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What is the current status of the Mojave landscape relative to its ability to sustain biodiversity, particularlly native land vertibrates?

How has the landscape been altered by human activities? Which stressors have had significant impact on biodiversity and related environmental concerns?

How might the landscape be altered by the year 2020? What will the concomitant effects of a number of land use scenarios on biodiversity and related environmental concerns?

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Analysis and Assessment of Impacts on Biodiversity: A Framework for Environmental Management on DoD Lands within the California Mojave Desert: A Research Plan

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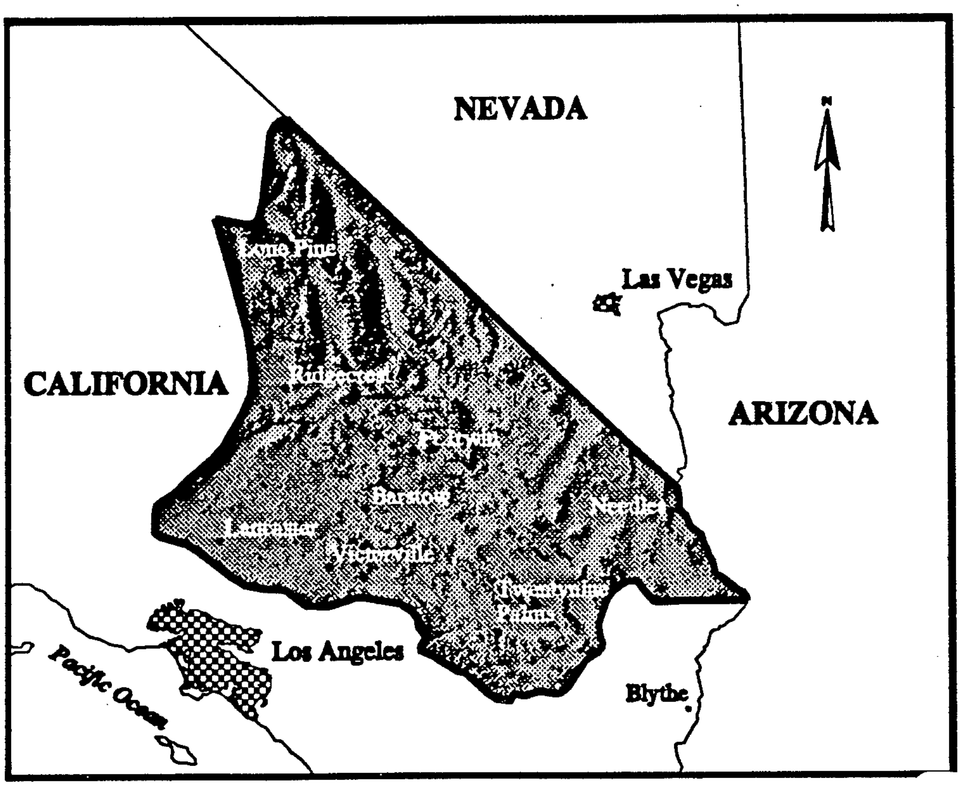

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NOTICE

1.0 Introduction

The Mojave Desert ecoregion (Hickman, 1993; Bailey, 1994) encompasses over 12 million hectares, covering large portions of southeastern California and southern Nevada and smaller areas within northwestern Arizona and southwestern Utah. The study area for this project is the California portion of the Mojave Desert (Figure 1). It is an area of extremes. The nation's lowest mean annual precipitation (35 mm annually) and highest temperature (57°C) occur within the region. Yet it often snows in the winter. It contains the lowest elevation in the Western Hemisphere, in Death Valley, but mountain ranges are ubiquitous, ranging up to 3350-m Telescope Peak. It's a high desert of dry lakes, sloping bajadas, sand dunes, young and old lava flows, cinder cones, and empty basins divided by abrupt, jagged mountains.

Figure 1. The Mojave Desert of California with prominent place names.

