162 | *Mephitis mephitis* | Striped Skunk |
| M165 | *Felis concolor* | Mountain Lion |
| M166 | *Lynx rufus* | Bobcat |
| M181 | *Odocoileus hemionus* | Mule Or Black-tailed Deer |
| M183 | *Ovis canadensis* | Mountain Sheep |
| | Introduced (n=9) | |
| A046 | *Rana catesbeiana* | Bullfrog |
| B132 | *Alectoris chukar* | Chukar |
| B250 | *Columba livia* | Rock Dove |
| B411 | *Sturnus vulgaris* | European Starling |
| B547 | *Passer domesticus* | House Sparrow |
| M142 | *Mus musclus* | House Mouse |
| M174 | *Equus caballus* | Feral Hourse |
| M174 | *Equus assinus* | Feral Ass |
| M176 | *Sus scrofa* | Wild Pig |

# Appendix F

## Bibliographic database including descriptive data for the 274 resident or breeding vertebrate species in the Mojave Desert

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# Appendix G

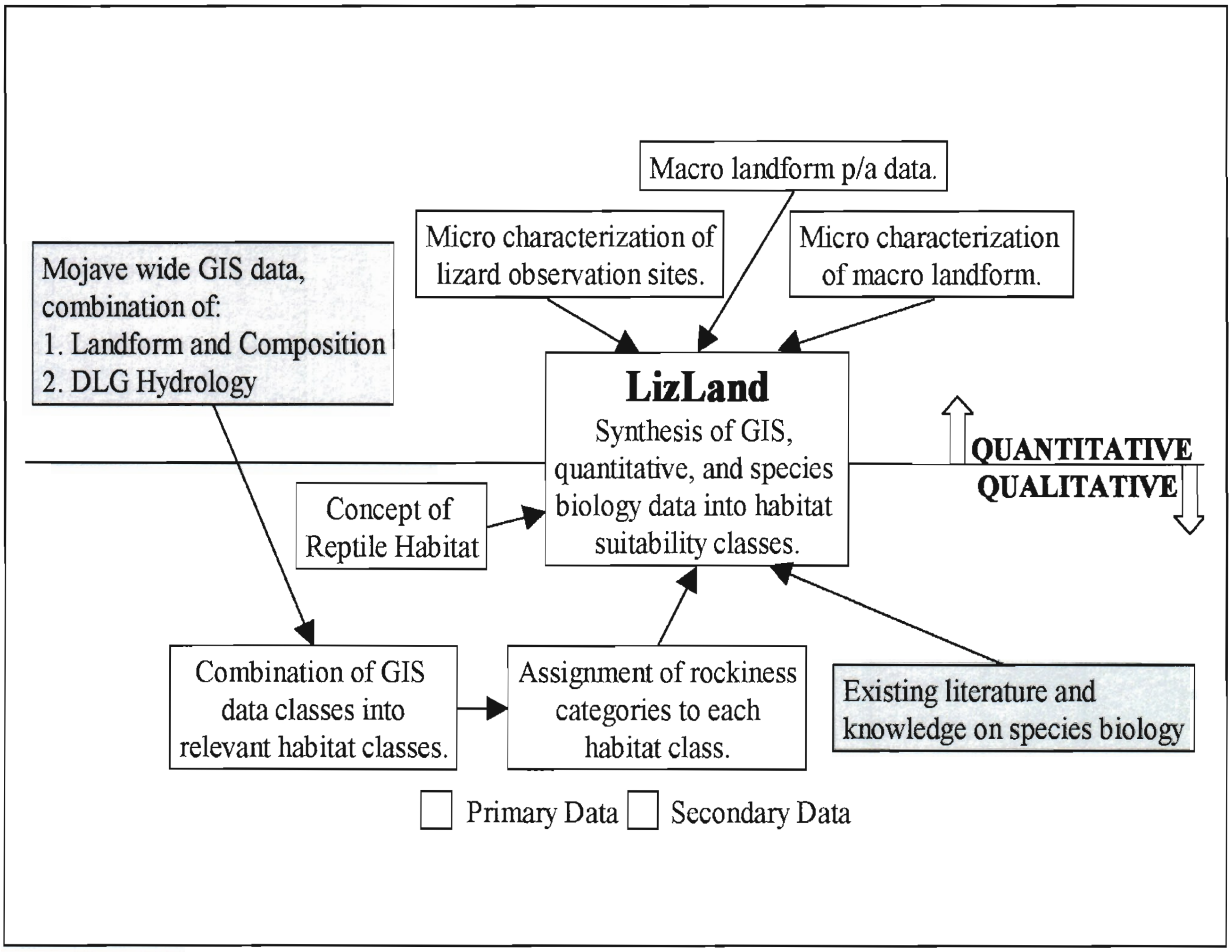


Figure 7.1. LizLand conceptual framework.

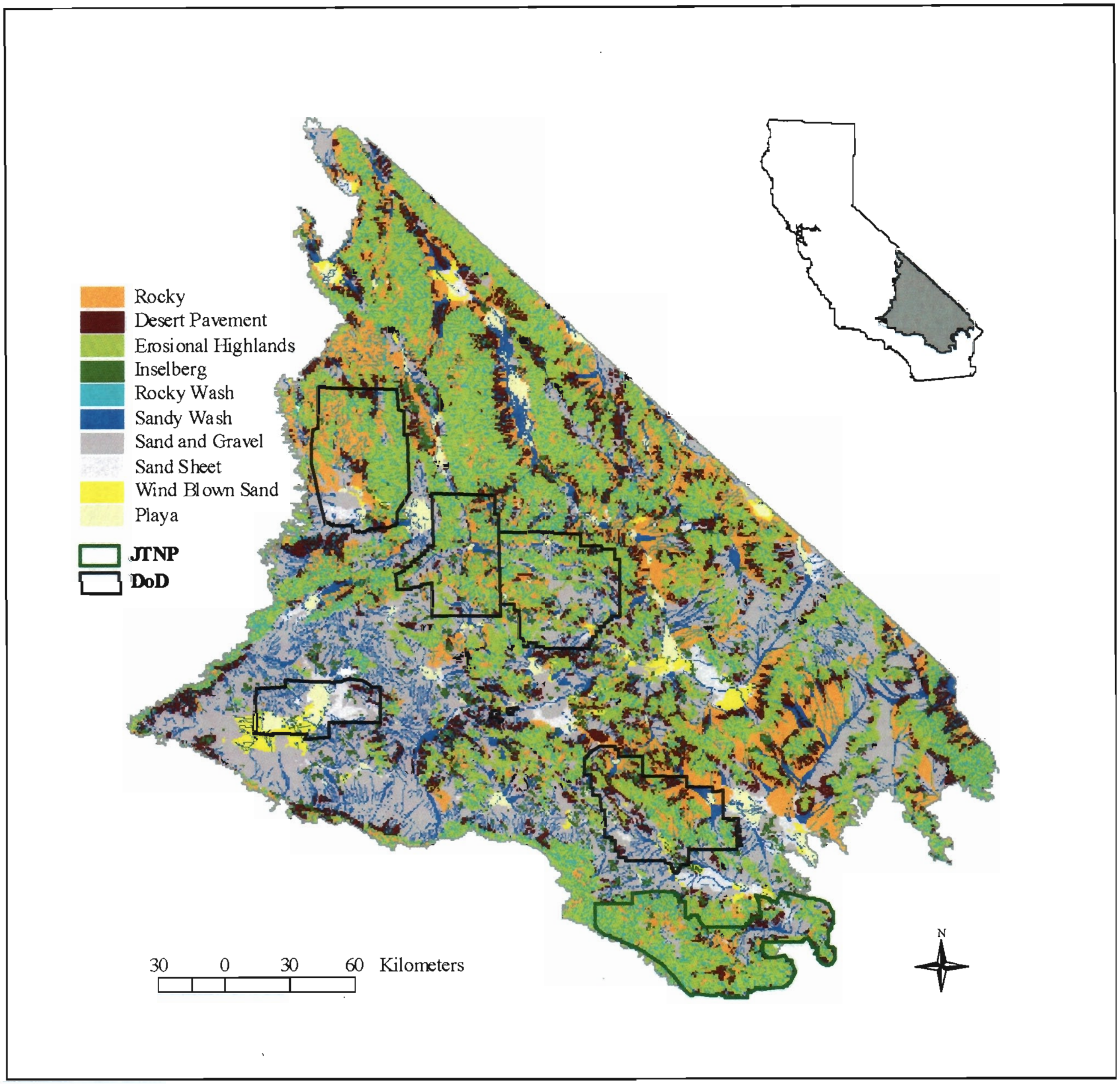


FIgure 7.2. Geo-spatial representation of the LizLand model.

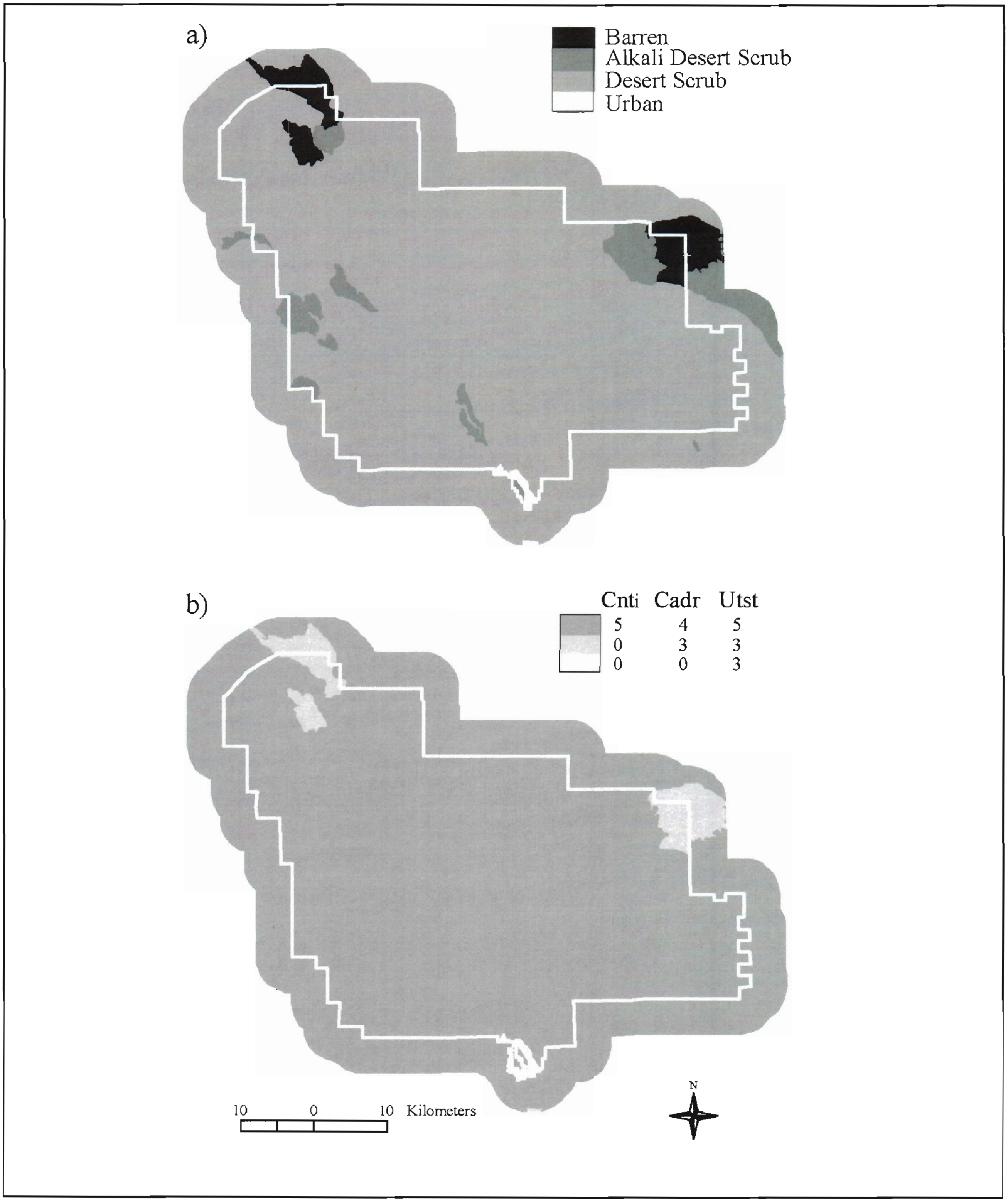


Figure 7.3. a) California GAP terrestrial vertebrate habitat classes for MCAGCC with a 5 km buffer. b) California GAP habitat models for three focal species: Cnti = *Cnemidophorus tigris*; Cadr = *Callisaurus draconoides*; Utst = *Uta stansburiana*. 0 = unsuitable; 3 = >50% low, medium or high habitat suitability; 4 = >50% medium or high habitat suitability; 5 = >50% high habitat suitability.

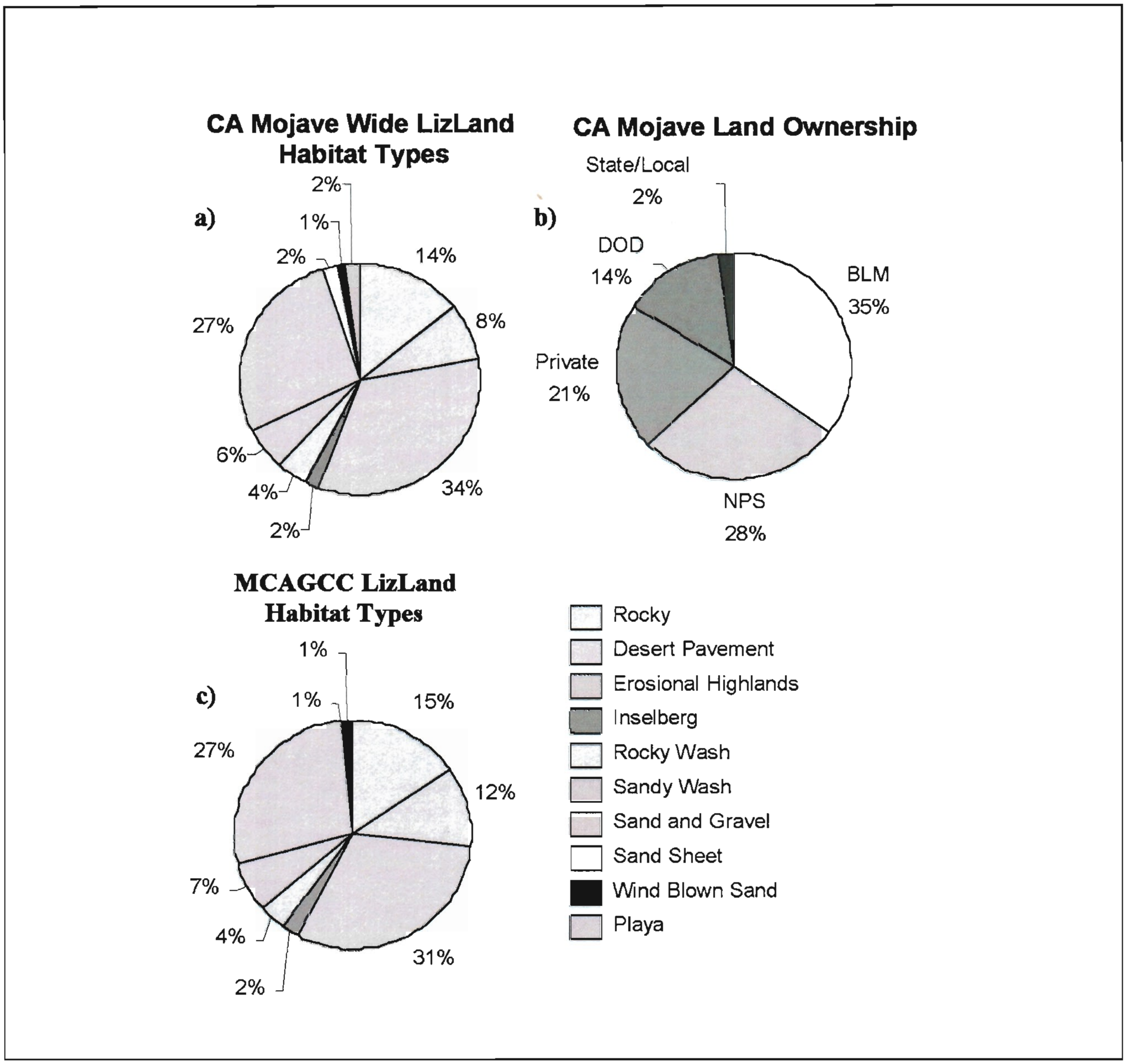


Figure 7.4. Distribution of LizLand habitat types and land ownership.
a) LizLand habitat across the California Mojave Desert; b) distribution of lands among the five major landowners in the California Mojave Desert; c) LizLand habitat within MCAGCC.

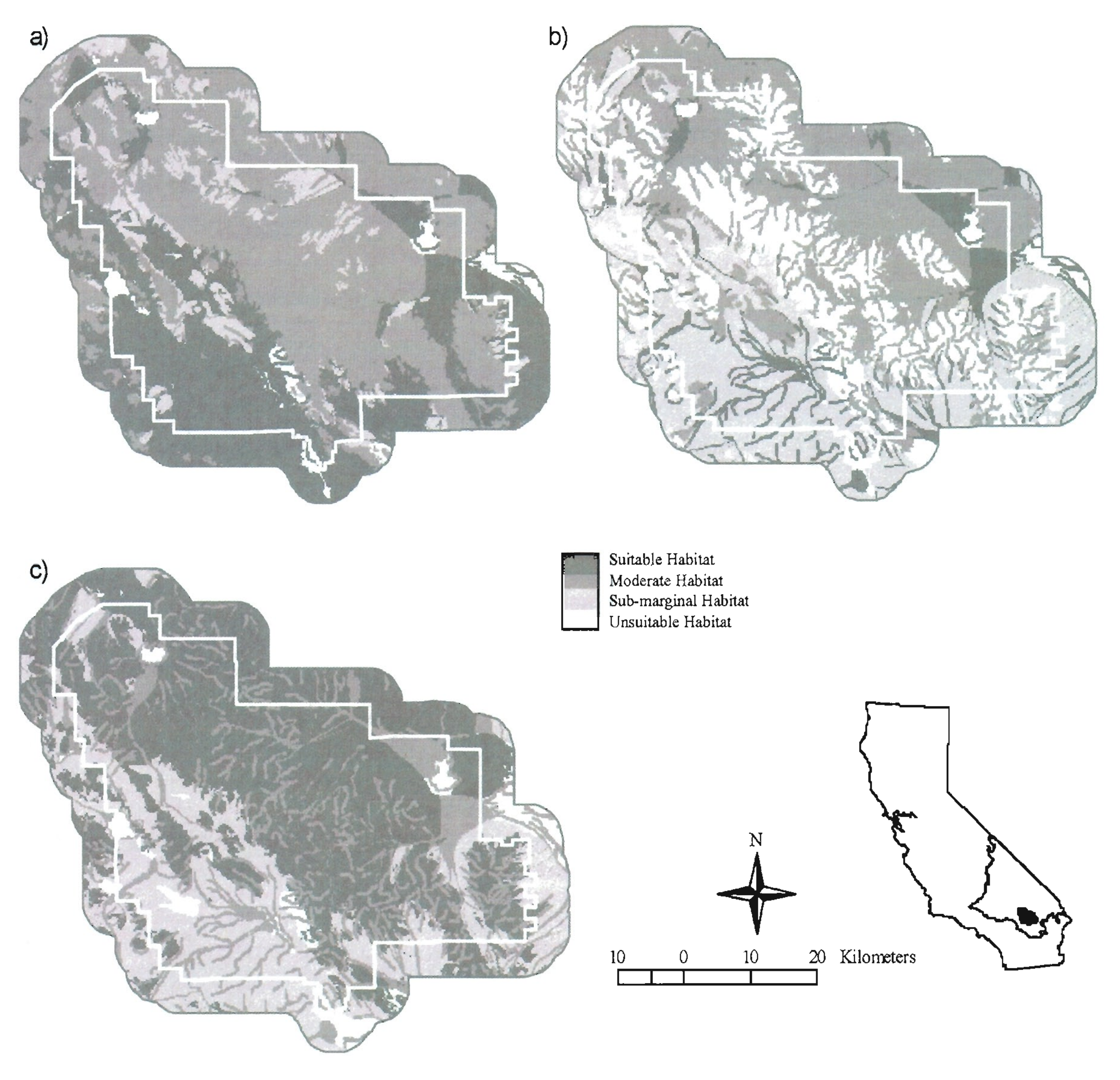


Figure 7.5. LizLand habitat models for three lizard species on MCAGCC.
a) *Cnemidophorus tigris*; b) *Callisaurus draconoides*; c) *Uta stansburiana*.

# Appendix H

## Appendix G: GLSCGIS[1] to LizLand Cross-walk.

| LF_TYPE[2] | EARTH_MAT[2] | ROCK_SAND[3] | LIZLAND_NAME[3] |
|---|---|---|---|
| Active_Alluvial_Deposit | Granitoid | 1 | Sand and Gravel |
| Active_Alluvial_Plain | Undifferentiated_Igneous_Rock | 1 | Sand and Gravel |
| Active_Alluvial_Plain | Siltstone/Mudstone/Claystone | 1 | Sand and Gravel |
| Active_Alluvial_Plain | Gravel/Sandstone | 1 | Sand and Gravel |
| Active_Alluvial_Plain | Undifferentiated_Clastic_Sedimentary_Rock | 1 | Sand and Gravel |
| Active_Alluvial_Plain | Aluminous_Metamorphic_Rock | 1 | Sand and Gravel |
| Active_Alluvial_Plain | Felsic_Metamorphic_Rock | 1 | Sand and Gravel |
| Active_Alluvial_Plain | Undifferentiated_Metamorphic_Rock | 1 | Sand and Gravel |
| Active_Alluvial_Plain | Gabbroid | 1 | Sand and Gravel |
| Active_Alluvial_Plain | Dioritoid | 1 | Sand and Gravel |
| Active_Alluvial_Plain | Granitoid | 1 | Sand and Gravel |
| Active_Alluvial_Plain | Undifferentiated_Plutonic_Rock | 1 | Sand and Gravel |
| Active_Alluvial_Plain | Undifferentiated_Sedimentary_Rock | 1 | Sand and Gravel |
| Active_Alluvial_Plain | Origin_Undefined-Clay_Mineral-rich_Sediments | 1 | Sand and Gravel |
| Active_Alluvial_Plain | Origin_Undefined-Quartz-Feldspar-rich_Sediments | 1 | Sand and Gravel |
| Active_Alluvial_Plain | Undifferentiated_Sediments | 1 | Sand and Gravel |
| Active_Alluvial_Plain | Andesitoid | 1 | Sand and Gravel |
| Active_Alluvial_Plain | Basaltoid | 1 | Sand and Gravel |
| Active_Alluvial_Plain | Dacitoid | 1 | Sand and Gravel |
| Active_Alluvial_Plain | Undifferentiated_Volcanic_Rock | 1 | Sand and Gravel |
| Alluvial_Fan | Dolostone | 2 | Rocky |
| Alluvial_Fan | Limestone | 2 | Rocky |
| Alluvial_Fan | Gravel/Sandstone | 1 | Sand and Gravel |
| Alluvial_Fan | Marble_Metamorphic_Rock | 2 | Rocky |
| Alluvial_Fan | Felsic_Metamorphic_Rock | 2 | Rocky |
| Alluvial_Fan | Undifferentiated_Metamorphic_Rock | 1 | Sand and Gravel |

| | | | |
|---|---|---|---|
| Alluvial_Fan | Gabbroid | 1 | Sand and Gravel |
| Alluvial_Fan | Dioritoid | 2 | Rocky |
| Alluvial_Fan | Granitoid | 1 | Sand and Gravel |
| Alluvial_Fan | Undifferentiated_Plutonic_Rock | 2 | Rocky |
| Alluvial_Fan | Undifferentiated_Sedimentary_Rock | 2 | Rocky |
| Alluvial_Fan | Basaltoid | 2 | Rocky |
| Alluvial_Fan | Undifferentiated_Volcanic_Rock | 2 | Rocky |
| Bajada | Dolostone | 2 | Rocky |
| Bajada | Limestone | 2 | Rocky |
| Bajada | Undifferentiated_Chemical_Sedimentary_Rock | 1 | Sand and Gravel |
| Bajada | Undifferentiated_Igneous_Rock | 2 | Rocky |
| Bajada | Siltstone/Mudstone/Claystone | 1 | Sand and Gravel |
| Bajada | Gravel/Sandstone | 1 | Sand and Gravel |
| Bajada | Undifferentiated_Clastic_Sedimentary_Rock | 2 | Rocky |
| Bajada | Aluminous_Metamorphic_Rock | 2 | Rocky |
| Bajada | Felsic_Metamorphic_Rock | 2 | Rocky |
| Bajada | Undifferentiated_Metamorphic_Rock | 1 | Sand and Gravel |
| Bajada | Gabbroid | 1 | Sand and Gravel |
| Bajada | Dioritoid | 2 | Rocky |
| Bajada | Granitoid | 1 | Sand and Gravel |
| Bajada | Undifferentiated_Plutonic_Rock | 1 | Sand and Gravel |
| Bajada | Undifferentiated_Sedimentary_Rock | 2 | Rocky |
| Bajada | Andesitoid | 2 | Rocky |
| Bajada | Basaltoid | 2 | Rocky |
| Bajada | Dacitoid | 2 | Rocky |
| Bajada | Rhyolitoid | 2 | Rocky |
| Bajada | Undifferentiated_Volcanic_Rock | 2 | Rocky |
| Barchanoid_Dune_Field | Origin_Undefined-Quartz-Feldspar-rich_Sediments | 6 | Wind Blown Sand |
| Bedrock_Plain | Gravel/Sandstone | 1 | Sand and Gravel |
| Bedrock_Plain | Dioritoid | 2 | Rocky |
| Bedrock_Plain | Granitoid | 1 | Sand and Gravel |
| Bedrock_Plain | Rhyolitoid | 2 | Rocky |
| Bedrock_Plain | Undifferentiated_Metamorphic_Rock | 2 | Rocky |

| | | | |
|---|---|---|---|
| Bedrock_Plain | Siltstone/Mudstone/Claystone | 1 | Sand and Gravel |
| Bedrock_Plain | Gravel/Sandstone | 1 | Sand and Gravel |
| Canyon_Bottomland | Dolostone | 10 | Rocky Wash |
| Canyon_Bottomland | Limestone | 10 | Rocky Wash |
| Canyon_Bottomland | Waterlain_Tuff | 10 | Rocky Wash |
| Canyon_Bottomland | Undifferentiated_Chemical_Sedimentary_Rock | 10 | Rocky Wash |
| Canyon_Bottomland | Undifferentiated_Igneous_Rock | 10 | Rocky Wash |
| Canyon_Bottomland | Siltstone/Mudstone/Claystone | 10 | Rocky Wash |
| Canyon_Bottomland | Gravel/Sandstone | 10 | Rocky Wash |
| Canyon_Bottomland | Undifferentiated_Clastic_Sedimentary_Rock | 10 | Rocky Wash |
| Canyon_Bottomland | Aluminous_Metamorphic_Rock | 10 | Rocky Wash |
| Canyon_Bottomland | Felsic_Metamorphic_Rock | 10 | Rocky Wash |
| Canyon_Bottomland | Mafic_Metamorphic_Rock | 10 | Rocky Wash |
| Canyon_Bottomland | Quartzite_Metamorphoric_Rock | 10 | Rocky Wash |
| Canyon_Bottomland | Undifferentiated_Metamorphic_Rock | 10 | Rocky Wash |
| Canyon_Bottomland | Gabbroid | 10 | Rocky Wash |
| Canyon_Bottomland | Dioritoid | 10 | Rocky Wash |
| Canyon_Bottomland | Granitoid | 10 | Rocky Wash |
| Canyon_Bottomland | Undifferentiated_Plutonic_Rock | 10 | Rocky Wash |
| Canyon_Bottomland | Undifferentiated_Sedimentary_Rock | 10 | Rocky Wash |
| Canyon_Bottomland | Origin_Undefined-Quartz-Feldspar-rich_Sediments | 10 | Rocky Wash |
| Canyon_Bottomland | Undifferentiated_Sediments | 10 | Rocky Wash |
| Canyon_Bottomland | Andesitoid | 10 | Rocky Wash |
| Canyon_Bottomland | Basaltoid | 10 | Rocky Wash |
| Canyon_Bottomland | Dacitoid | 10 | Rocky Wash |
| Canyon_Bottomland | Rhyolitoid | 10 | Rocky Wash |
| Canyon_Bottomland | Undifferentiated_Volcanic_Rock | 10 | Rocky Wash |
| Climbing/Falling_Dune_Fie | Origin_Undefined-Quartz-Feldspar-rich_Sediments | 6 | Wind Blown Sand |
| Coppice_Dune_Field | Origin_Undefined-Clay_Mineral-rich_Sediments | 6 | Wind Blown Sand |
| Coppice_Dune_Field | Origin_Undefined-Quartz-Feldspar-rich_Sediments | 6 | Wind Blown Sand |
| Disturbed | Undifferentiated_Sediments | 9 | Disturbed |
| Erosional_Highland | Limestone | 5 | Erosional Highland |
| Erosional_Highland | Undifferentiated_Igneous_Rock | 5 | Erosional Highland |

| | | | |
|---|---|---|---|
| Erosional_Highland | Siltstone/Mudstone/Claystone | 5 | Erosional Highland |
| Erosional_Highland | Gravel/Sandstone | 5 | Erosional Highland |
| Erosional_Highland | Aluminous_Metamorphic_Rock | 5 | Erosional Highland |
| Erosional_Highland | Marble_Metamorphic_Rock | 5 | Erosional Highland |
| Erosional_Highland | Felsic_Metamorphic_Rock | 5 | Erosional Highland |
| Erosional_Highland | Mafic_Metamorphic_Rock | 5 | Erosional Highland |
| Erosional_Highland | Quartzite_Metamorphoric_Rock | 5 | Erosional Highland |
| Erosional_Highland | Undifferentiated_Metamorphic_Rock | 5 | Erosional Highland |
| Erosional_Highland | Gabbroid | 5 | Erosional Highland |
| Erosional_Highland | Dioritoid | 5 | Erosional Highland |
| Erosional_Highland | Granitoid | 5 | Erosional Highland |
| Erosional_Highland | Undifferentiated_Plutonic_Rock | 5 | Erosional Highland |
| Erosional_Highland | Undifferentiated_Sedimentary_Rock | 5 | Erosional Highland |
| Erosional_Highland | Basaltoid | 5 | Erosional Highland |
| Erosional_Highland | Dacitoid | 5 | Erosional Highland |
| Erosional_Highland | Rhyolitoid | 5 | Erosional Highland |
| Erosional_Highland | Undifferentiated_Volcanic_Rock | 5 | Erosional Highland |
| Erosional_Highland | Dolostone | 5 | Erosional Highland |
| Erosional_Highland | Limestone | 5 | Erosional Highland |
| Erosional_Highland | Undifferentiated_Chemical_Sedimentary_Rock | 5 | Erosional Highland |
| Erosional_Highland | Gravel/Sandstone | 5 | Erosional Highland |
| Erosional_Highland | Undifferentiated_Clastic_Sedimentary_Rock | 5 | Erosional Highland |
| Erosional_Highland | Aluminous_Metamorphic_Rock | 5 | Erosional Highland |
| Erosional_Highland | Marble_Metamorphic_Rock | 5 | Erosional Highland |
| Erosional_Highland | Felsic_Metamorphic_Rock | 5 | Erosional Highland |
| Erosional_Highland | Quartzite_Metamorphoric_Rock | 5 | Erosional Highland |
| Erosional_Highland | Undifferentiated_Metamorphic_Rock | 5 | Erosional Highland |
| Erosional_Highland | Gabbroid | 5 | Erosional Highland |
| Erosional_Highland | Granitoid | 5 | Erosional Highland |
| Erosional_Highland | Undifferentiated_Sedimentary_Rock | 5 | Erosional Highland |
| Erosional_Highland | Dolostone | 5 | Erosional Highland |
| Erosional_Highland | Limestone | 5 | Erosional Highland |
| Erosional_Highland | Undifferentiated_Chemical_Sedimentary_Rock | 5 | Erosional Highland |

| | | | |
|---|---|---|---|
| Erosional_Highland | Siltstone/Mudstone/Claystone | 5 | Erosional Highland |
| Erosional_Highland | Gravel/Sandstone | 5 | Erosional Highland |
| Erosional_Highland | Undifferentiated_Clastic_Sedimentary_Rock | 5 | Erosional Highland |
| Erosional_Highland | Marble_Metamorphic_Rock | 5 | Erosional Highland |
| Erosional_Highland | Felsic_Metamorphic_Rock | 5 | Erosional Highland |
| Erosional_Highland | Mafic_Metamorphic_Rock | 5 | Erosional Highland |
| Erosional_Highland | Quartzite_Metamorphoric_Rock | 5 | Erosional Highland |
| Erosional_Highland | Undifferentiated_Metamorphic_Rock | 5 | Erosional Highland |
| Erosional_Highland | Granitoid | 5 | Erosional Highland |
| Erosional_Highland | Undifferentiated_Sedimentary_Rock | 5 | Erosional Highland |
| Erosional_Highland | Chert-organic | 5 | Erosional Highland |
| Erosional_Highland | Limestone | 5 | Erosional Highland |
| Erosional_Highland | Waterlain_Tuff | 5 | Erosional Highland |
| Erosional_Highland | Undifferentiated_Chemical_Sedimentary_Rock | 5 | Erosional Highland |
| Erosional_Highland | Undifferentiated_Igneous_Rock | 5 | Erosional Highland |
| Erosional_Highland | Siltstone/Mudstone/Claystone | 5 | Erosional Highland |
| Erosional_Highland | Gravel/Sandstone | 5 | Erosional Highland |
| Erosional_Highland | Undifferentiated_Clastic_Sedimentary_Rock | 5 | Erosional Highland |
| Erosional_Highland | Felsic_Metamorphic_Rock | 5 | Erosional Highland |
| Erosional_Highland | Gabbroid | 5 | Erosional Highland |
| Erosional_Highland | Dioritoid | 5 | Erosional Highland |
| Erosional_Highland | Granitoid | 5 | Erosional Highland |
| Erosional_Highland | Undifferentiated_Sedimentary_Rock | 5 | Erosional Highland |
| Erosional_Highland | Andesitoid | 5 | Erosional Highland |
| Erosional_Highland | Basaltoid | 5 | Erosional Highland |
| Erosional_Highland | Dacitoid | 5 | Erosional Highland |
| Erosional_Highland | Rhyolitoid | 5 | Erosional Highland |
| Erosional_Highland | Undifferentiated_Volcanic_Rock | 5 | Erosional Highland |
| Fluvial_Channel | Origin_Undefined-Quartz-Feldspar-rich_Sediments | 3 | Sandy Wash |
| Fluvial_Floodplain | Origin_Undefined-Clay_Mineral-rich_Sediments | 3 | Sandy Wash |
| Fluvial_Floodplain | Origin_Undefined-Carbonate-rich_Sediments | 3 | Sandy Wash |
| Fluvial_Floodplain | Origin_Undefined-Quartz-Feldspar-rich_Sediments | 3 | Sandy Wash |
| Fluvial_Floodplain | Undifferentiated_Sediments | 3 | Sandy Wash |

| | | | |
|---|---|---|---|
| Fluvial_Terrace | Origin_Undefined-Carbonate-rich_Sediments | 3 | Sandy Wash |
| Fluvial_Terrace | Origin_Undefined-Quartz-Feldspar-rich_Sediments | 3 | Sandy Wash |
| Inselberg | Limestone | 11 | Inselberg |
| Inselberg | Undifferentiated_Igneous_Rock | 11 | Inselberg |
| Inselberg | Siltstone/Mudstone/Claystone | 11 | Inselberg |
| Inselberg | Gravel/Sandstone | 11 | Inselberg |
| Inselberg | Aluminous_Metamorphic_Rock | 11 | Inselberg |
| Inselberg | Marble_Metamorphic_Rock | 11 | Inselberg |
| Inselberg | Felsic_Metamorphic_Rock | 11 | Inselberg |
| Inselberg | Mafic_Metamorphic_Rock | 11 | Inselberg |
| Inselberg | Quartzite_Metamorphoric_Rock | 11 | Inselberg |
| Inselberg | Undifferentiated_Metamorphic_Rock | 11 | Inselberg |
| Inselberg | Gabbroid | 11 | Inselberg |
| Inselberg | Dioritoid | 11 | Inselberg |
| Inselberg | Granitoid | 11 | Inselberg |
| Inselberg | Undifferentiated_Plutonic_Rock | 11 | Inselberg |
| Inselberg | Andesitoid | 11 | Inselberg |
| Inselberg | Dacitoid | 11 | Inselberg |
| Inselberg | Rhyolitoid | 11 | Inselberg |
| Inselberg | Undifferentiated_Volcanic_Rock | 11 | Inselberg |
| Inselberg | Dolostone | 11 | Inselberg |
| Inselberg | Limestone | 11 | Inselberg |
| Inselberg | Gravel/Sandstone | 11 | Inselberg |
| Inselberg | Aluminous_Metamorphic_Rock | 11 | Inselberg |
| Inselberg | Felsic_Metamorphic_Rock | 11 | Inselberg |
| Inselberg | Quartzite_Metamorphoric_Rock | 11 | Inselberg |
| Inselberg | Undifferentiated_Metamorphic_Rock | 11 | Inselberg |
| Inselberg | Dioritoid | 11 | Inselberg |
| Inselberg | Granitoid | 11 | Inselberg |
| Inselberg | Undifferentiated_Plutonic_Rock | 11 | Inselberg |
| Inselberg | Undifferentiated_Sedimentary_Rock | 11 | Inselberg |
| Inselberg | Dolostone | 11 | Inselberg |
| Inselberg | Limestone | 11 | Inselberg |

|  |  |  |  |
|---|---|---|---|
| Inselberg | Undifferentiated_Chemical_Sedimentary_Rock | 11 | Inselberg |
| Inselberg | Siltstone/Mudstone/Claystone | 11 | Inselberg |
| Inselberg | Gravel/Sandstone | 11 | Inselberg |
| Inselberg | Undifferentiated_Clastic_Sedimentary_Rock | 11 | Inselberg |
| Inselberg | Marble_Metamorphic_Rock | 11 | Inselberg |
| Inselberg | Felsic_Metamorphic_Rock | 11 | Inselberg |
| Inselberg | Undifferentiated_Metamorphic_Rock | 11 | Inselberg |
| Inselberg | Undifferentiated_Sedimentary_Rock | 11 | Inselberg |
| Inselberg | Limestone | 11 | Inselberg |
| Inselberg | Waterlain_Tuff | 11 | Inselberg |
| Inselberg | Undifferentiated_Chemical_Sedimentary_Rock | 11 | Inselberg |
| Inselberg | Undifferentiated_Igneous_Rock | 11 | Inselberg |
| Inselberg | Siltstone/Mudstone/Claystone | 11 | Inselberg |
| Inselberg | Gravel/Sandstone | 11 | Inselberg |
| Inselberg | Undifferentiated_Clastic_Sedimentary_Rock | 11 | Inselberg |
| Inselberg | Felsic_Metamorphic_Rock | 11 | Inselberg |
| Inselberg | Undifferentiated_Metamorphic_Rock | 11 | Inselberg |
| Inselberg | Gabbroid | 11 | Inselberg |
| Inselberg | Dioritoid | 11 | Inselberg |
| Inselberg | Granitoid | 11 | Inselberg |
| Inselberg | Undifferentiated_Sedimentary_Rock | 11 | Inselberg |
| Inselberg | Andesitoid | 11 | Inselberg |
| Inselberg | Basaltoid | 11 | Inselberg |
| Inselberg | Dacitoid | 11 | Inselberg |
| Inselberg | Rhyolitoid | 11 | Inselberg |
| Inselberg | Undifferentiated_Volcanic_Rock | 11 | Inselberg |
| Intramontane_Alluvial_Pla | Chert-organic | 2 | Rocky |
| Intramontane_Alluvial_Pla | Dolostone | 2 | Rocky |
| Intramontane_Alluvial_Pla | Limestone | 2 | Rocky |
| Intramontane_Alluvial_Pla | Undifferentiated_Igneous_Rock | 2 | Rocky |
| Intramontane_Alluvial_Pla | Gravel/Sandstone | 2 | Rocky |
| Intramontane_Alluvial_Pla | Aluminous_Metamorphic_Rock | 2 | Rocky |
| Intramontane_Alluvial_Pla | Felsic_Metamorphic_Rock | 2 | Rocky |

| | | | |
|---|---|---|---|
| Intramontane_Alluvial_Pla | Undifferentiated_Metamorphic_Rock | 2 | Rocky |
| Intramontane_Alluvial_Pla | Granitoid | 2 | Rocky |
| Intramontane_Alluvial_Pla | Undifferentiated_Plutonic_Rock | 2 | Rocky |
| Intramontane_Alluvial_Pla | Undifferentiated_Sedimentary_Rock | 2 | Rocky |
| Intramontane_Alluvial_Pla | Andesitoid | 2 | Rocky |
| Intramontane_Alluvial_Pla | Basaltoid | 2 | Rocky |
| Intramontane_Alluvial_Pla | Dacitoid | 2 | Rocky |
| Intramontane_Alluvial_Pla | Rhyolitoid | 2 | Rocky |
| Intramontane_Alluvial_Pla | Undifferentiated_Volcanic_Rock | 2 | Rocky |
| Intramontane_Undifferenti | Dolostone | 2 | Rocky |
| Intramontane_Undifferenti | Limestone | 2 | Rocky |
| Intramontane_Undifferenti | Undifferentiated_Igneous_Rock | 2 | Rocky |
| Intramontane_Undifferenti | Siltstone/Mudstone/Claystone | 2 | Rocky |
| Intramontane_Undifferenti | Gravel/Sandstone | 2 | Rocky |
| Intramontane_Undifferenti | Undifferentiated_Clastic_Sedimentary_Rock | 2 | Rocky |
| Intramontane_Undifferenti | Aluminous_Metamorphic_Rock | 2 | Rocky |
| Intramontane_Undifferenti | Marble_Metamorphic_Rock | 2 | Rocky |
| Intramontane_Undifferenti | Felsic_Metamorphic_Rock | 2 | Rocky |
| Intramontane_Undifferenti | Undifferentiated_Metamorphic_Rock | 2 | Rocky |
| Intramontane_Undifferenti | Gabbroid | 2 | Rocky |
| Intramontane_Undifferenti | Dioritoid | 2 | Rocky |
| Intramontane_Undifferenti | Granitoid | 2 | Rocky |
| Intramontane_Undifferenti | Undifferentiated_Plutonic_Rock | 2 | Rocky |
| Intramontane_Undifferenti | Undifferentiated_Sedimentary_Rock | 2 | Rocky |
| Intramontane_Undifferenti | Andesitoid | 2 | Rocky |
| Intramontane_Undifferenti | Basaltoid | 2 | Rocky |
| Intramontane_Undifferenti | Dacitoid | 2 | Rocky |
| Intramontane_Undifferenti | Rhyolitoid | 2 | Rocky |
| Intramontane_Undifferenti | Undifferentiated_Volcanic_Rock | 2 | Rocky |
| Lacustrine_Terrace | Origin_Undefined-Clay_Mineral-rich_Sediments | 1 | Sand and Gravel |
| Lacustrine_Terrace | Origin_Undefined-Carbonate-rich_Sediments | 1 | Sand and Gravel |
| Lacustrine_Terrace | Origin_Undefined-Quartz-Feldspar-rich_Sediments | 1 | Sand and Gravel |
| Lacustrine_Terrace | Undifferentiated_Sediments | 1 | Sand and Gravel |