While the Mojave has been described by some as "scorched outback" or "the place that God forgot," it is home to about 2600 species of plants and animals. One fourth of its 2000 plant species are endemic to the region (Rowlands et al., 1982). Although diverse, both geologically and ecologically, 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," characterizing its future as: "[T]he 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, Figures 2 and 3). 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. 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	100

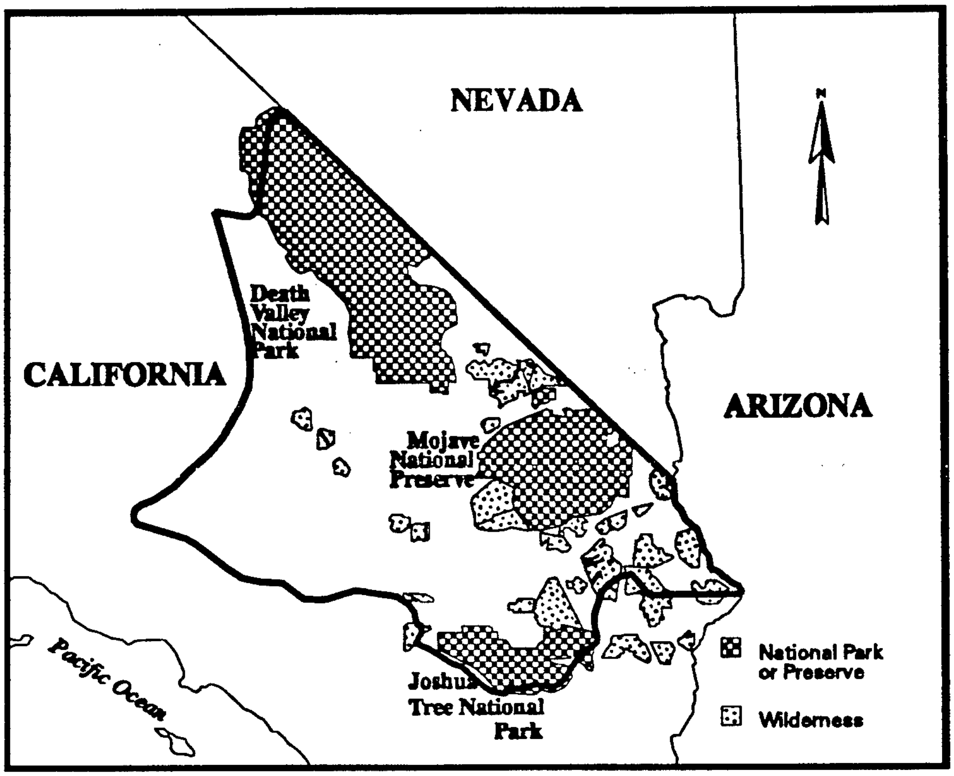


Figure 2. National Parks and Wilderness Areas with the California Mojave Desert.