| | | | |
|---|---|---|---|
| Lava_Field | Basaltoid | 2 | Rocky |
| Lava_Field | Dacitoid | 2 | Rocky |
| Lava_Field | Rhyolitoid | 2 | Rocky |
| Lava_Field | Undifferentiated_Volcanic_Rock | 2 | Rocky |
| Linear_Dune_Field | Origin_Undefined-Quartz-Feldspar-rich_Sediments | 6 | Wind Blown Sand |
| Older_Alluvial_Deposit | Dolostone | 4 | Desert Pavement |
| Older_Alluvial_Deposit | Limestone | 4 | Desert Pavement |
| Older_Alluvial_Deposit | Waterlain_Tuff | 4 | Desert Pavement |
| Older_Alluvial_Deposit | Undifferentiated_Chemical_Sedimentary_Rock | 4 | Desert Pavement |
| Older_Alluvial_Deposit | Undifferentiated_Igneous_Rock | 4 | Desert Pavement |
| Older_Alluvial_Deposit | Siltstone/Mudstone/Claystone | 4 | Desert Pavement |
| Older_Alluvial_Deposit | Gravel/Sandstone | 4 | Desert Pavement |
| Older_Alluvial_Deposit | Undifferentiated_Clastic_Sedimentary_Rock | 4 | Desert Pavement |
| Older_Alluvial_Deposit | Aluminous_Metamorphic_Rock | 4 | Desert Pavement |
| Older_Alluvial_Deposit | Felsic_Metamorphic_Rock | 4 | Desert Pavement |
| Older_Alluvial_Deposit | Mafic_Metamorphic_Rock | 4 | Desert Pavement |
| Older_Alluvial_Deposit | Quartzite_Metamorphoric_Rock | 4 | Desert Pavement |
| Older_Alluvial_Deposit | Undifferentiated_Metamorphic_Rock | 4 | Desert Pavement |
| Older_Alluvial_Deposit | Gabbroid | 4 | Desert Pavement |
| Older_Alluvial_Deposit | Dioritoid | 4 | Desert Pavement |
| Older_Alluvial_Deposit | Granitoid | 4 | Desert Pavement |
| Older_Alluvial_Deposit | Undifferentiated_Plutonic_Rock | 4 | Desert Pavement |
| Older_Alluvial_Deposit | Undifferentiated_Sedimentary_Rock | 4 | Desert Pavement |
| Older_Alluvial_Deposit | Origin_Undefined-Clay_Mineral-rich_Sediments | 4 | Desert Pavement |
| Older_Alluvial_Deposit | Origin_Undefined-Quartz-Feldspar-rich_Sediments | 4 | Desert Pavement |
| Older_Alluvial_Deposit | Undifferentiated_Sediments | 4 | Desert Pavement |
| Older_Alluvial_Deposit | Andesitoid | 4 | Desert Pavement |
| Older_Alluvial_Deposit | Basaltoid | 4 | Desert Pavement |
| Older_Alluvial_Deposit | Dacitoid | 4 | Desert Pavement |
| Older_Alluvial_Deposit | Rhyolitoid | 4 | Desert Pavement |
| Older_Alluvial_Deposit | Undifferentiated_Volcanic_Rock | 4 | Desert Pavement |
| Older_Alluvial_Plain | Undifferentiated_Igneous_Rock | 1 | Sand and Gravel |
| Older_Alluvial_Plain | Gravel/Sandstone | 1 | Sand and Gravel |

| | | | |
|---|---|---|---|
| Older_Alluvial_Plain | Undifferentiated_Metamorphic_Rock | 1 | Sand and Gravel |
| Older_Alluvial_Plain | Granitoid | 1 | Sand and Gravel |
| Older_Alluvial_Plain | Undifferentiated_Plutonic_Rock | 1 | Sand and Gravel |
| Older_Alluvial_Plain | Undifferentiated_Sedimentary_Rock | 1 | Sand and Gravel |
| Older_Alluvial_Plain | Origin_Undefined-Quartz-Feldspar-rich_Sediments | 1 | Sand and Gravel |
| Older_Alluvial_Plain | Basaltoid | 1 | Sand and Gravel |
| Parabolic_Dune_Field | Origin_Undefined-Quartz-Feldspar-rich_Sediments | 6 | Wind Blown Sand |
| Playa | Origin_Undefined-Clay_Mineral-rich_Sediments | 7 | Playa |
| Playa | Origin_Undefined-Evaporite_Salt-rich_Sediments | 7 | Playa |
| Playa | Undifferentiated_Sediments | 7 | Playa |
| Reservoir | Undifferentiated_Sediments | 8 | Reservoir |
| Sand_Sheet | Origin_Undefined-Iron-Magnesium- rich_Sediments | 12 | Sand Sheet |
| Sand_Sheet | Origin_Undefined-Quartz-Feldspar-rich_Sediments | 12 | Sand Sheet |
| Star_Dune_Field | Origin_Undefined-Quartz-Feldspar-rich_Sediments | 6 | Wind Blown Sand |
| Undifferentiated_Dune_Fie | Origin_Undefined-Quartz-Feldspar-rich_Sediments | 6 | Wind Blown Sand |
| Undifferentiated_Sediment | Undifferentiated_Sediments | 1 | Sand and Gravel |
| Volcanic_Dome | Basaltoid | 2 | Rocky |
| Volcanic_Dome | Dacitoid | 2 | Rocky |
| Volcanic_Dome | Rhyolitoid | 2 | Rocky |
| Volcanic_Tableland | Basaltoid | 2 | Rocky |
| Volcanic_Tableland | Dacitoid | 2 | Rocky |
| Volcanic_Tableland | Rhyolitoid | 2 | Rocky |
| Volcanic_Tableland | Undifferentiated_Volcanic_Rock | 2 | Rocky |
| Volcano | Andesitoid | 2 | Rocky |
| Volcano | Basaltoid | 2 | Rocky |
| Volcano | Dacitoid | 2 | Rocky |
| Volcano | Rhyolitoid | 2 | Rocky |
| Wash | Chert-organic | 3 | Sandy Wash |
| Wash | Dolostone | 3 | Sandy Wash |
| Wash | Limestone | 3 | Sandy Wash |
| Wash | Waterlain_Tuff | 3 | Sandy Wash |
| Wash | Undifferentiated_Chemical_Sedimentary_Rock | 3 | Sandy Wash |
| Wash | Undifferentiated_Igneous_Rock | 3 | Sandy Wash |

|  |  |  |  |
|---|---|---|---|
| Wash | Siltstone/Mudstone/Claystone | 3 | Sandy Wash |
| Wash | Gravel/Sandstone | 3 | Sandy Wash |
| Wash | Undifferentiated_Clastic_Sedimentary_Rock | 3 | Sandy Wash |
| Wash | Aluminous_Metamorphic_Rock | 3 | Sandy Wash |
| Wash | Felsic_Metamorphic_Rock | 3 | Sandy Wash |
| Wash | Undifferentiated_Metamorphic_Rock | 3 | Sandy Wash |
| Wash | Gabbroid | 3 | Sandy Wash |
| Wash | Dioritoid | 3 | Sandy Wash |
| Wash | Granitoid | 3 | Sandy Wash |
| Wash | Undifferentiated_Plutonic_Rock | 3 | Sandy Wash |
| Wash | Undifferentiated_Sedimentary_Rock | 3 | Sandy Wash |
| Wash | Andesitoid | 3 | Sandy Wash |
| Wash | Basaltoid | 3 | Sandy Wash |
| Wash | Dacitoid | 3 | Sandy Wash |
| Wash | Rhyolitoid | 3 | Sandy Wash |
| Wash | Undifferentiated_Volcanic_Rock | 3 | Sandy Wash |

[1] Geomorphic Landforms and Surface Composition GIS of the California Mojave Desert,  Mojave Desert Ecosystem Program, 2000.
[2] GLSCGIS category
[3] LizLand category

# Appendix I

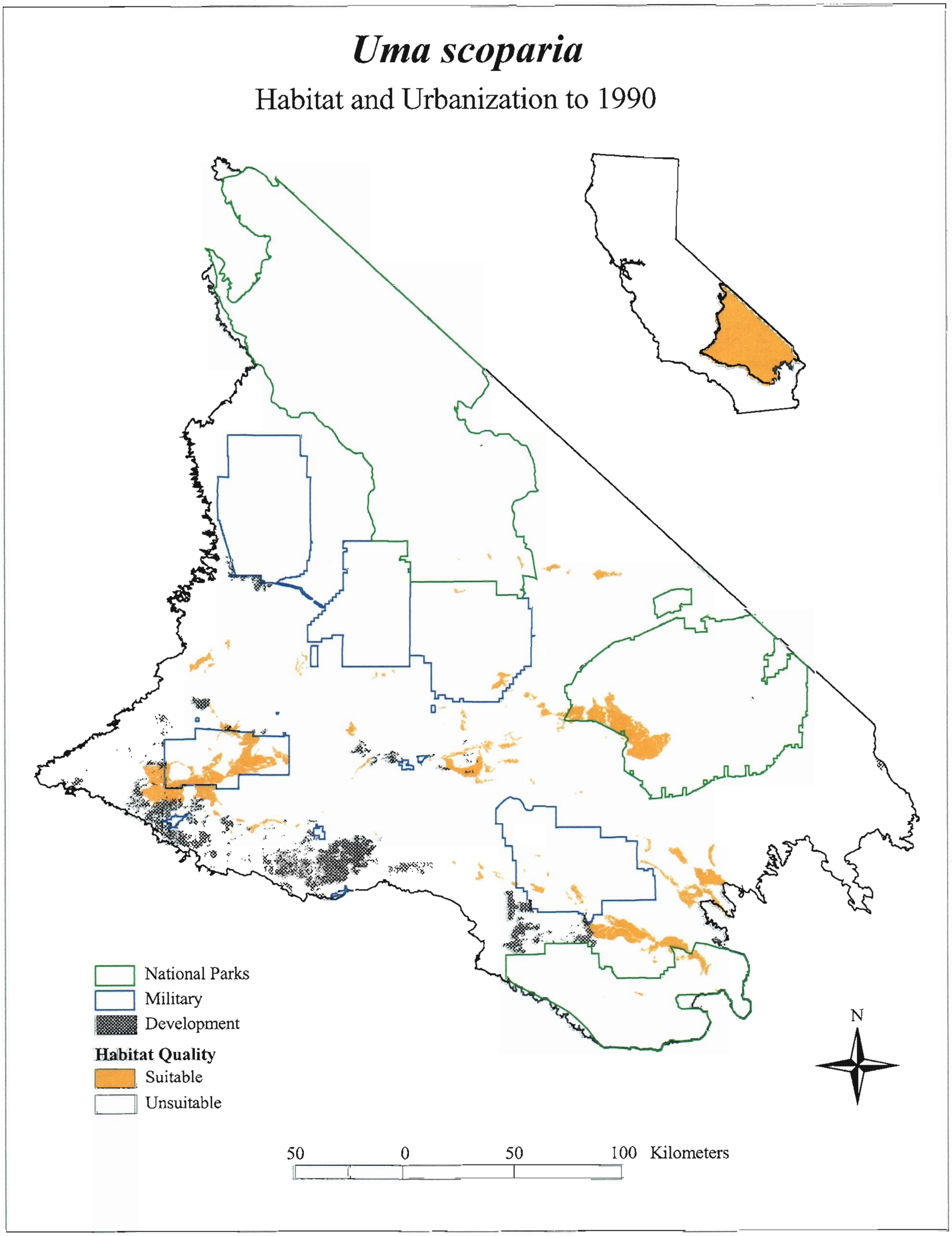


Figure 8.1. Distribution of *Uma scoparia* (Mojave Fringe-toed Lizard) habitat for 1990.

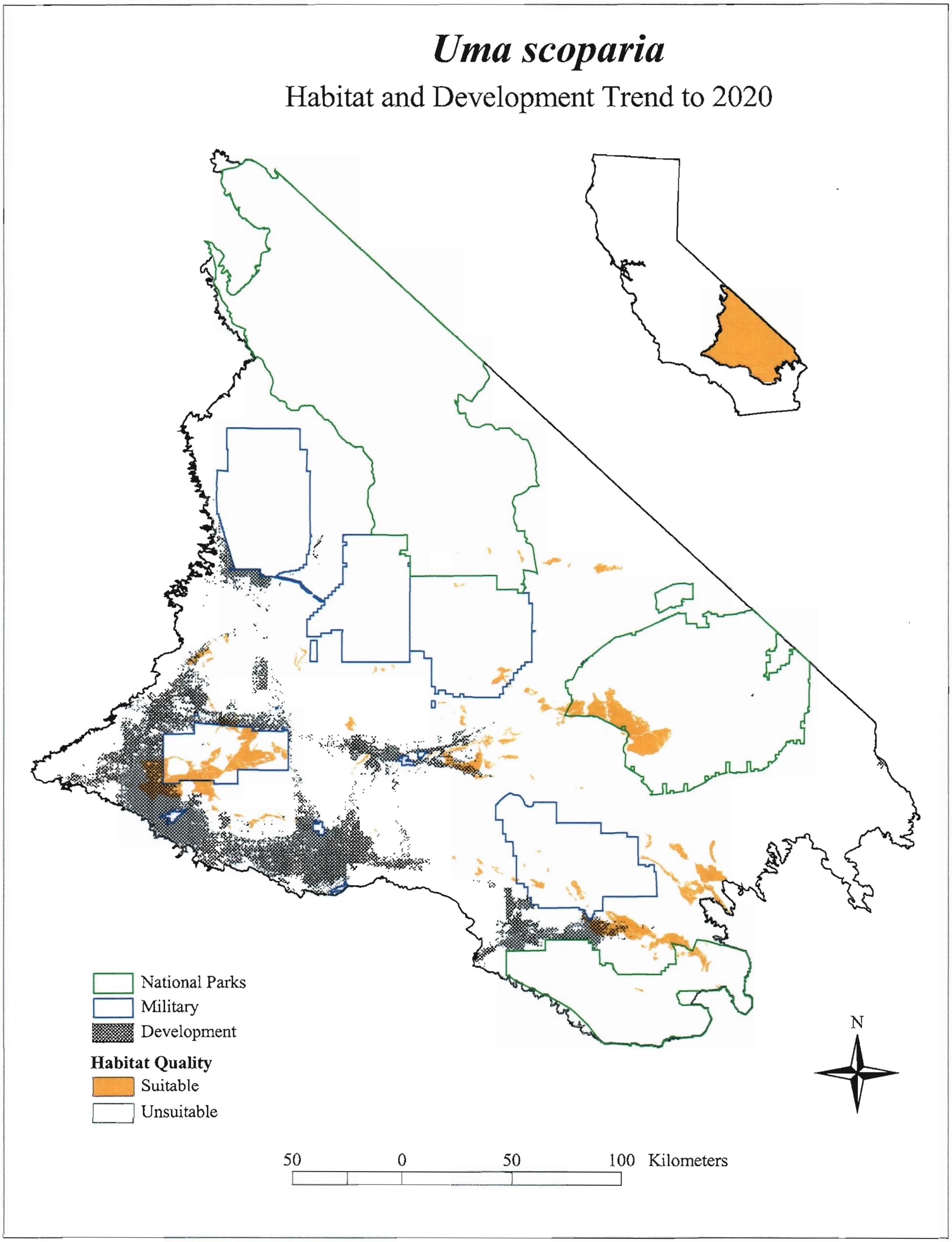


Figure 8.2. Distribution of *Uma scoparia* (Mojave Fringe-toed Lizard) habitat for the Trend future.

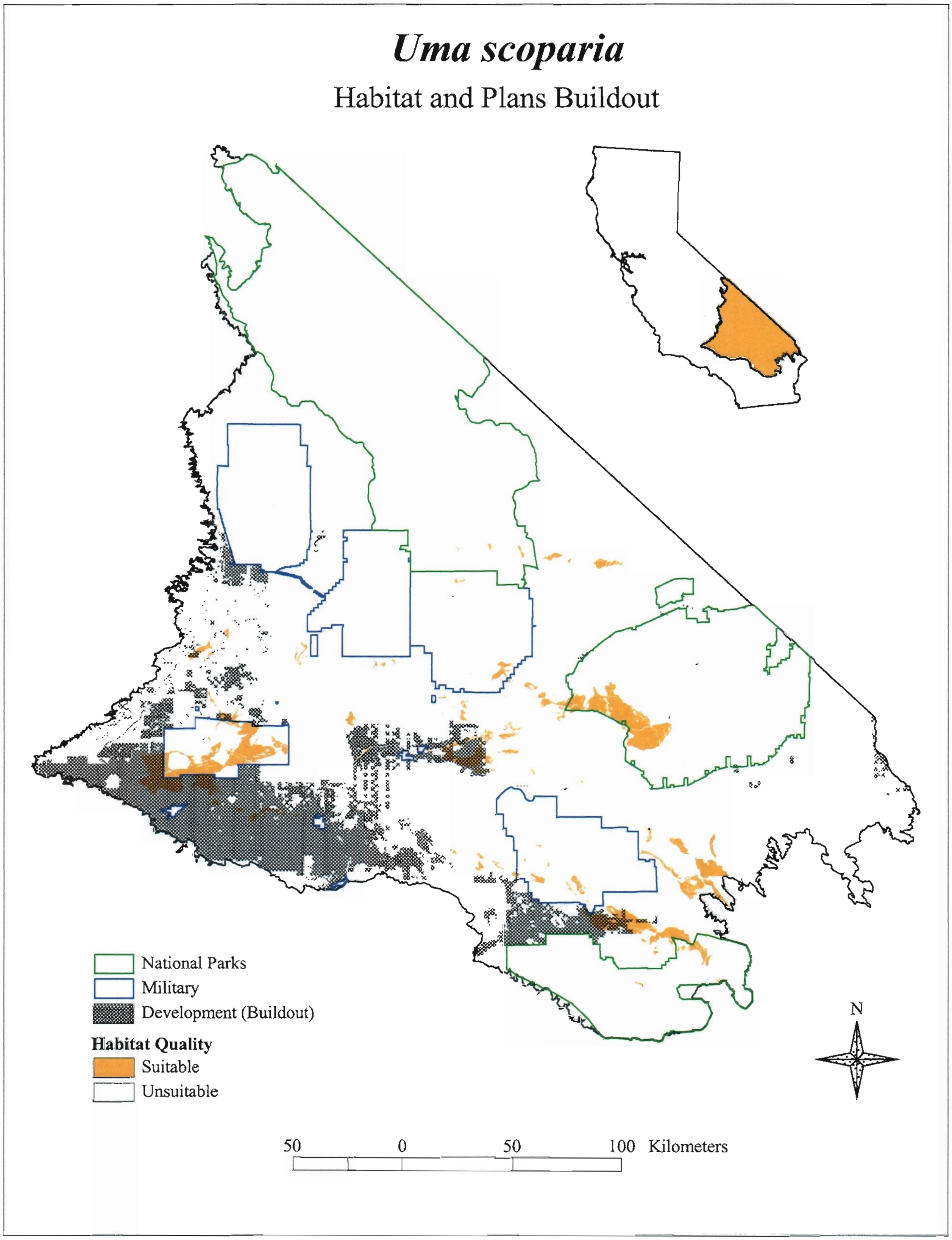


Figure 8.3. Distribution of *Uma scoparia* (Mojave Fringe-toed Lizard) habitat for the Plans Build-out future.