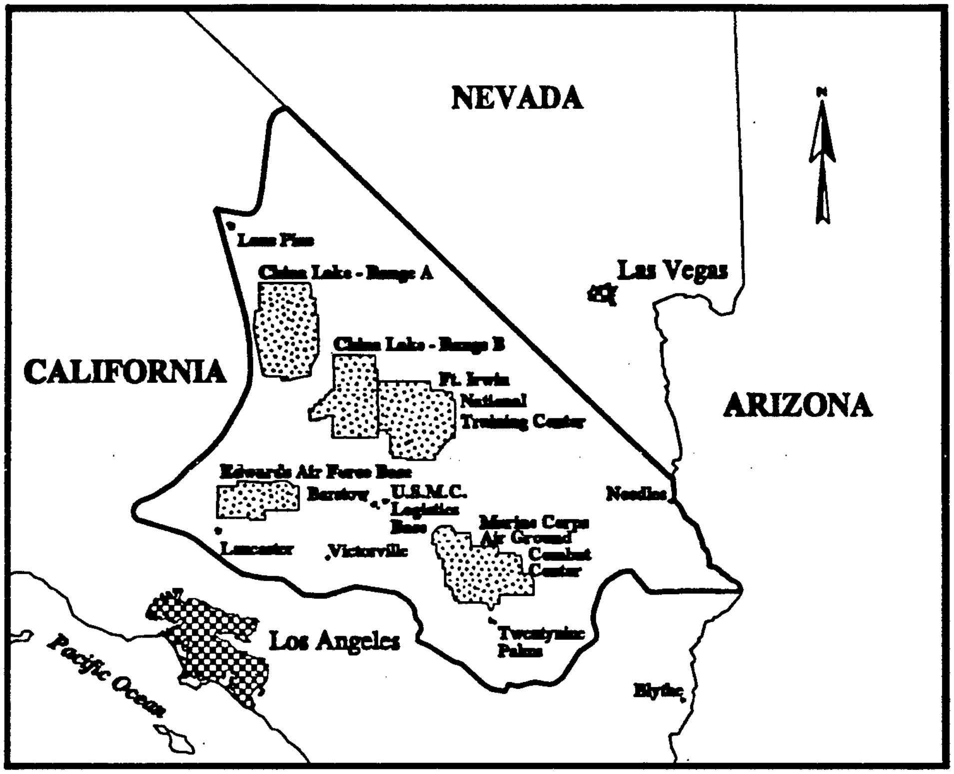


Figure 3. Military Installations within the California Mojave Desert.

1.1 Research Objectives

The purpose of the research proposed in this document is to evaluate the effects of human activities on biodiversity[1] and related environmental concerns within the Mojave ecoregion of California both at the present 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 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 will address the following major questions:

• What is the current status of the Mojave landscape relative to its ability to sustain biodiversity, in particular native terrestrial vertebrates?

• How has the landscape been altered by human activities? Which stressors have had significant impact on biodiversity and related environmental concerns?

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.

• How might the landscape be altered (by the year 2020)? What will be the concomitant effects of a number of land use scenarios on biodiversity and related environmental concerns?

We can re-state these questions in terms of specific research objectives:

• 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 using remote sensing, and assess the accuracy and precision of these landscape assessments.

• 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.

While the research will be 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.

The research described is being funded by the DoD as part of the Strategic Environmental Research and Development Program (SERDP). SERDP, established through the 1991 Defense Authorization Act, is a partnership among DoD, the Department of Energy (DOE), and U.S. Environmental Protection Agency (EPA) to address the environmental concerns of the DoD and DOE. This project was selected for funding via a competitive process and associated review by SERDP's external Science Advisory Board.

The DoD manages large portions of the Mojave region and actively uses these lands for training and testing considered critical to maintaining the nation's military readiness. Land holdings include Edwards Air Force Base, the China Lake Naval Weapons Center, Marine Corps Air Ground Combat Center at 29 Palms, Marine Corps Logistics Base (Barstow), and the U.S. Army's Fort Irwin National Training Center (Figure 3). The Mojave's flat, desert terrain and wide open spaces provide conditions ideal for military training and testing not available elsewhere in the U.S. As land development pressures increase, however, the potential for land use conflicts and biodiversity declines place additional constraints on military activities. The DoD has recognized that responsibility for large tracts of public land implies management of these lands for multiple missions and needs, including biodiversity. Thus, this research was funded specifically to achieve the following goal:

- Provide DoD with the information and analytical tools needed to effectively carry out its military mission in the context of regional management of biodiversity and related environmental concerns, and to consider these issues not only within the boundaries of military installations but also in the context of the surrounding stakeholders and the cultural and ecological resources they manage.

Thus, we are interested in the Mojave ecosystem overall, but with a special emphasis on the role and impacts of the military installations in the region. We have arbitrarily chosen the California-Nevada border as the eastern limit of the study area to make the study area of manageable size and still cover the context region of the California military bases.

1.2 Study Area

The study area for this research is the portion of the Mojave ecoregion occurring within the State of California, an area of nearly 74,000 km^2 (Figure 1). While the Mojave 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 (see Section 7). 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 objectives outlined in Section 1.1. The state line boundary is 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 are coordinating (in particular work conducted under the auspices of the MDEI and funded by DoD's Legacy Program; see Section 2) had previously selected the border as their eastern boundary for data collection.

We will characterize landscape condition and assess effects on biodiversity across the entire study area. However, we anticipate studying smaller areas, in closer proximity to the DoD military installations, in greater detail. These more detailed studies are described in Sections 3 and 4.

1.3 Organization of Research Plan

We begin, in Section 2, by providing additional background information on the natural history and human activities in the Mojave and on related research projects with which we will coordinate. Section 3 describes our proposed approach for characterizing the current landscape and how the landscape has, and may in the future, be altered by human activities. As noted earlier, the landscape analyses will focus specifically on those habitat and landscape features that are relevant to an assessment of biodiversity and species viability. Section 4 then describes our objectives and approach for assessing biodiversity responses to landscape change. Section 5 describes how the research on Biodiversity Response and Landscape Change will be integrated with stakeholder concerns to assess the effects of alternative land use strategies on biodiversity and related environmental concerns. We also emphasize in this section our approach to ensure that our results and analytical techniques will be readily available and useful to decision makers in the Mojave region. Section 6 presents the research management structure and Section 7 presents the budget. Section 8 presents a summary of our expected outputs and project schedule. Literature cited is listed in Section 9. Resumes for the two lead researchers are provided in Appendix A.

2.0 Background

2.1 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 wildland resource of extraordinary and inestimable value for this and future generations;
>
> (2) these desert wildlands display unique scenic, historical, archeological, environmental, ecological, wildlife, cultural, scientific, educational, and recreational values used and enjoyed by millions of Americans for hiking, camping, scientific study and scenic appreciation;
>
> (3) the public land resources of the California desert now face and are increasingly threatened by adverse pressures which would impair, dilute, and destroy, their public and natural values;

These values and concerns are the societal context for the work of this plan. All of society is intended to benefit by this plan.

However, in the California Mojave desert the U.S. Department of Defense is one of the major land owners and stakeholders in its future. The military bring to the Mojave Desert three major concerns of their own. 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 requires 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 their operations in conformance to 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 their concerns. This concern is especially important with regard to land use negotiations (Creswell, 1988).

2.2 Natural History of the Mojave Desert

The Mojave Desert as we know it today has resulted from the climate change brought about by 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 means that is consists of a series of sharply uplifted mountains with relatively flat basins between them. This geology and regional geomorphology are exposed with very little soil and vegetation to protect them. This in turn means that hydrologic and aeolian 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. These winds create both small scale patterns of erosion and large scale landscapes such as sand 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.

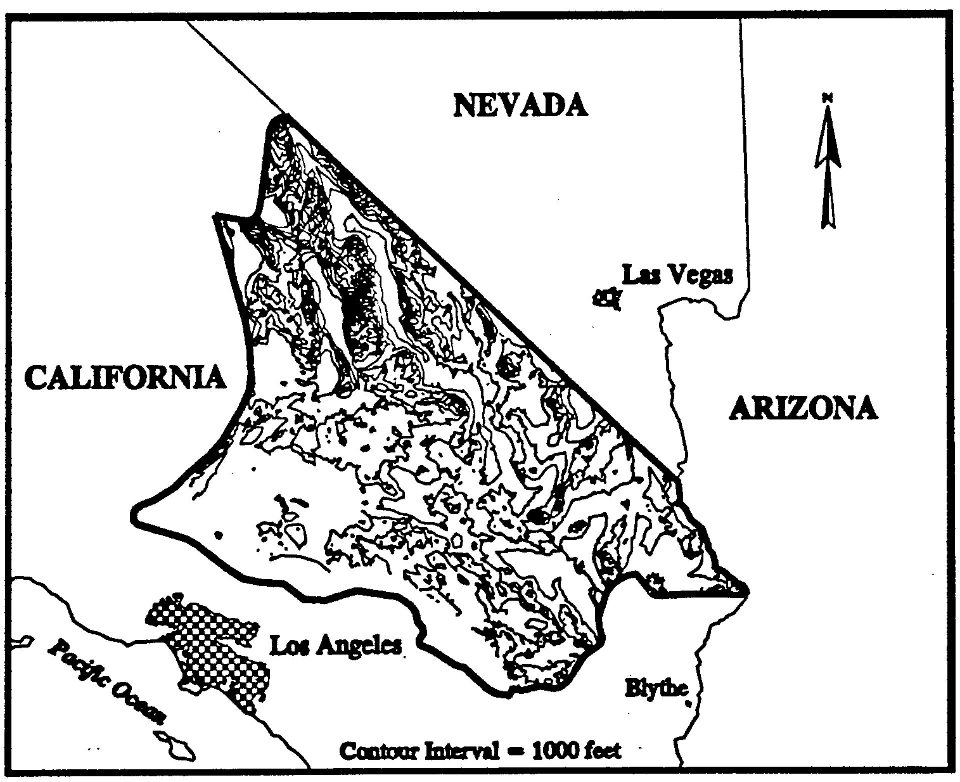


Figure 4. Topographic relief in the California Mojave Desert.