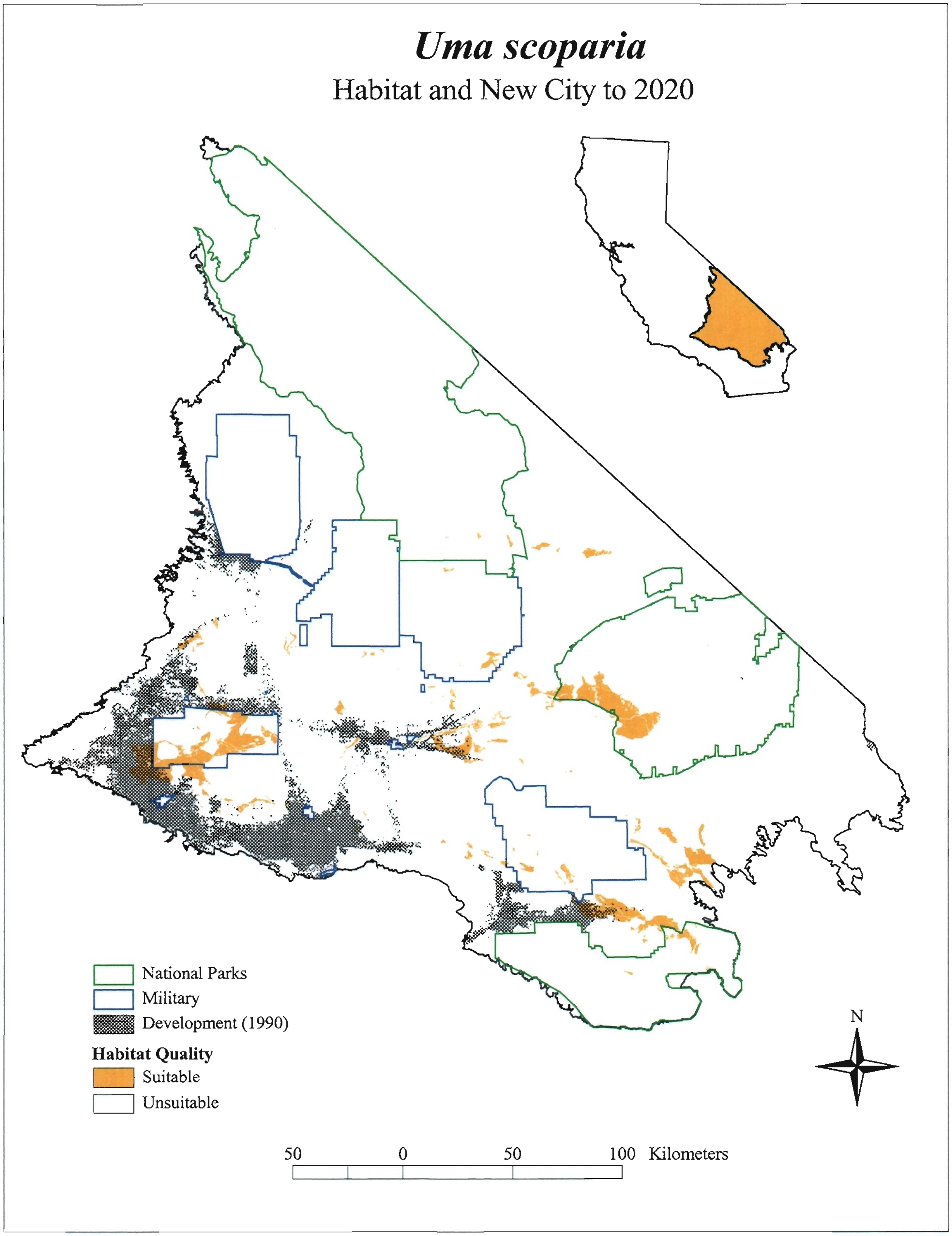


Figure 8.4. Distribution of *Uma scoparia* (Mojave Fringe-toed Lizard) habitat for the New City future.

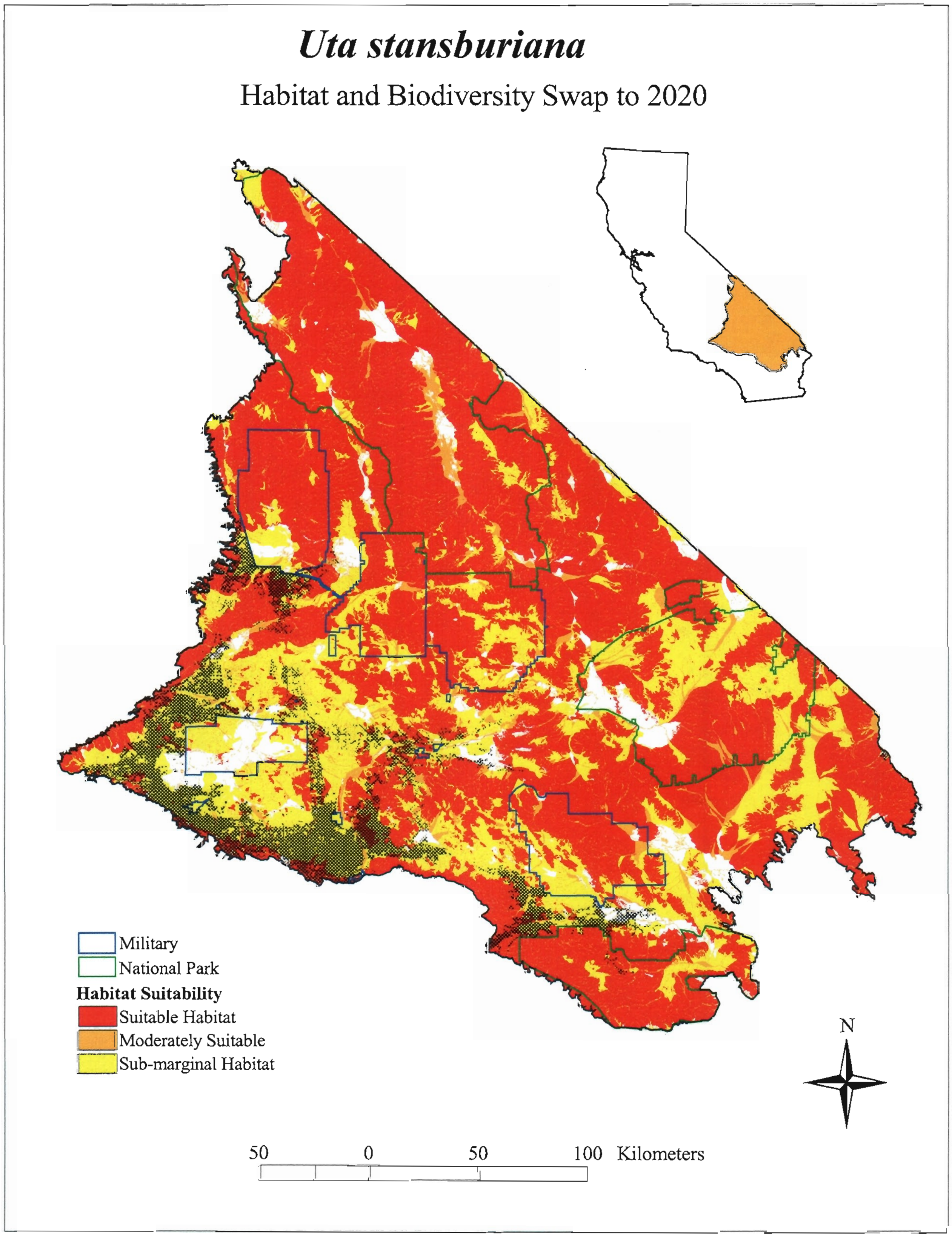


Figure 8.5. Distribution of *Uma scoparia* (Mojave Fringe-toed Lizard) habitat for the Biodiversity Swap future.

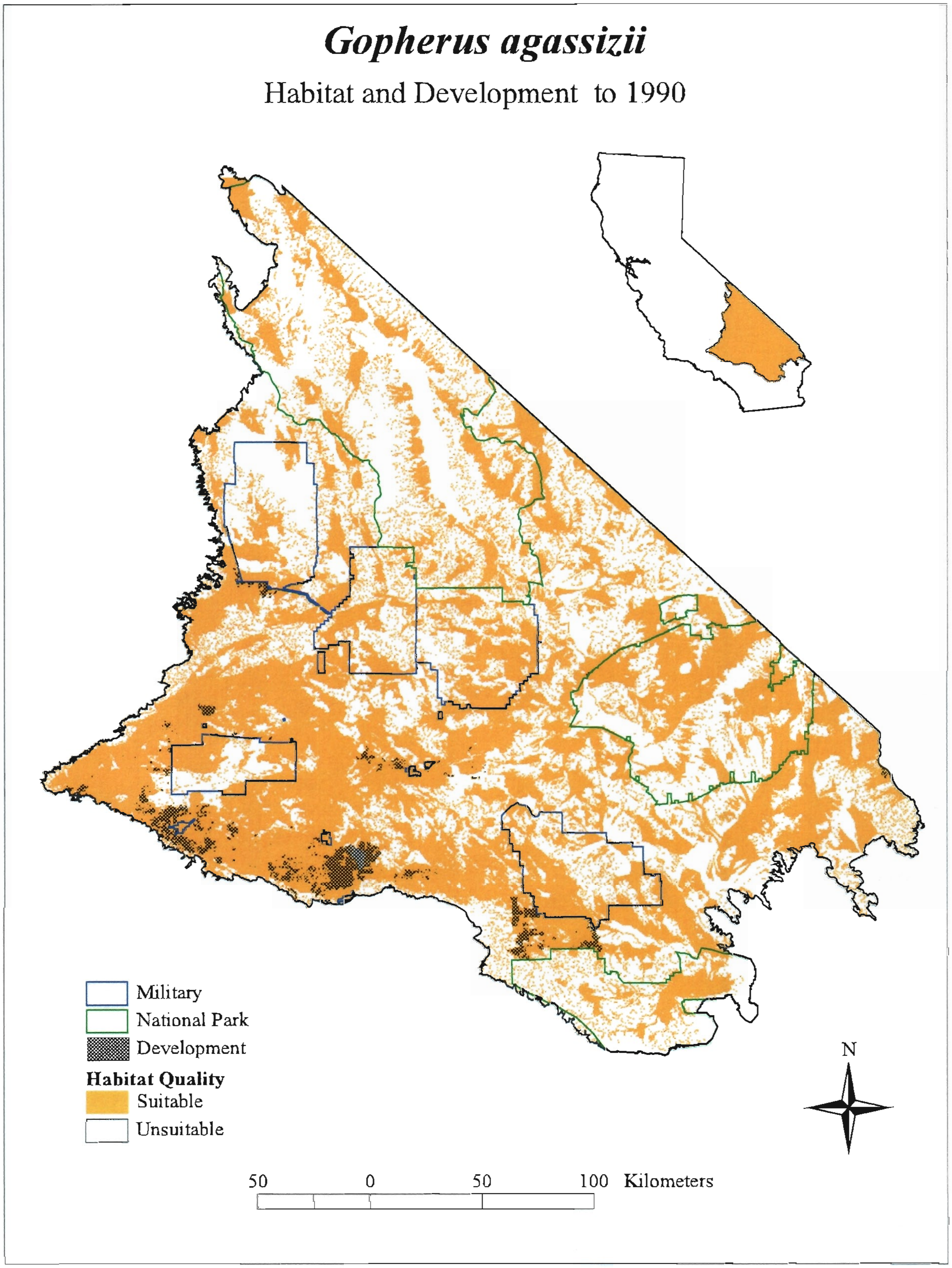


Figure 8.6. Distribution of *Gopherus agassizii* (Desert Tortoise) habitat for 1990.

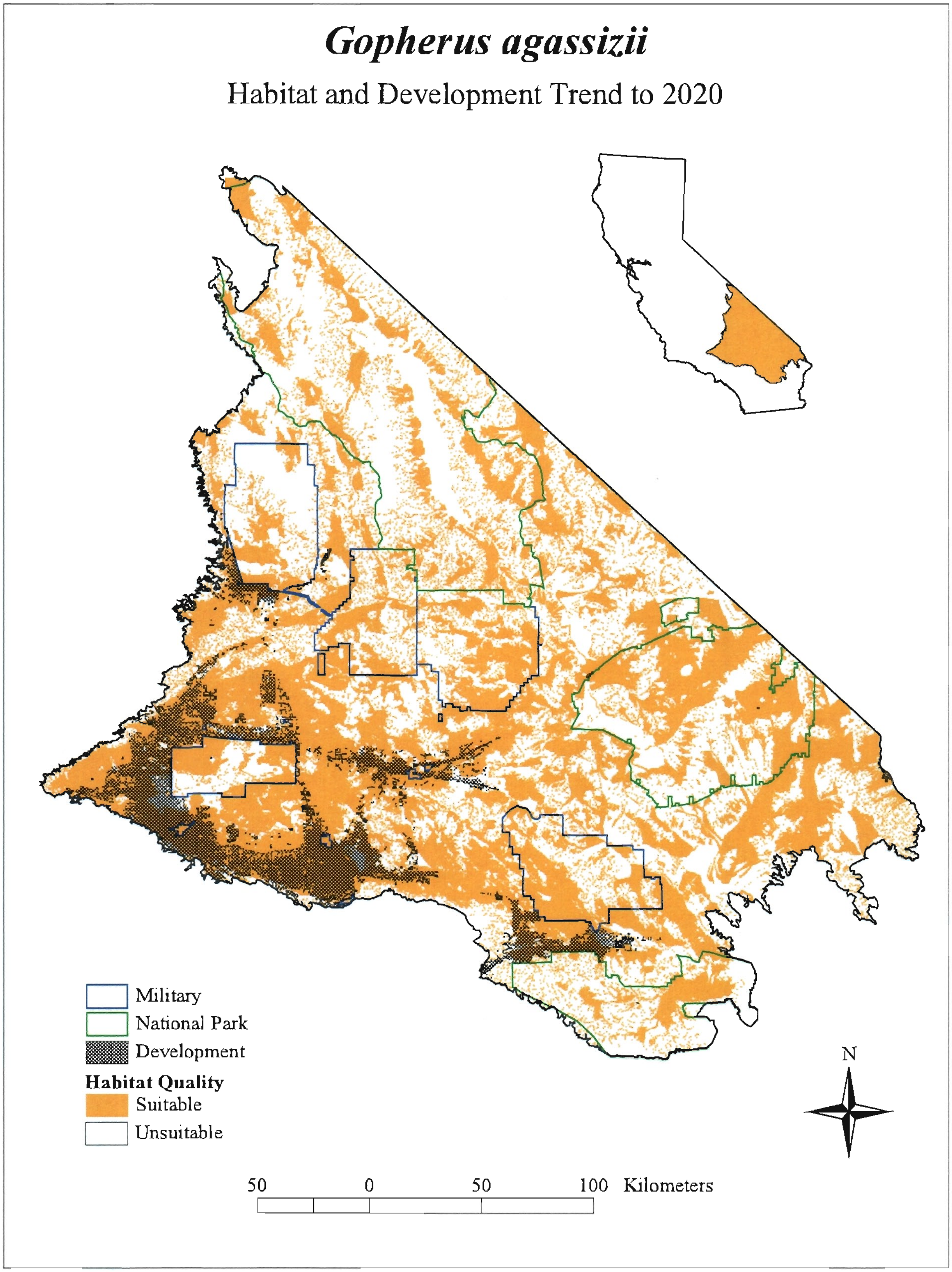


Figure 8.7. Distribution of *Gopherus agassizii* (Desert Tortoise) habitat for the Trend future.

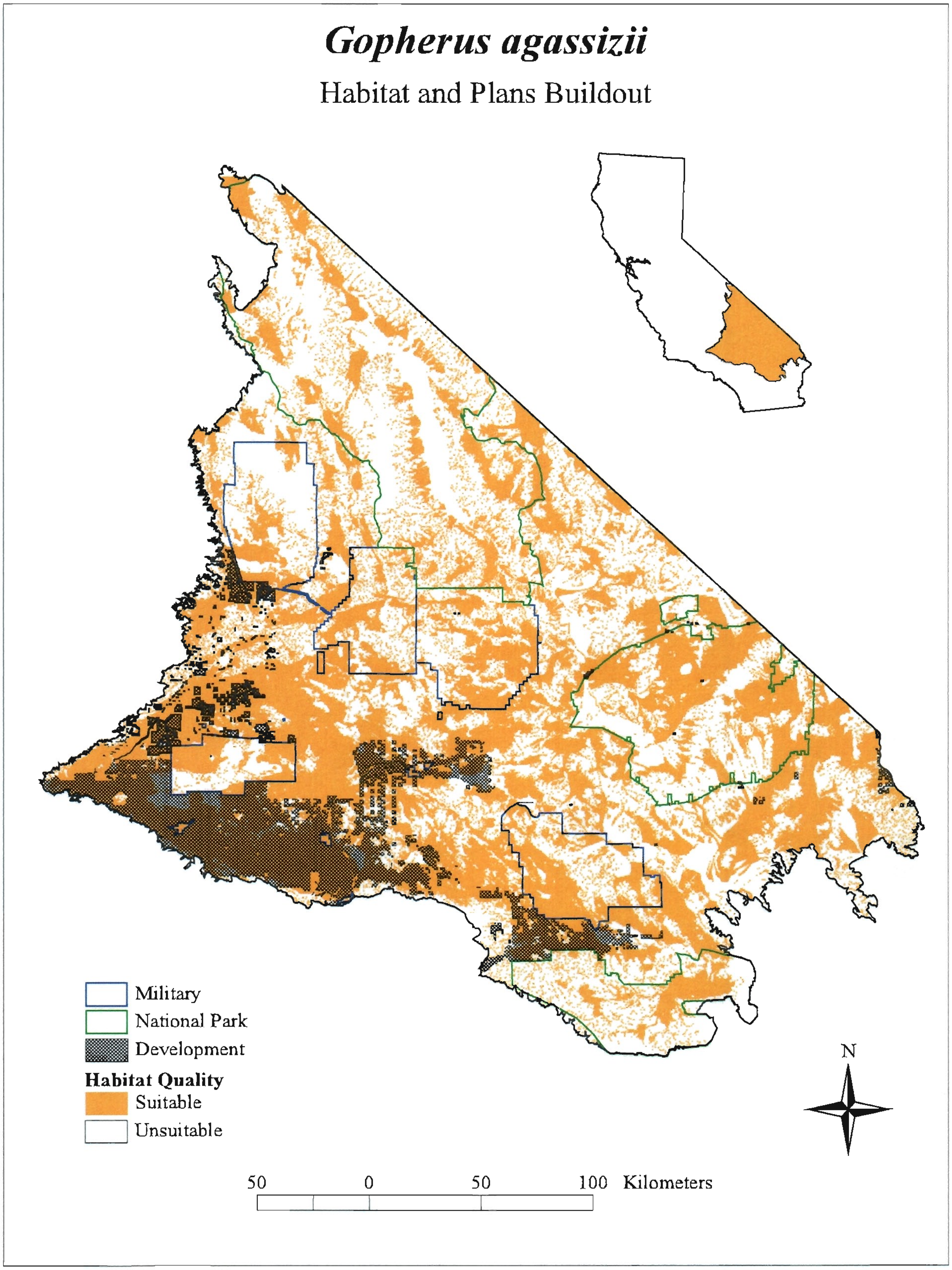


Figure 8.8. Distribution of *Gopherus agassizii* (Desert Tortoise) habitat for the Plans Build-out future.

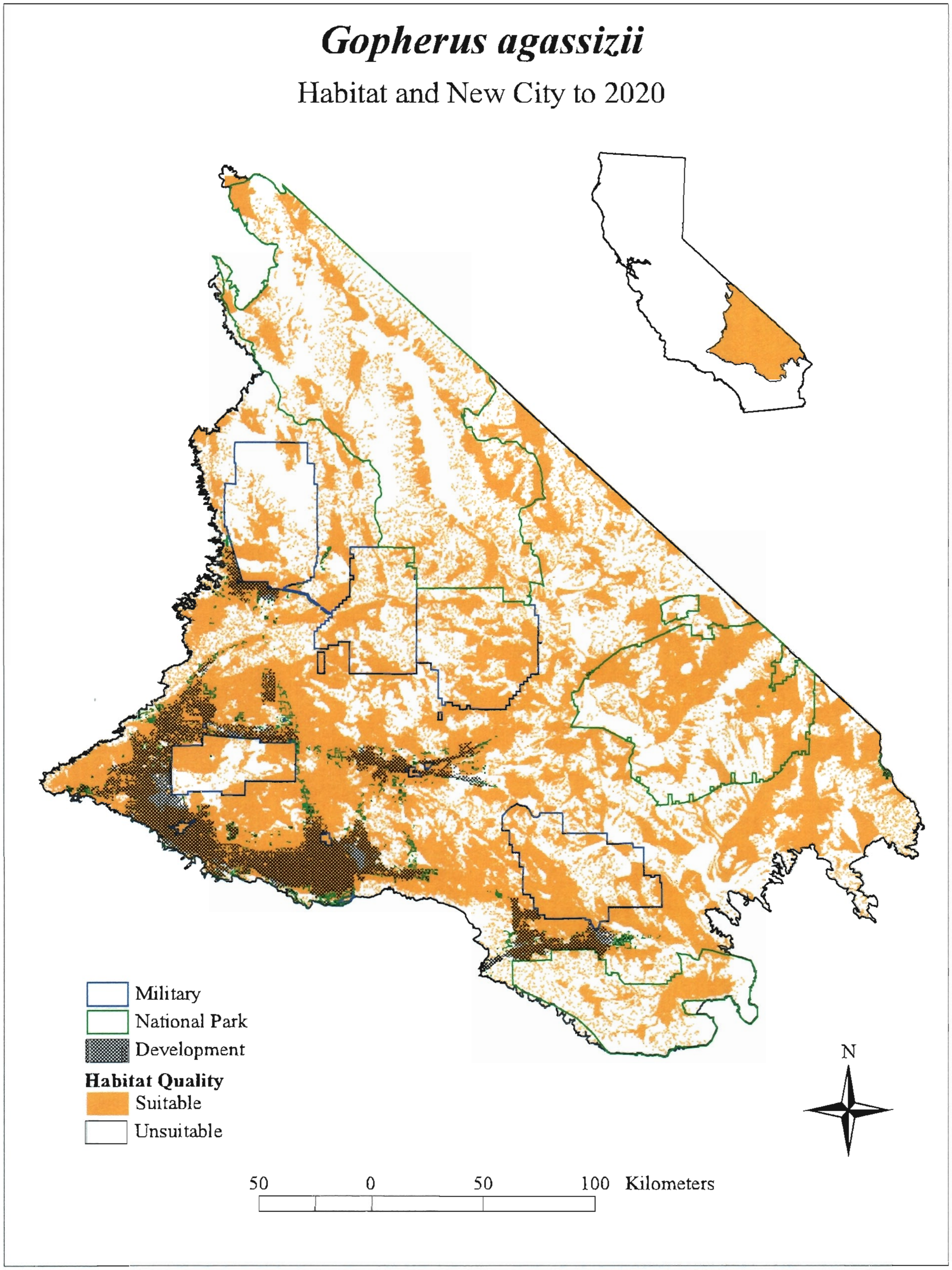


Figure 8.9. Distribution of *Gopherus agassizii* (Desert Tortoise) habitat for the New City future.