Given the harshness of the environment and its relatively young age, it is remarkable that the flora of the Mojave desert is estimated to be between 1750 and 2000 species (Rowlands et al., 1982). These include forms 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. Rowlands et al. (1982) review some eight systems with the numbers of classes ranging from 7 to 30. Some of the most important classes are Creosotebush Scrub, Sagebrush Scrub, Joshua Tree Woodland, and Pinyon-Juniper Woodland. Many of the vegetation types are restricted to 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 areas and springs. Perhaps creosotebush 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 desert (Vasek, 1980).

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. There are as many as 94 species of mammals, 211 species of resident birds, 38 species of reptiles, and 6 species of amphibians (Zeiner et al., 1988, 1990a, 1990b) for a total of 349 species. Invertebrates are less well-known, but number in the tens of thousands of species. For example, over 2000 species of ants are known from the Mojave Desert. Most of these species are known from only one collection. Our focus will be primarily on vertebrates. We will also focus more on those species endemic to or characteristic of the Mojave Desert.

A common procedure for studying the distribution of vertebrate species is to model species ranges through the use of a Wildlife Habitat Relations (WHR) model (Verner et al., 1986). This model essentially consists of a lookup table that associates each species with the set of mappable habitats that the species occurs in. These habitats are usually determined by dominant vegetation type. The California Wildlife Habitat Relations System maintained by the California State Department of Fish and Game is an example of such a system. Often the virtue of the WHR approach is that it can rely substantially on remote sensing to map the habitats, making it easy and relatively inexpensive to model species ranges (Scott et al., 1993). The problem presented by the Mojave Desert and the sparseness of its vegetation is then twofold. First, animals do not, in fact, match up very well with vegetation cover categories, and second remotely sensed images of the desert contain mostly rock or bare soil and not vegetation. These concerns have led to the development of a concept of habitat more germaine to the Mojave Desert. In this model, measures of small scale geomorphology, microterrain, surface lithography, and soil are used to create a structural classification of habitats which are then mapped onto animal species both directly and through a model of these strategic attributes to vegetation and then from vegetation to animal species. (see Figure 5 in Section 4).

To meet the extraordinary challenges of desert life, plant and animal species have evolved a marvelous series of adaptations (Rundel and Gibson, 1996). Indeed, it is these adaptations that constitute one of the great sources of fascination the we have for the desert. Understanding these special adaptations is crucial for any biodiversity planning. For example, many species of animals are dependent on burrows to retreat from lethal daytime temperatures. Any plan that did not consider these special aspects of the environment would be in-complete.

2.3 Human History of the Mojave Desert

2.3.1 Indigenous People

People appear to have been in the Mojave roughly since its inception 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 around 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 too 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.

2.3.2 American Civilians

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 some number of outlaws. 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 to occur these concerns led to the Desert Protection Act of 1994.

2.3.3 American Military

The American Military began operations in the Mojave Desert in the mid 19th Century to protect settlers and travellers from attacks by the Native Americans. Their presence continued and expanded as some of the largest military installations in the country were established there. 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). These lands gave the military room to maneuver, fire large naval guns, engage in aerial gunnery and bombing practice, and many other activities that are too dangerous to be done anywhere near 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.

2.4 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. The big difference is that 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 (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, 29 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 effects 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 of Edwards Air Force Base. However, a number of unique vegetation classes and plant species occur in these regions also 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 be 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 real grasslands are left. Cattle are therefore not dense, 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 to tend and round up the cattle.

Exotic species: The Mojave Desert is beset by a variety of exotic plant and animal species. Tumbleweeds (Russian thistle) are sometimes taken as emblematic of the desert, but, in fact, are introduced species. Several 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 BLM revolves around the difficult issues of managing these 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 even encourage, cross-country travel in 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 the most difficult management issue for BLM and the public. (BLM, 1980)

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

Water redirection: What little water naturally exists in the Mojave is the subject of intense management. In particular, the Mojave River itself has been subjected to numerous channelings and diversions. Wells in other parts have possibly 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 metals has been a major activity in the Mojave for nearly 150 years. Mining impacts include the extraction of minerals from dry lakes which alter the pattern of biodiversity that can appear in them during wet weather. Shaft 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, themselves an environmental issue due to the danger they are perceived to present. 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 that elsewhere. There is some evidence that noise from vehicles adversely affects some species. Noise from aircraft may also be a problem.

2.5 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 of 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 the reactive nature 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 to those generated by the civilian population. The infrastructure of bases and the usual activities of military personnel create environmental effects essentially the same way 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 part 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: Clouds of various kinds of obscurants are often generated as part of an intentional effort to conceal military activity. These clouds may have effects on the behavior of a variety of animals.

2.6 Past and Current Related Research in the Mojave Desert

The Mojave Desert has a long history of ecological research. Today the sheer number and magnitude of other ongoing research efforts is a major challenge for anyone seeking to do research there. All government agencies which control or manage land in the Mojave Desert, dozens of universities, and most major conservation organizations have research projects there. The Department of Defense has begun to integrate many of their projects under the Mojave Desert Ecosystem Initiative (MDEI) which is led by the Army out of Fort Irwin. Since 1991 the DoD's Legacy Resource Management Program has been actively working with many other agencies and organizations to characterize the resources of the Mojave. Many results and datasets are now available, often through the Mojave Ecosystem Database program (MEDP) also being managed by Fort Irwin. An important part of the initial work of this Plan will be to create a catalog of available data resources useful to the project and to access appropriate information.

With the listing of the Desert Tortoise as a Federally Threatened Species the amount of research on it exploded. The Desert Tortoise Recovery Team began working on a Draft Recovery Plan for the Fish and Wildlife Service. A development near Las Vegas funded much research overseen by The Nature Conservancy as part of its mitigation responsibilities. This work is reviewed in Section 4.1.1.

2.7 Biodiversity Research Consortium, SERDP, and EPA Research Background.

This plan draws heavily on previous work of the Biodiversity Research Consortium (Kiester et al., 1993) and the Environmental Protection Agency. In particular, it uses a methodology for the biodiversity assessment of alternative landscape and land use futures. This methodology was first applied in Monroe County, Pennsylvania (Steinitz et al., 1994; White et al., 1997). The basic idea is that possible choices that people may make about land use over time can be expressed in terms of the land cover at some time in the future that will result from those choices. These alternative choices are then evaluated for their impact on biodiversity through a series of models that relate species richness and viability through habitat requirements to land cover type and pattern. The alternative futures are either calculated or designed. Calculated futures can be built from synthesizing the implications of existing plans which are simply taken at their word. Designed futures are the result of a creative process by the designers which attempt to synthesize the issues with one or more ideas for their resolution. This method has also been applied to the Camp Pendleton study (Steinitz et al., 1996) and a study of the Muddy Creek Watershed of the Willamette Valley of Oregon (Freemark et al., 1996).

These studies form part of the work of the Biodiversity Research Consortium, a group of seven Federal Agencies, The Nature Conservancy, and eight Universities. The BRC was formed in response to the recognition that no single agency can effectively deal with biodiversity issues that transcend multiple political boundaries (Kiester et al., 1994). The BRC conducts research on policy relevant aspects of biodiversity at multiple scales (Kiester et al., 1994; White et al., in press). A key idea of the BRC which it shares with the GAP Analysis Program (Scott et al., 1993; Kiester et al., 1996) is that all species (usually of terrestrial vertebrates) are considered. That is, the focus is on biodiversity per se, rather than on any single species. This focus has two advantages. First, it allows statistical generalizations to be made about many species where the amount of information available for any one species is low. Second, it focuses management attention on protecting species before they become threatened or endangered which is a much more cost effective way to protect biodiversity since it is always less expensive to protect species when they are common or at least not rare (Scott et al., 1993).