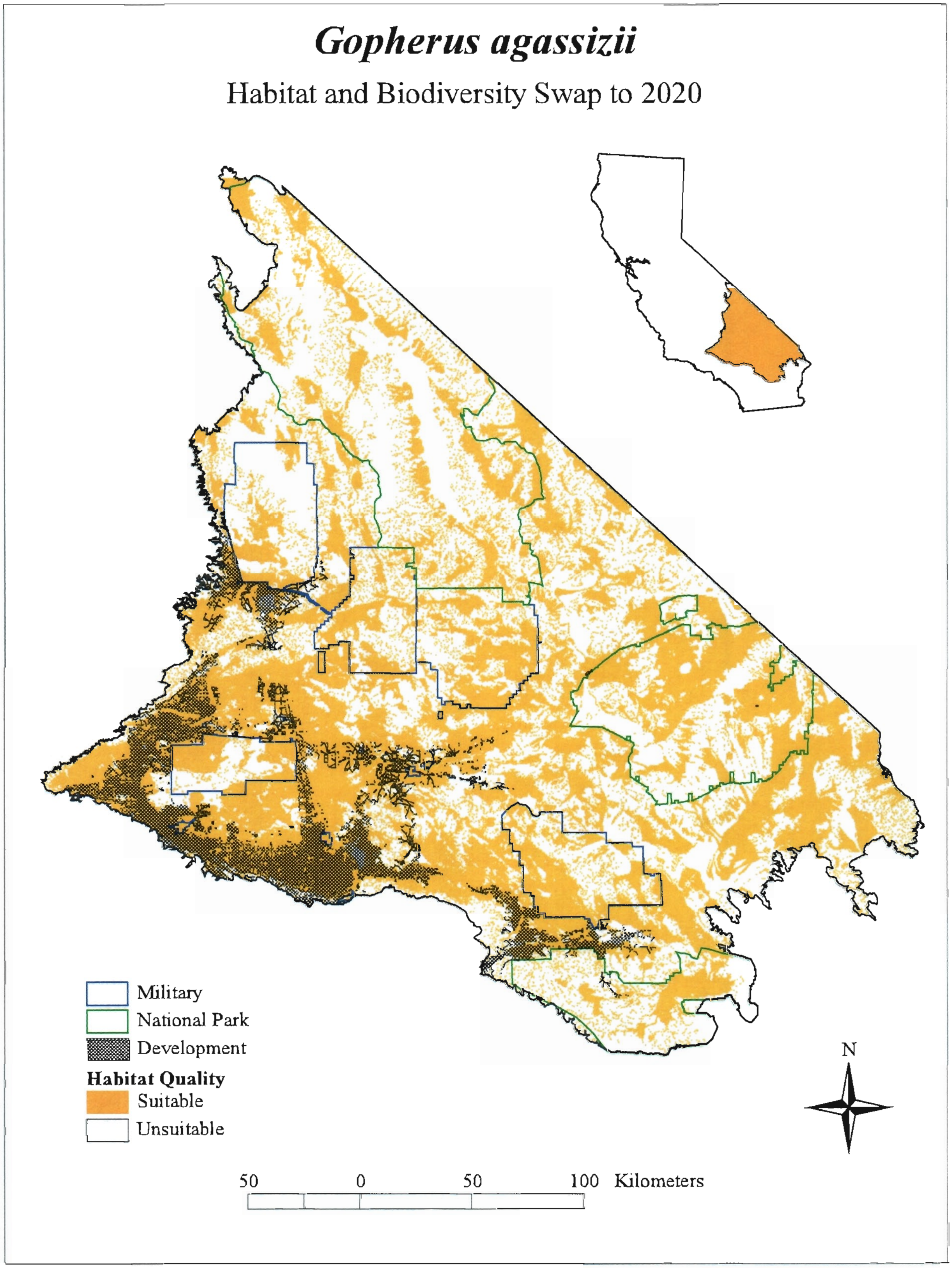


Figure 8.10. Distribution of *Gopherus agassizii* (Desert Tortoise) habitat for the Biodiversity Swap future.

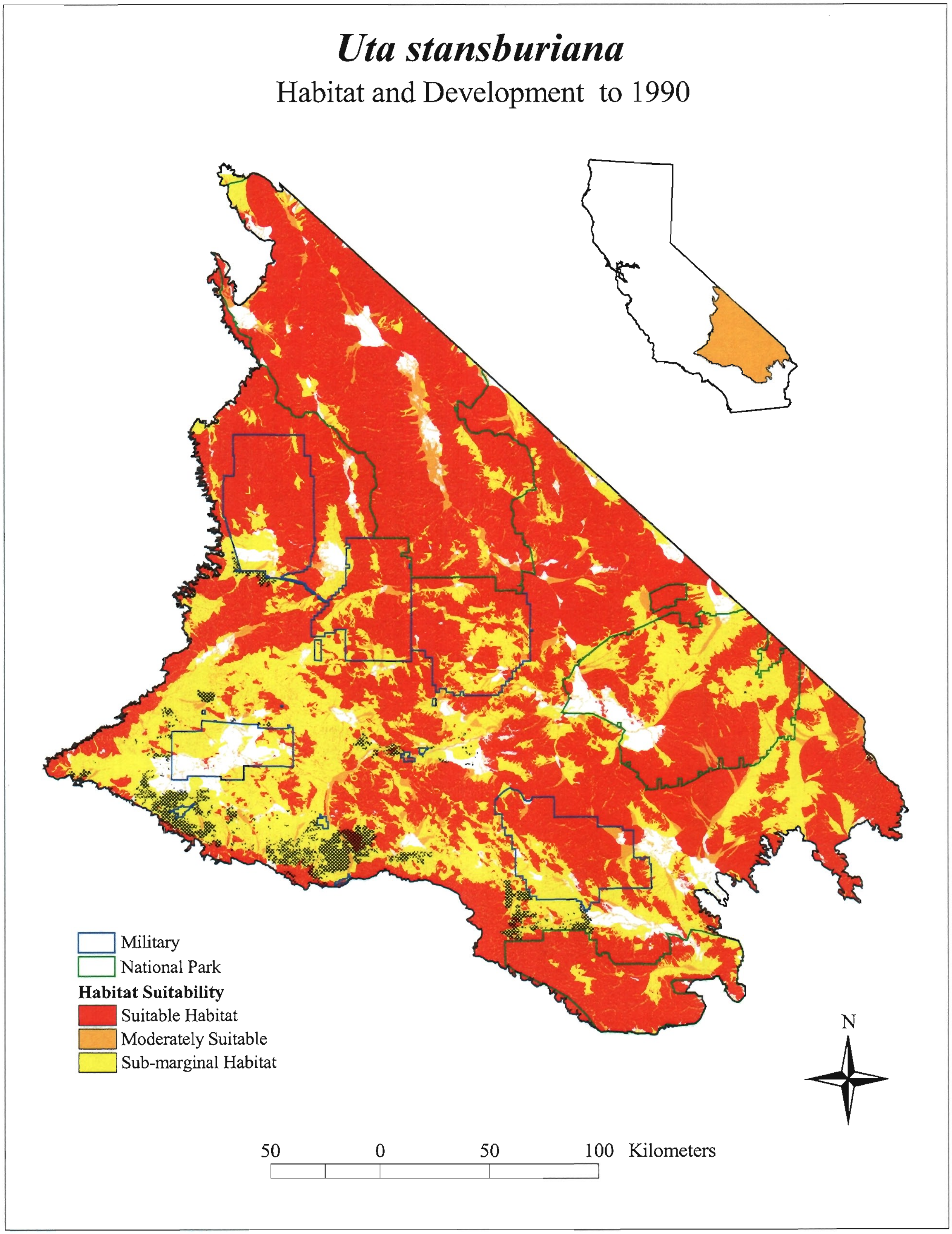


Figure 8.11. Distribution of *Uta stansburiana* (Side-blotched Lizard) habitat for 1990.

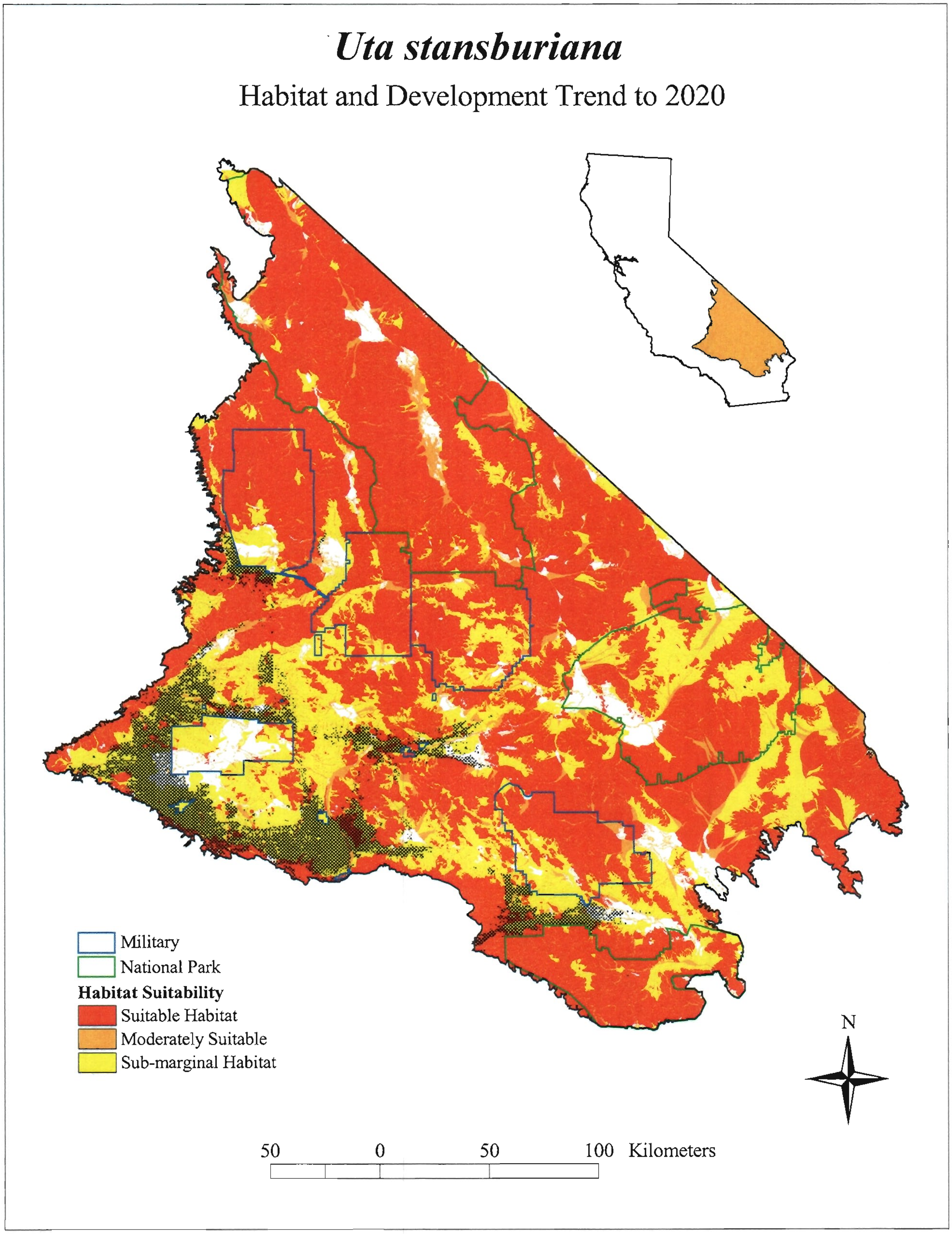


Figure 8.12. Distribution of *Uta stansburiana* (Side-blotched Lizard) habitat for the Trend future.

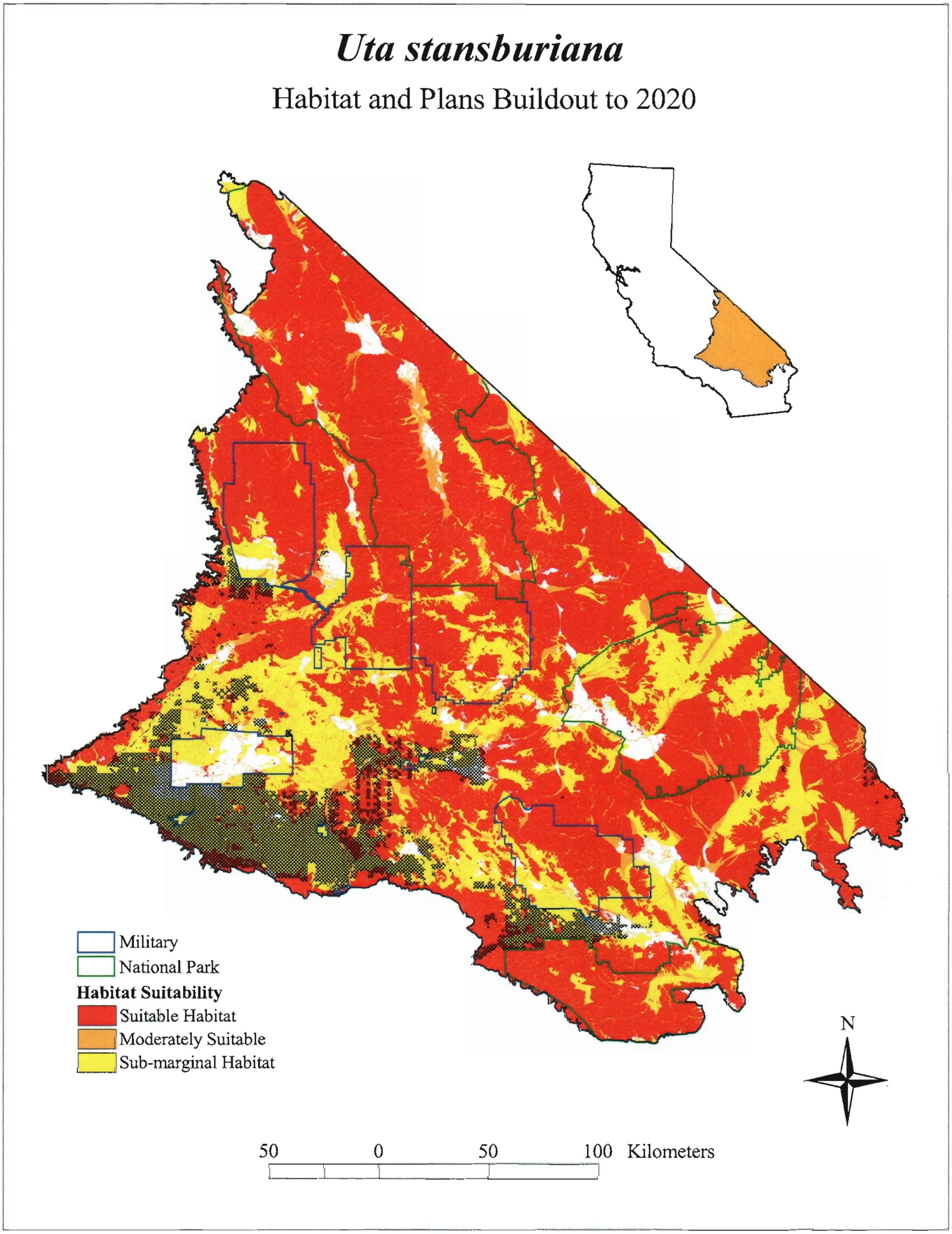


Figure 8.13. Distribution of *Uta stansburiana* (Side-blotched Lizard) habitat for the Plans Build-out future.

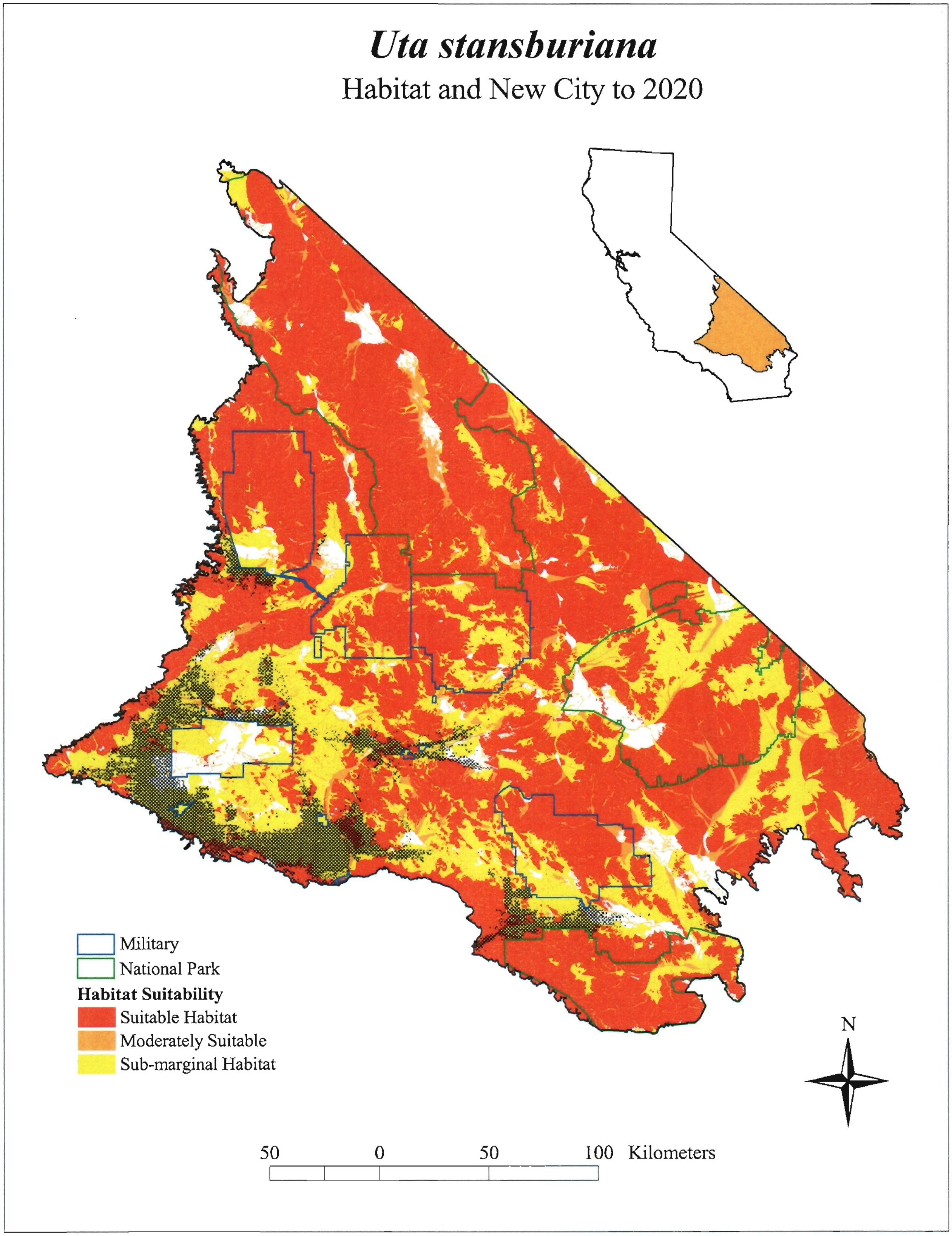


Figure 8.14. Distribution of *Uta stansburiana* (Side-blotched Lizard) habitat for the New City future.

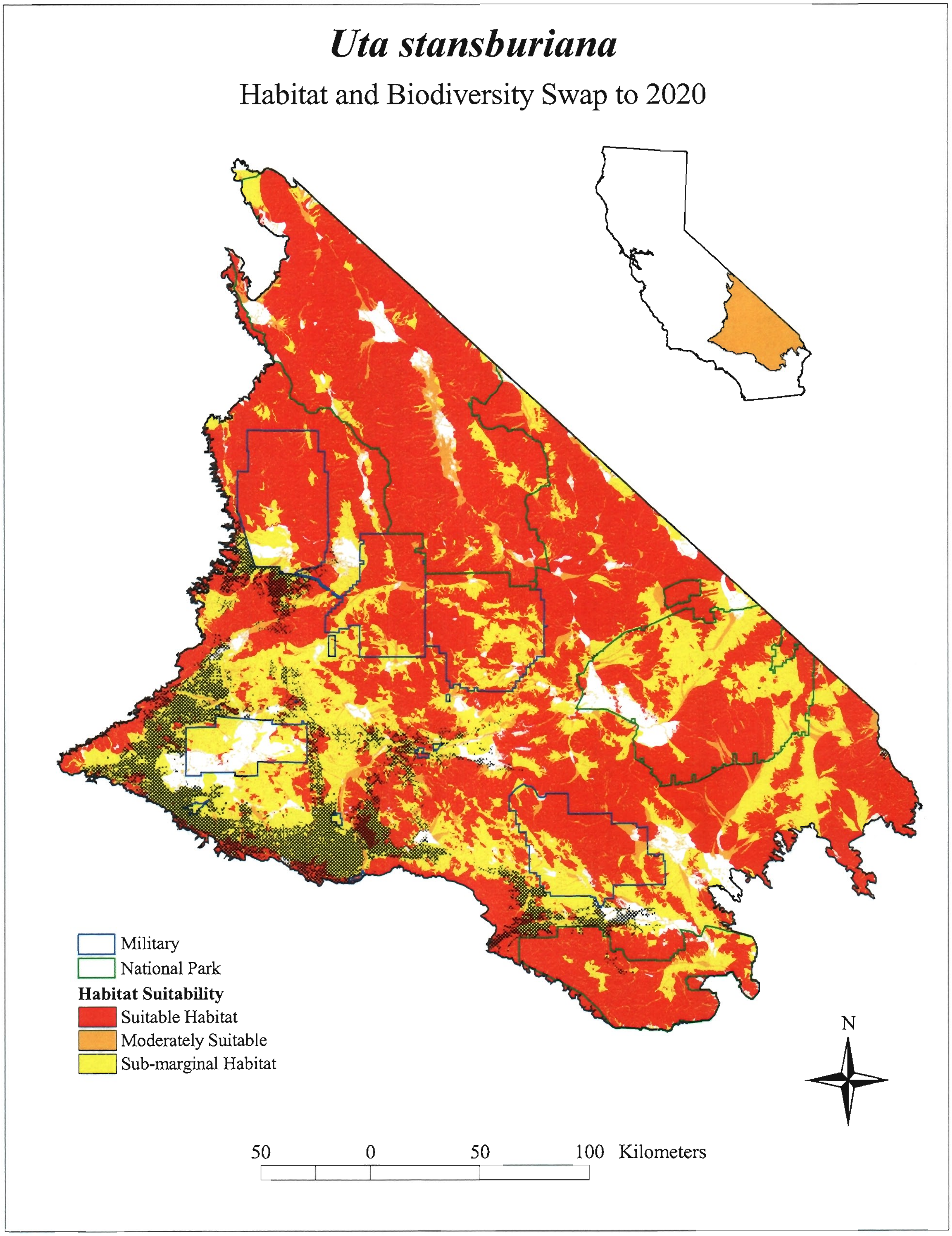


Figure 8.15. Distribution of *Uta stansburiana* (Side-blotched Lizard) habitat for the Biodiversity Swap future.

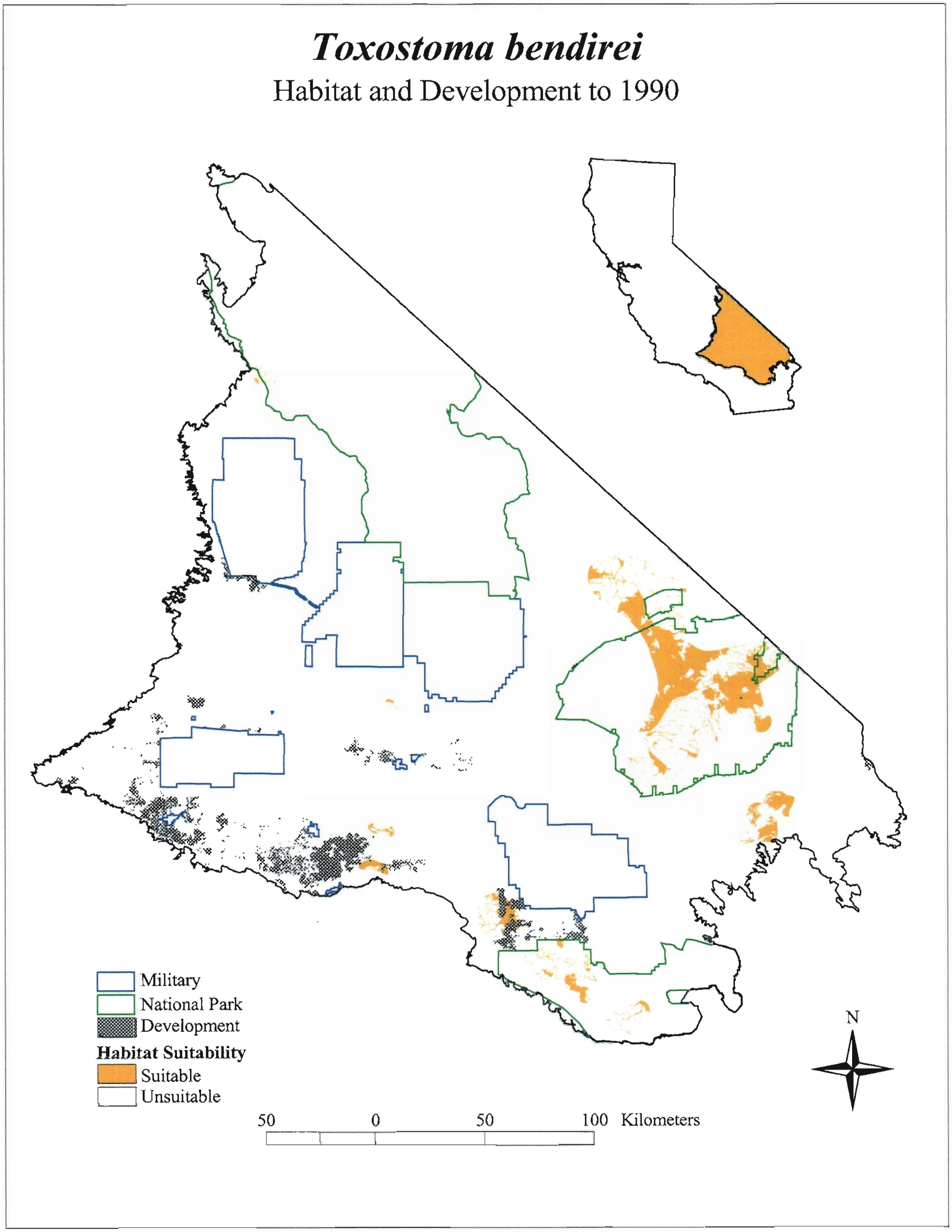


Figure 8.16. Distribution of *Toxostoma bendirei* (Bendire's Thrasher) habitat for 1990.

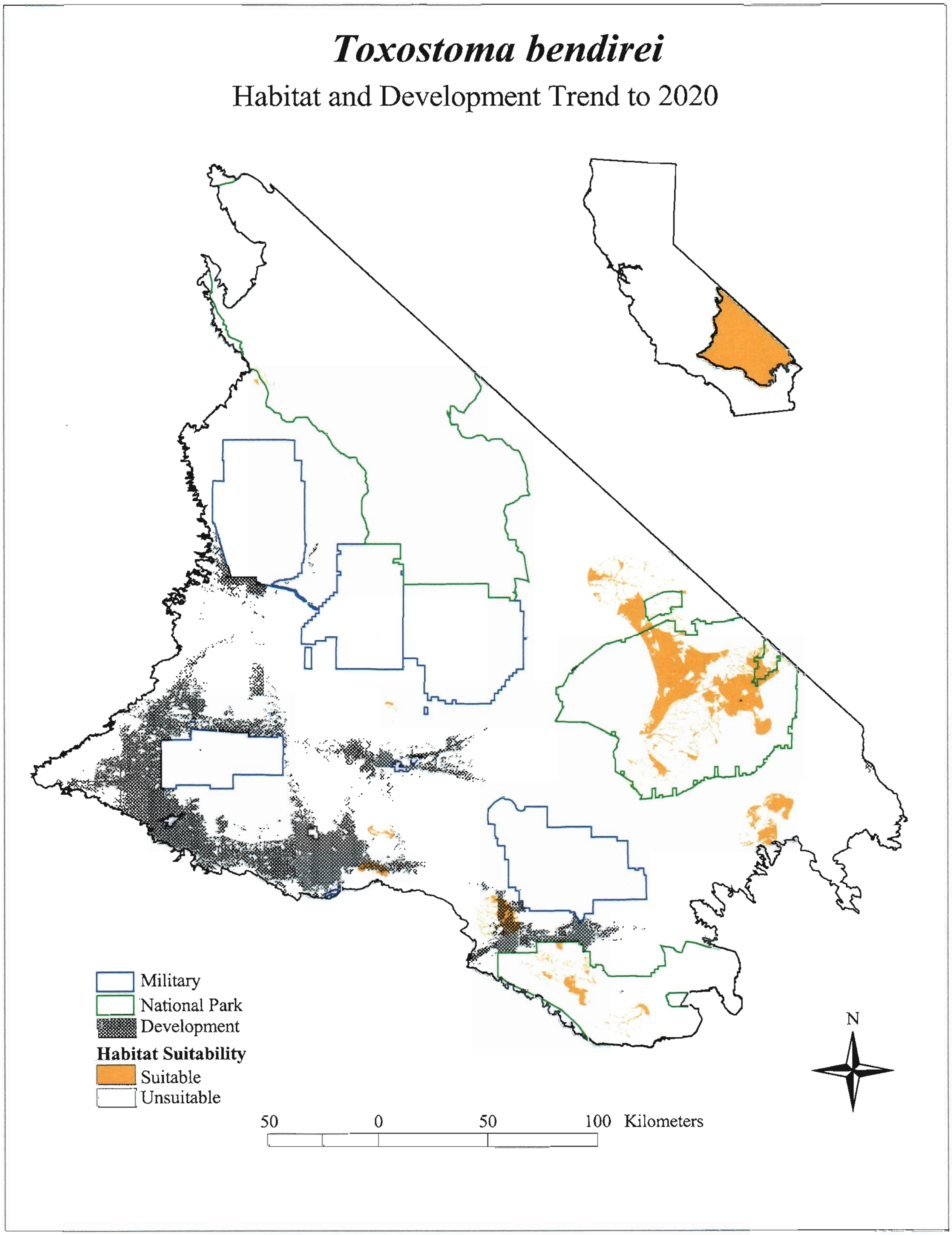


Figure 8.17. Distribution of *Toxostoma bendirei* (Bendire's Thrasher) habitat for the Trend future.

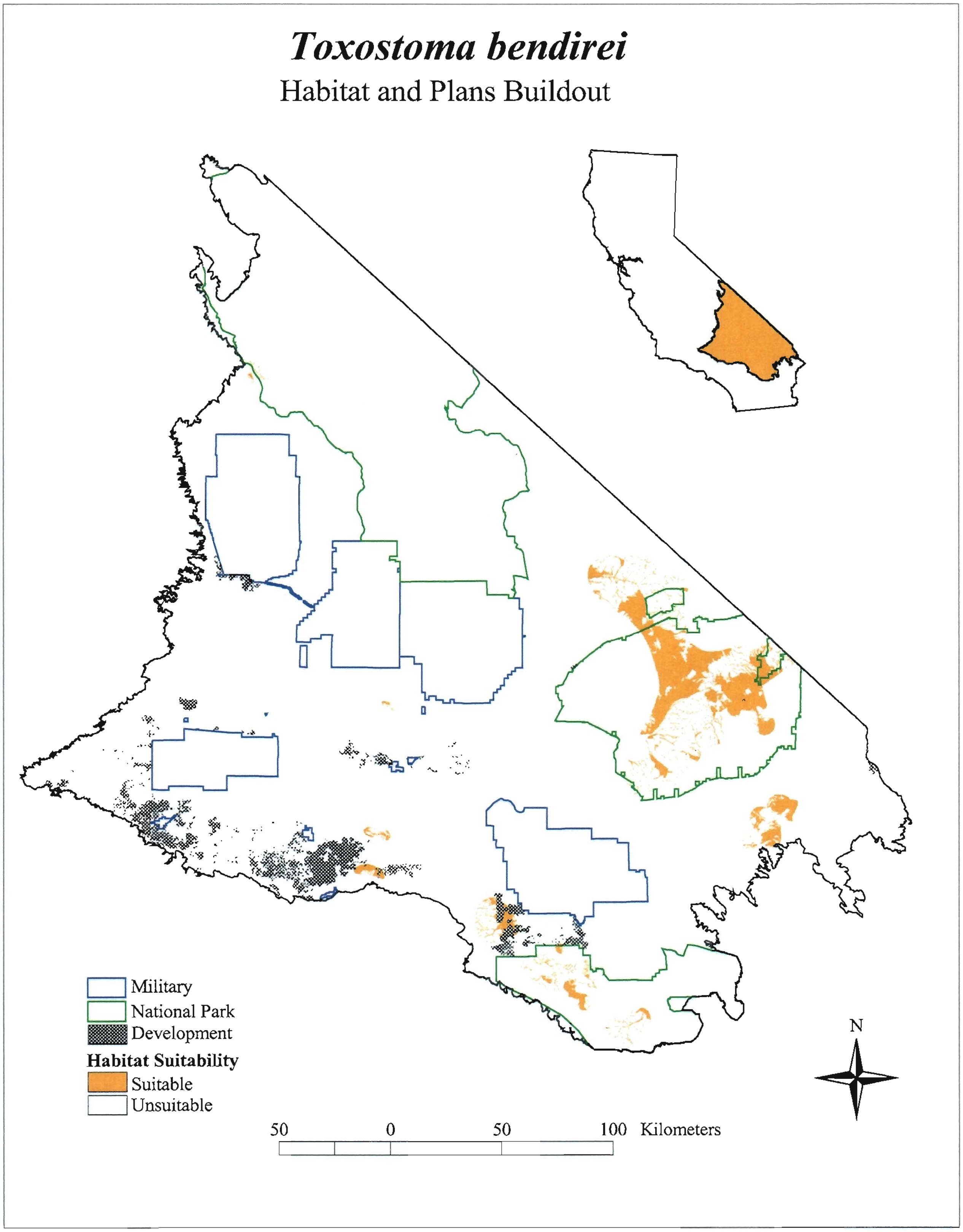


Figure 8.18. Distribution of *Toxostoma bendirei* (Bendire's Thrasher) habitat for the Plans Buildout future.

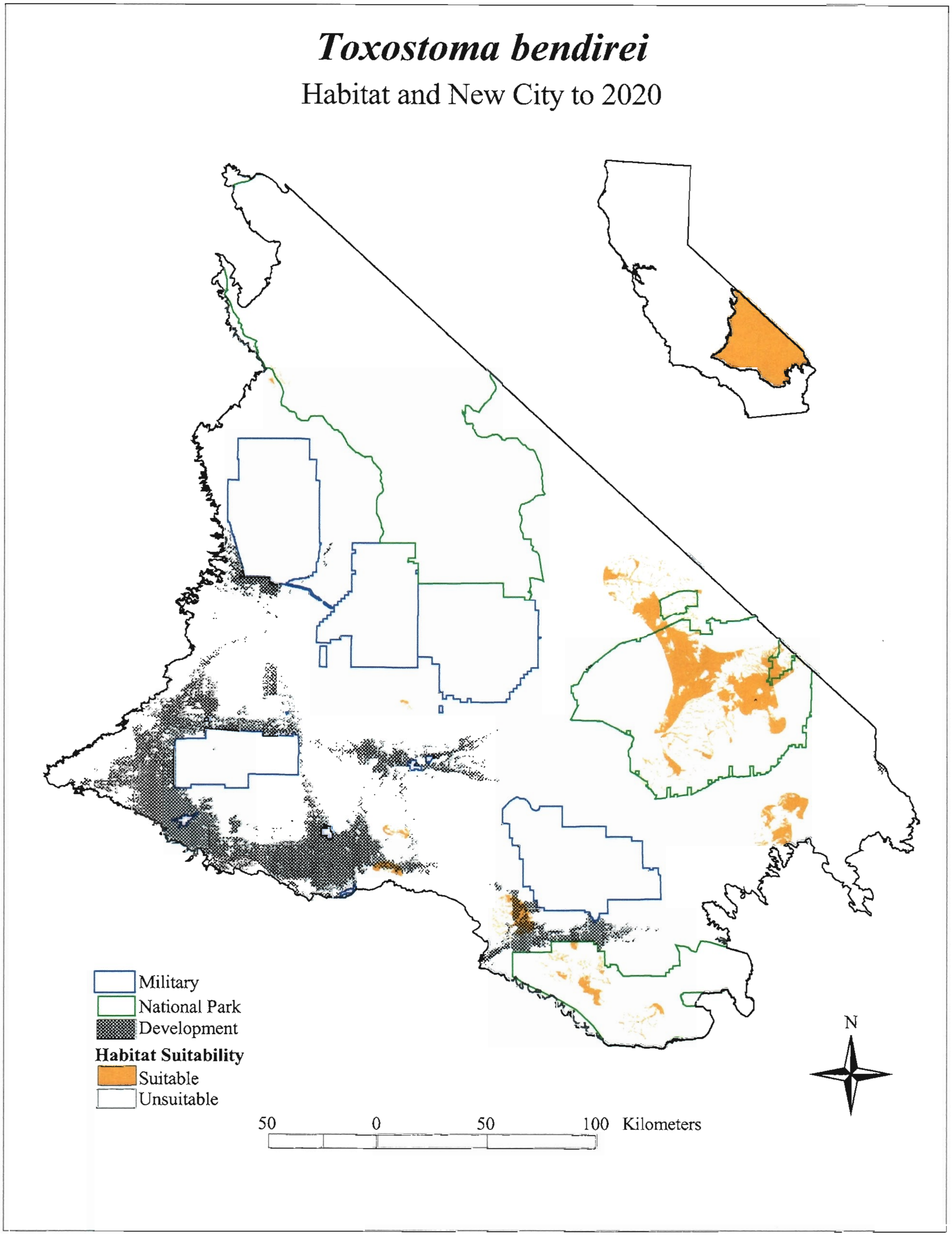
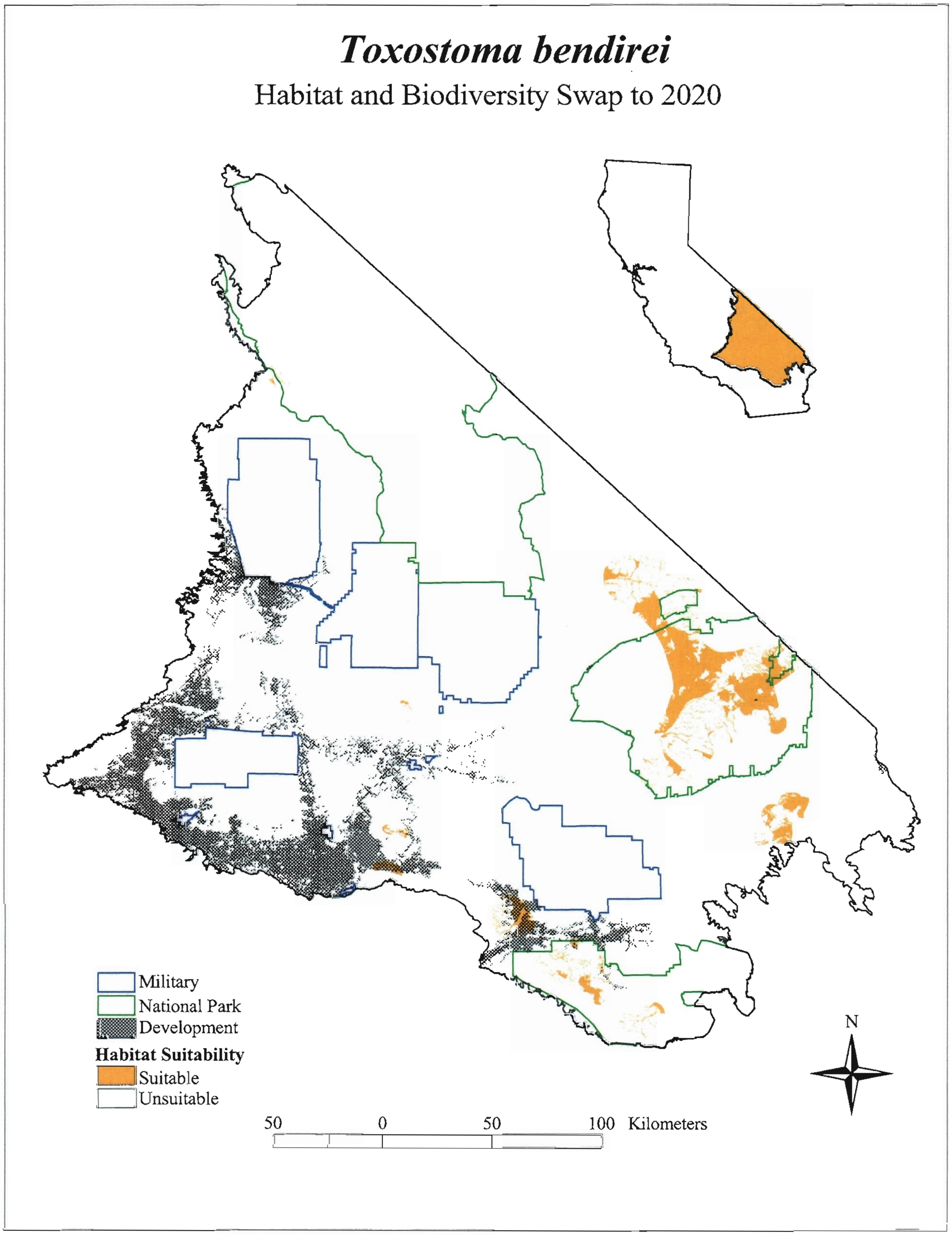


Figure 8.19. Distribution of *Toxostoma bendirei* (Bendire's Thrasher) habitat for the New City future.



*Toxostoma bendirei*

Habitat and Biodiversity Swap to 2020

Figure 8.20. Distribution of *Toxostoma bendirei* (Bendire's Thrasher) habitat for the Biodiversity Swap future.

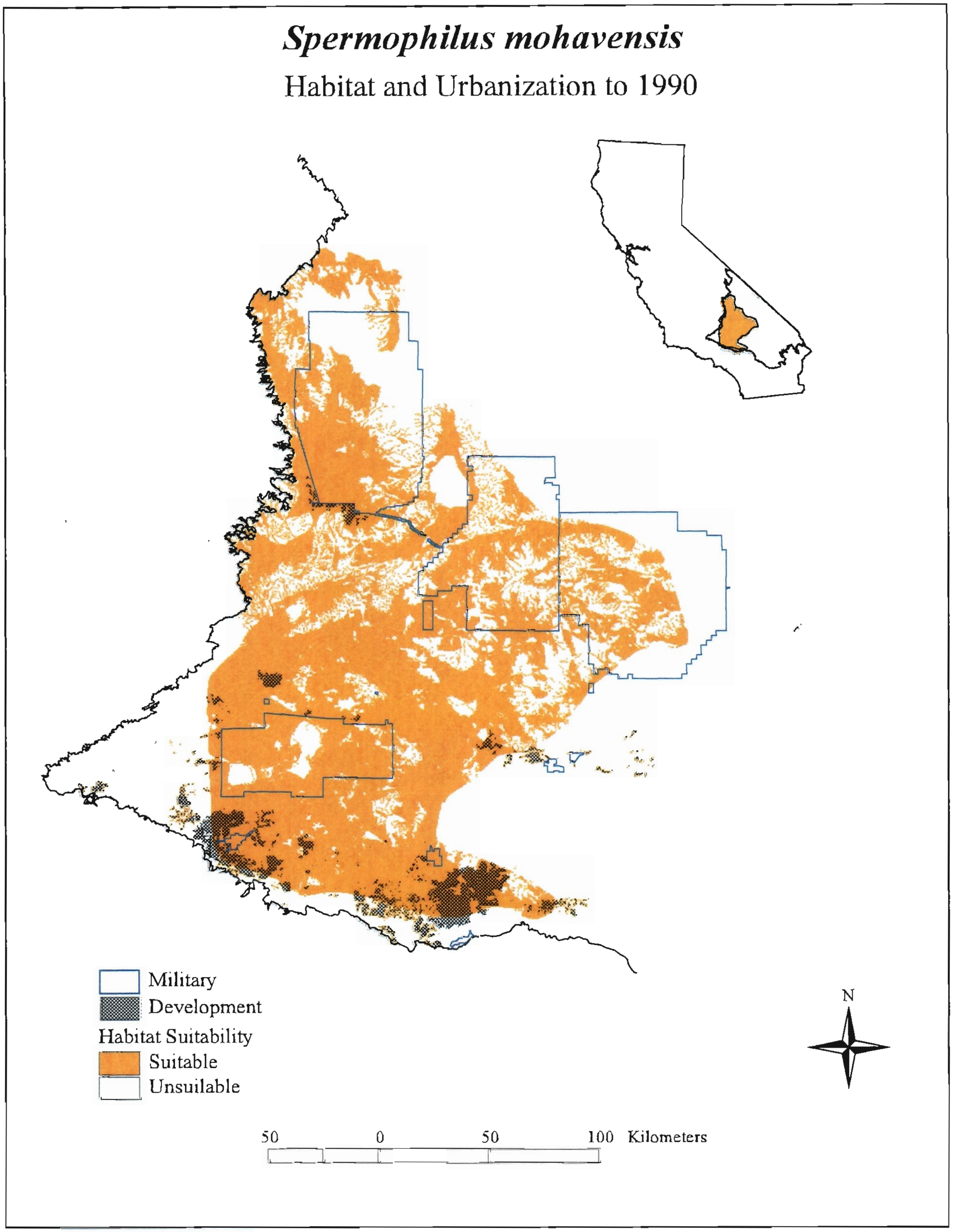


Figure 8.21. Distribution of *Spermophilus mohavensis* (Mohave Ground Squirrel) habitat for 1990.

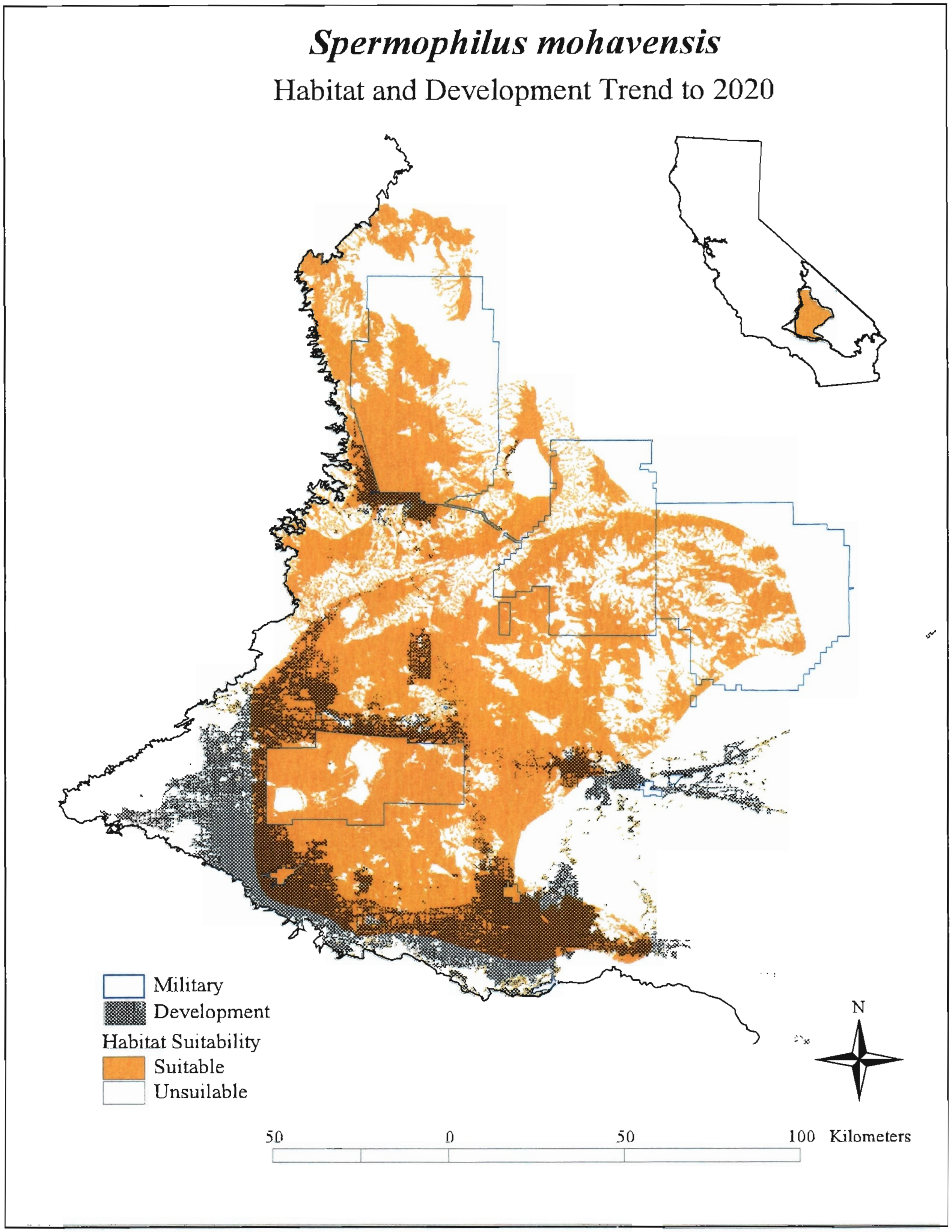


Figure 8.22. Distribution of *Spermophilus mohavensis* (Mohave Ground Squirrel) habitat for the Trend future.

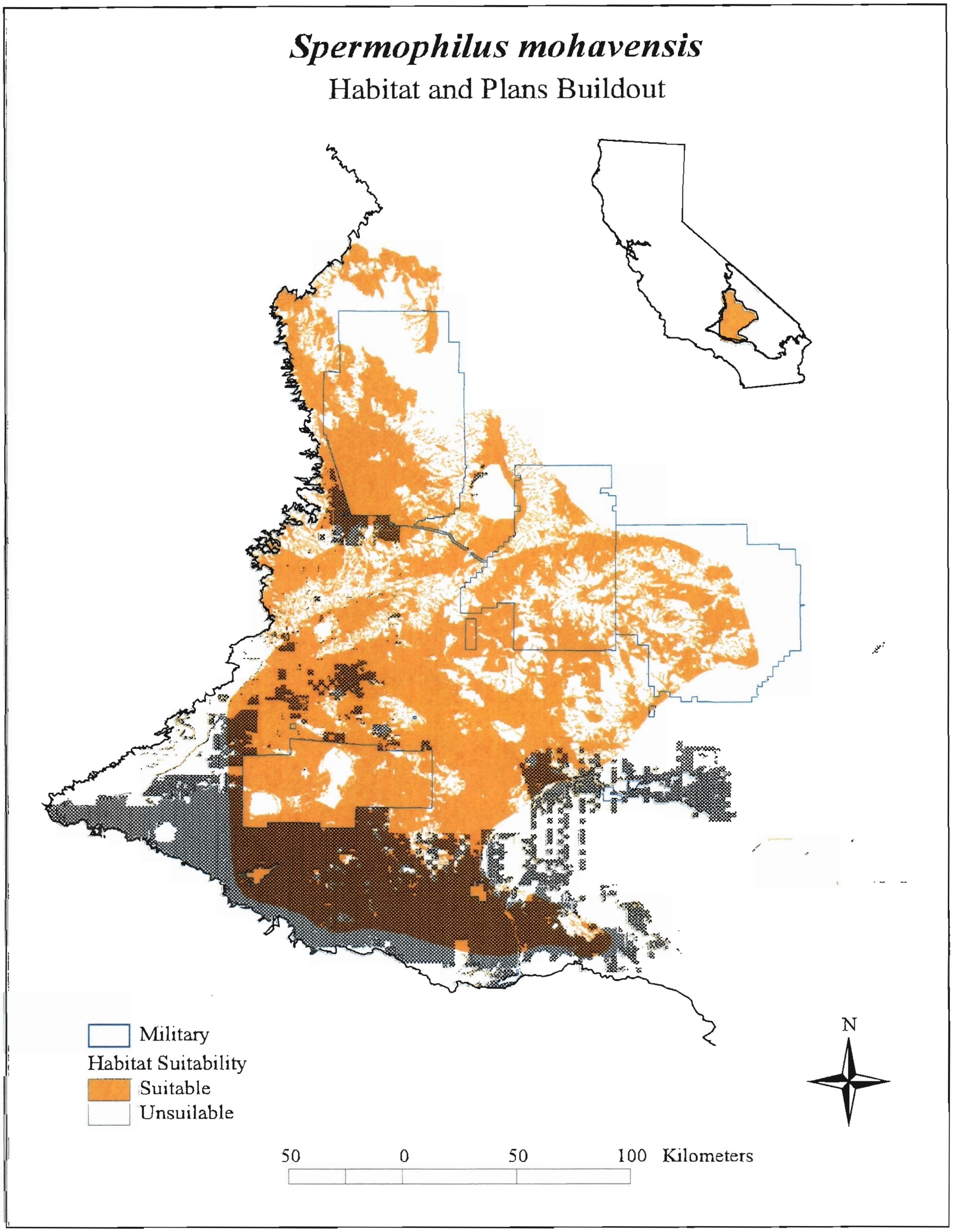


Figure 8.23. Distribution of *Spermophilus mohavensis* (Mohave Ground Squirrel) habitat for the Plans Build-out future.

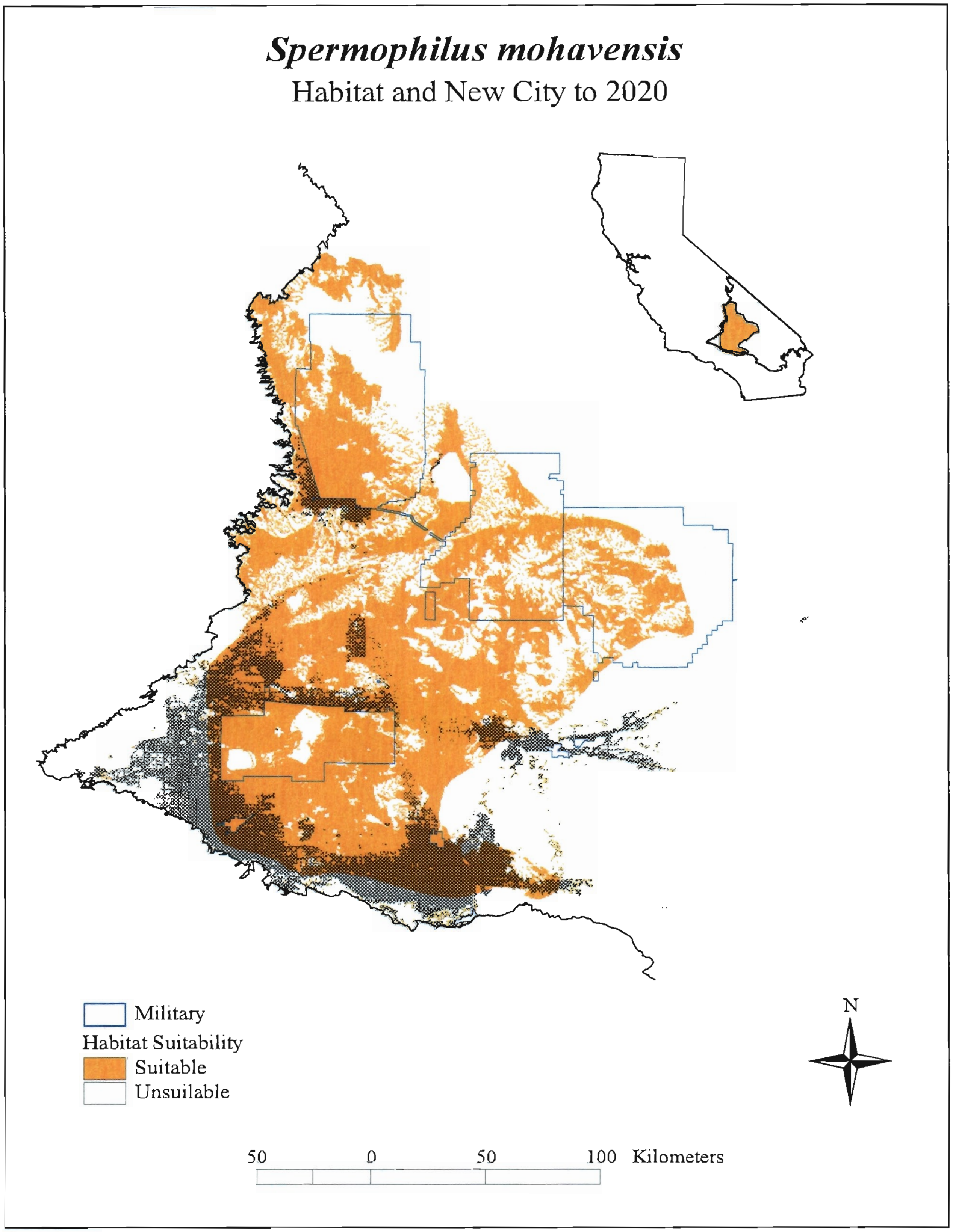


Figure 8.24. Distribution of *Spermophilus mohavensis* (Mohave Ground Squirrel) habitat for the New City future.

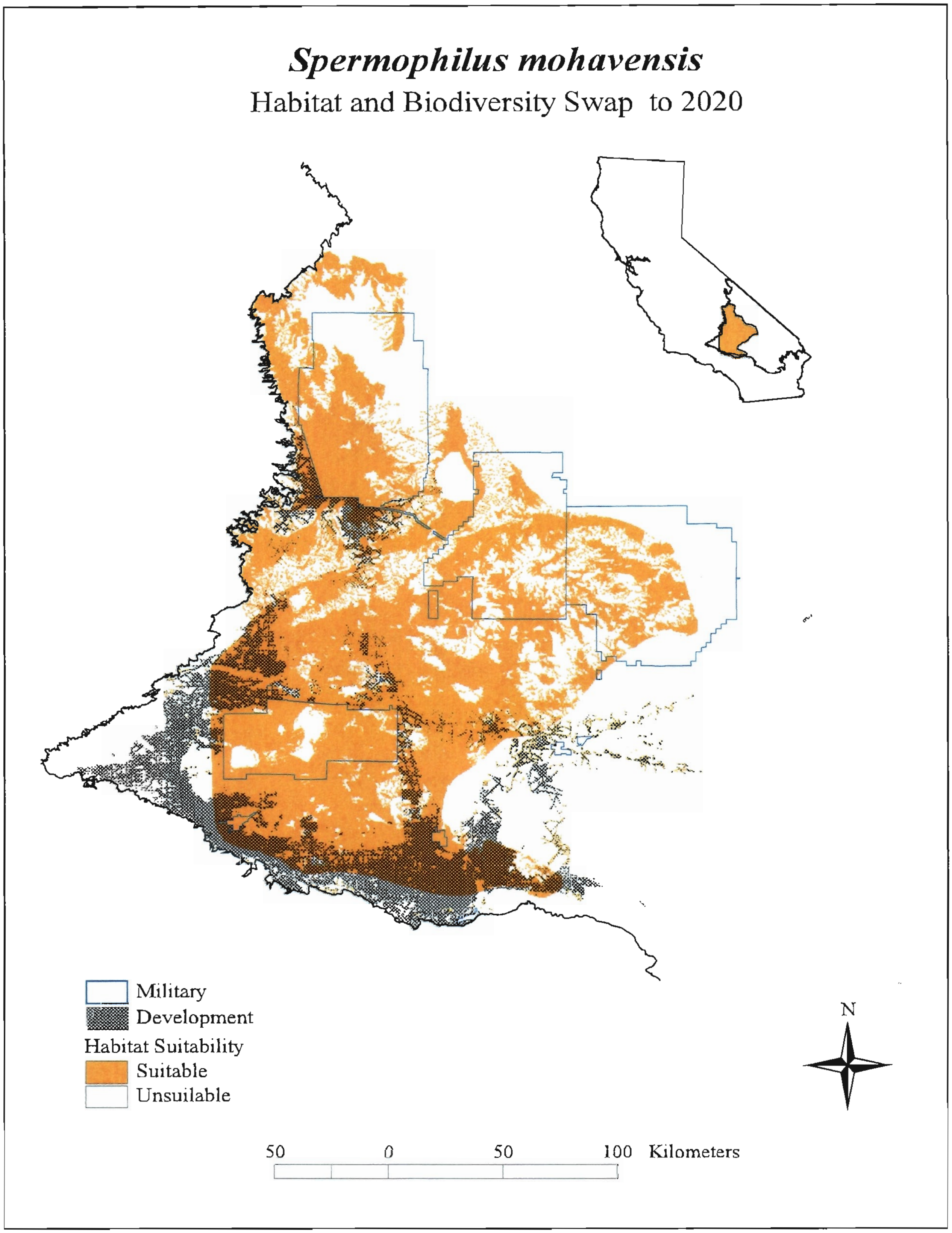


Figure 8.25. Distribution of *Spermophilus mohavensis* (Mohave Ground Squirrel) habitat for the Biodiversity Swap future.

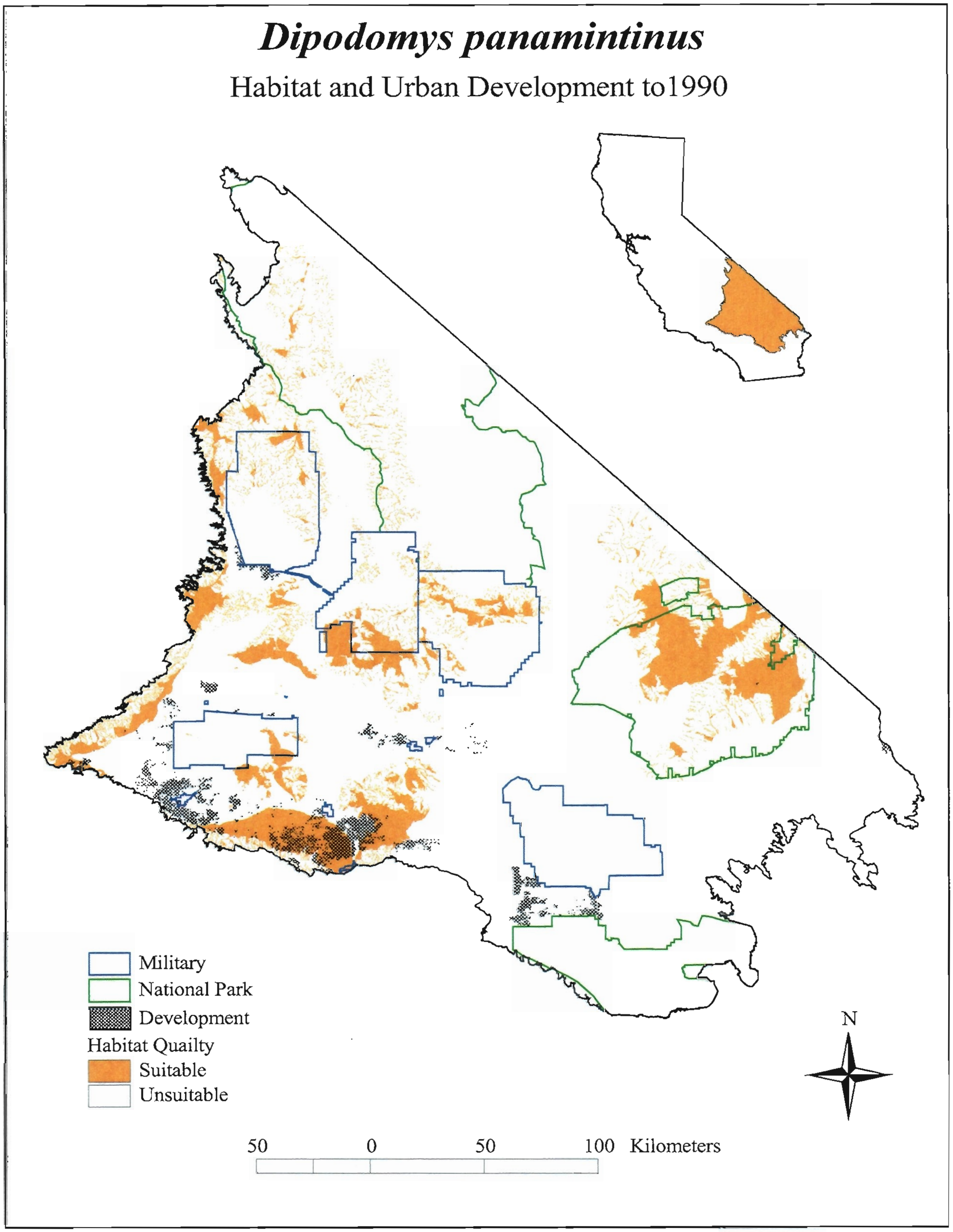


Figure 8.26. Distribution of *Dipodomys panamintinus* (Panamint Kangaroo Rat) habitat for 1990.

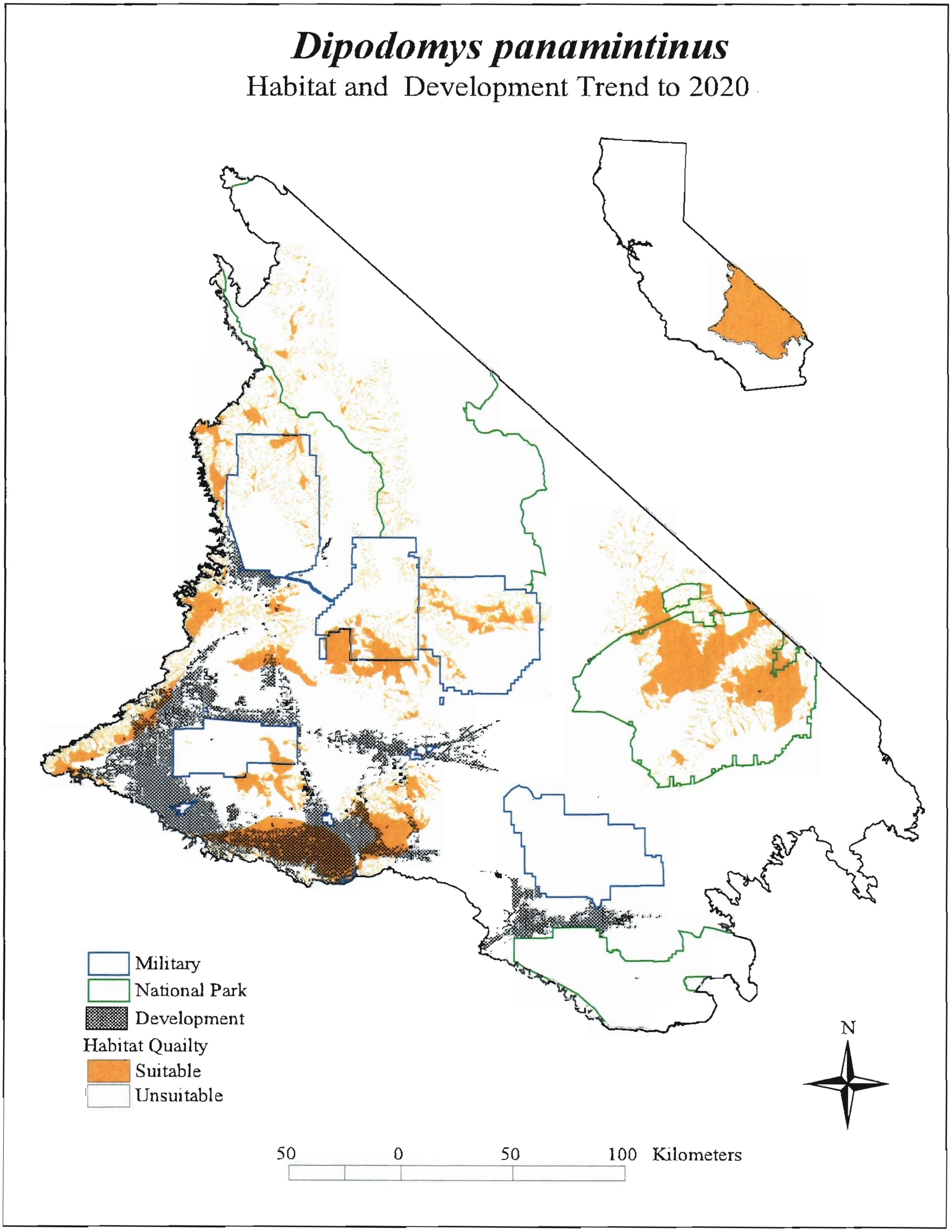


Figure 8.27. Distribution of *Dipodomys panamintinus* (Panamint Kangaroo Rat) habitat for the Trend future.

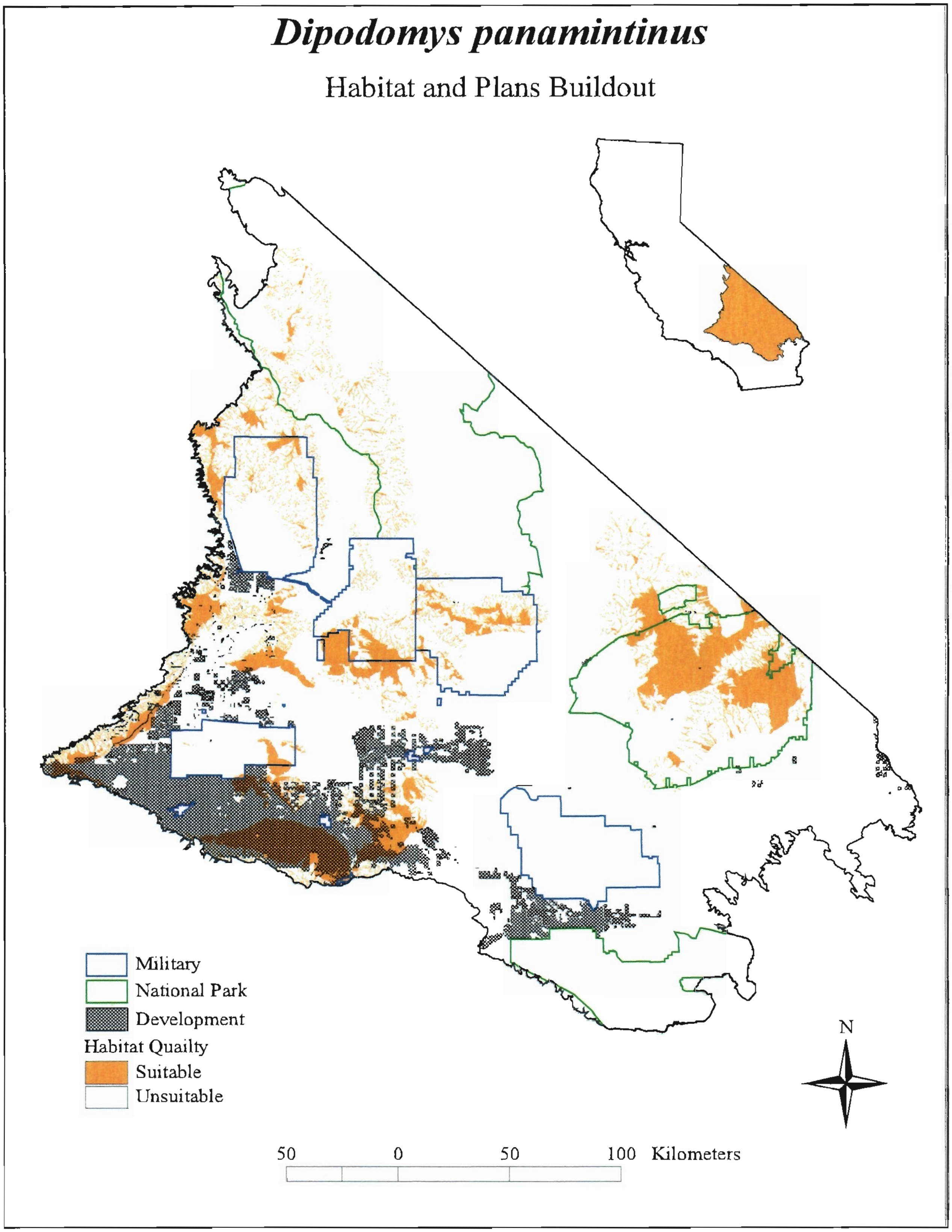


Figure 8.28. Distribution of *Dipodomys panamintinus* (Panamint Kangaroo Rat) habitat for the Plans Build-out future.

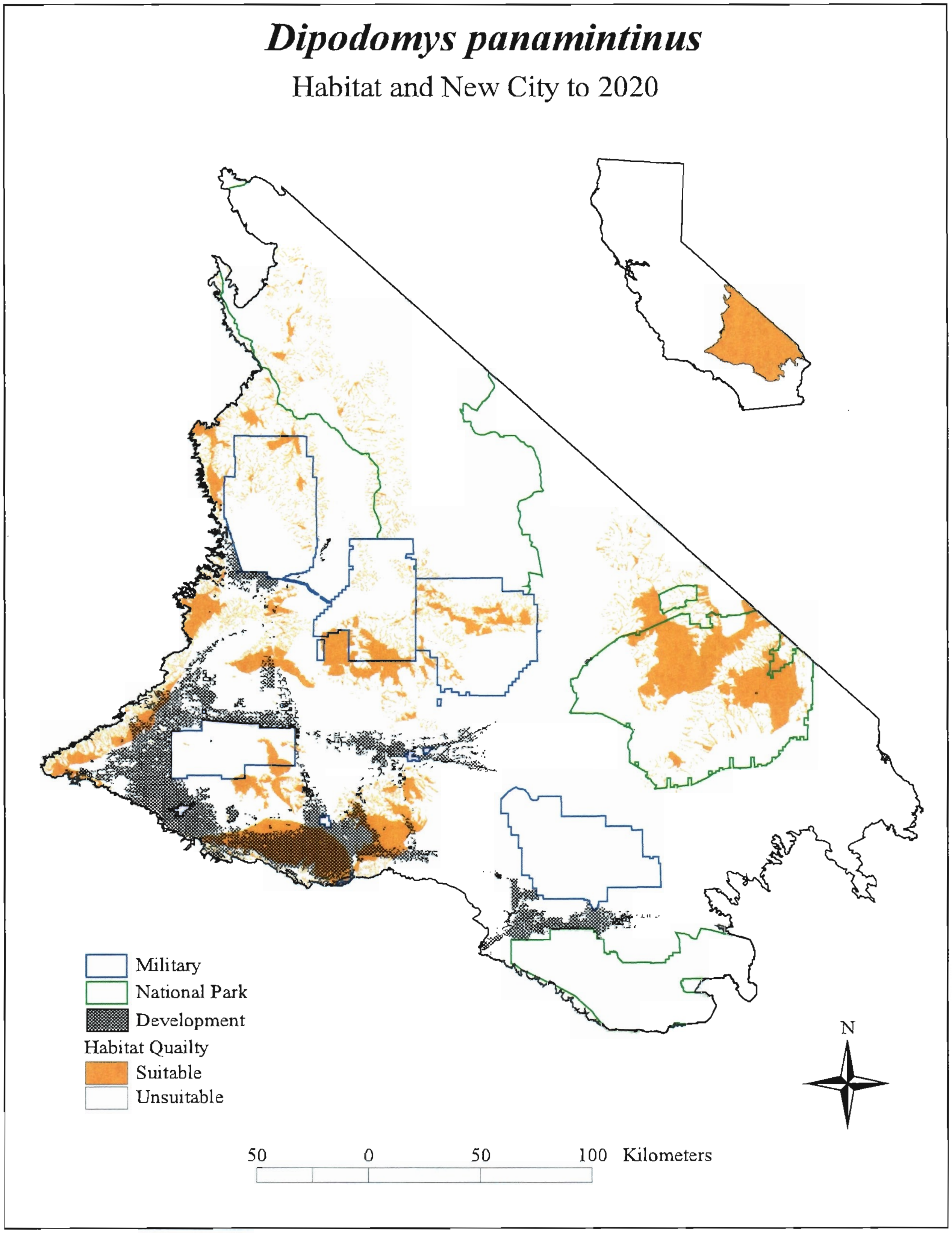


Figure 8.29. Distribution of *Dipodomys panamintinus* (Panamint Kangaroo Rat) habitat for the New City future.

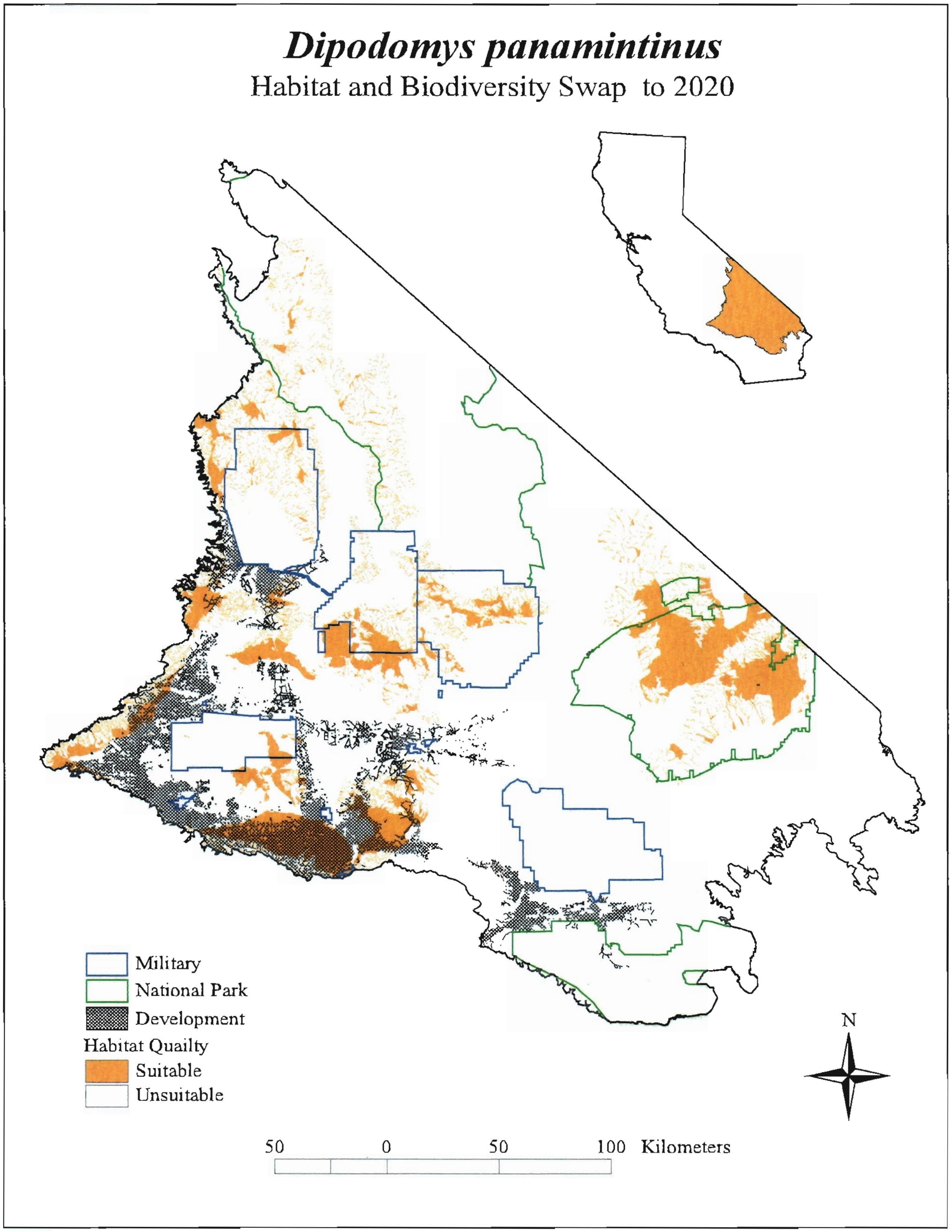


Figure 8.30. Distribution of *Dipodomys panamintinus* (Panamint Kangaroo Rat) habitat for the Biodiversity Swap future.

# Appendix J

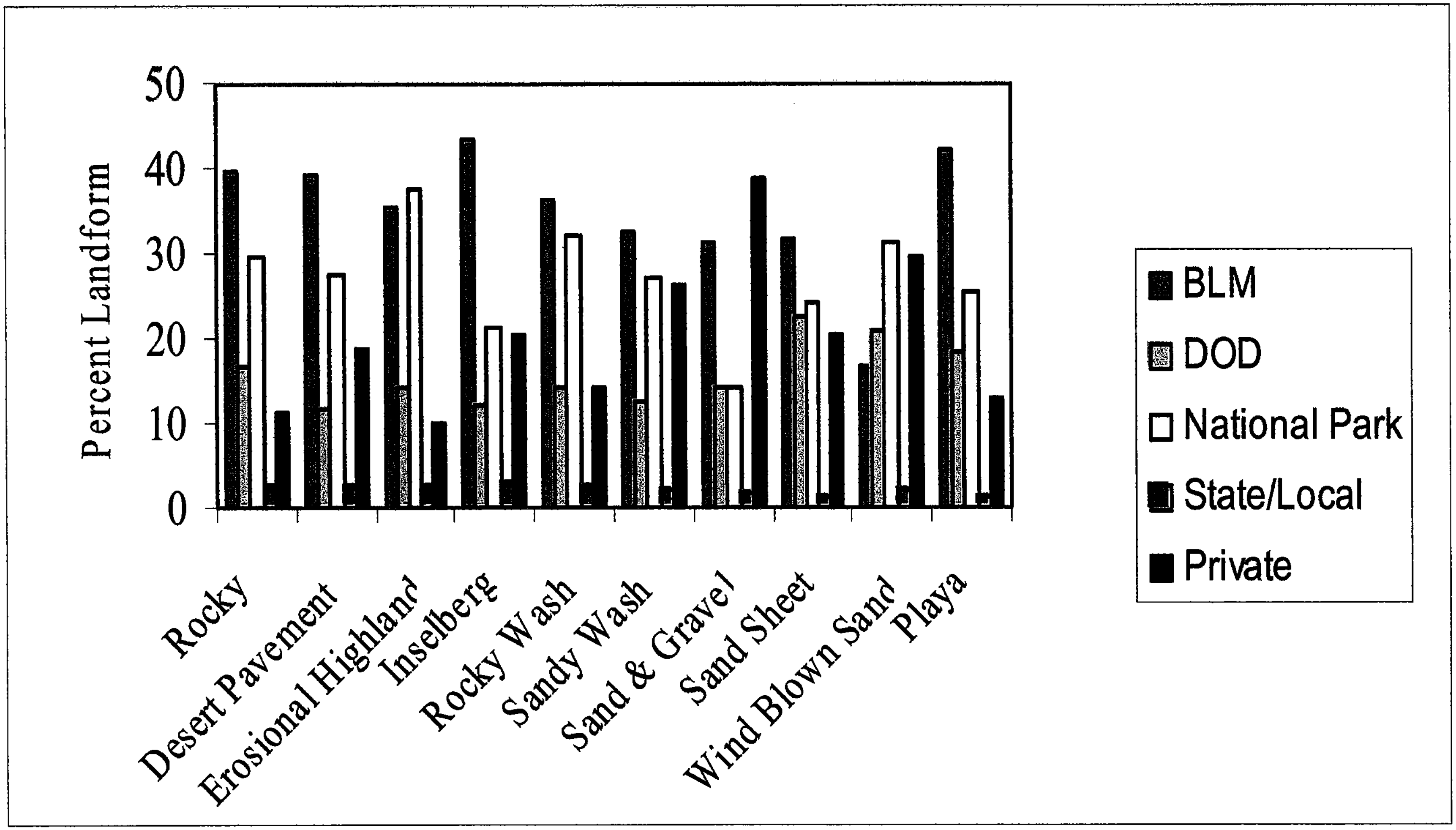


Figure 9.1. Relationship between land ownership and landform.