3.0 Landscape Status and Change

Landscape: a heterogeneous land area composed of a cluster of interacting ecosystems that are repeated in similar form throughout (Forman and Godron, 1986). Landscape ecology explores how a heterogeneous combination of ecosystem attributes is structured, functions, and changes. From "natural" to urbanized patterns, its focus is on the distribution patterns of landscape elements in ecosystems, the flow of animal, plant, energy, and nutrients among those elements, and the ecological changes in the landscape mosaic over time (adapted from Forman and Godron, 1986). Each landscape element (or ecosystem) at the arbitrary scale (both spatial as well as temporal scale) of the given landscape can be recognized as either a patch with significant shape and size, a corridor connecting two or more patches, or the background matrix. Attributes of these elements such as animals, plants, energy, water, nutrients, etc., may be heterogeneously distributed within and among these landscape elements. Distribution of these attributes varies with shape, configuration, connectivity, and composition of the landscape elements themselves. Landscape structure is defined by the analysis of these distributions. Landscape function as a system is defined by the interactions between landscape elements and landscape attributes.

While landscapes can be observed and studied from many points of view, Forman and Godron's first principle provides a general and useful framework for understanding them: Landscapes are heterogeneous and differ structurally in the distribution of species, energy, and materials among the patches, corridors, and matrix present. Consequently, landscapes differ functionally in the flows of species, energy, and materials among these structural landscape elements (Forman and Godron, 1986).

Our approach to landscape analysis is derived partly from Steinitz (1990) and is based on parts of Steinitz et al. (1996). We will:

1. Describe the landscape within the Mojave Research Project primarily in terms of vegetation, terrain, and human land use.

2. Evaluate the present landscape by understanding the causes of ecosystem degradation and change due to both military and non-military stressors and by analyzing the patterns of landscape structure.

3. Create analytical tools for simultaneously describing and evaluating Alternative Future Scenarios. (We will also produce a specification for a decision support system to be built on these tools. See section 5.)

4. Create habitat classifications useful to modeling biodiversity response.

We will pay particular attention to characterizing patterns of landscape degradation (see Section 3.2.2). We will use several measures of degradation include presence or absence of rills, phytogenic mounding, aeolian deposition, litter, footpaths, vehicular tracks, changes in albedo and changes in vegetation. These variables will be used to assess and verify areas identified as changed in satellite imagery. Landscape pattern may be used to assess degradation spatially where metrics derived from a relatively undisturbed area will be compared to metrics derived from a region similar ecologically, but degraded. This type of comparison may be a critical component for assessing impacts on biodiversity. Degradation cannot be assumed *a priori* to have occurred given the status of any of these factors. But a weight of evidence as expressed by observations in a number of these will be considered to indicate degradation. Part of our research will be to evaluate just what should constitute that weight of evidence. Assessing actual degradation from satellite imagery will be done using standard change detection methods. This change detection will rely on spectral variation in multitemporal images. Changes in condition on the landscape will be related in variations in spectral properties resulting in unique signatures over multiple dates of imagery. Imagery from 1972-1974, 1984-1986, and 1994-1996 will be used in this assessment. A major research problem will be to determine if there are threshold effects and other non-linearities in the relationship between amount of degradation and its impact.

3.1 Describe the Landscape.

The present status of the California Mojave Desert landscape will be described in terms of three major aspects that affect biodiversity: 1) vegetation, 2) terrain, and 3) land use. While there are additional attributes which could be included, these three taken together provide an inclusive picture of the landscape and can reflect changes which affect biodiversity. The physical characteristics of the landscape, such as vegetation and terrain features, will have sufficient spatial and thematic detail for an ecologically meaningful assessment to be used in the biodiversity response component of this project.

As with many definitive studies of landscape ecology, work will be undertaken at multiple spatial scales. The landscape will be characterized at a broad scale (1:120,000) for regional assessments, i.e., for the entire California Mojave Desert, and at a finer scale (1:24,000) for detailed habitat analysis. Table 2 presents some of the remotely sensed data that will be available for the project and gives an overview of the spatial resolution of each sensor as well as other general characteristics.

Evaluating the current status of the Mojave landscape will rely heavily on work currently being supported by DoD's Legacy Program through its Mojave Desert Ecosystem Initiative (MDEI; the MDEI will become the Mojave Ecosystem Database Program, MEDP, at the end of FY97). Current spatially-referenced Legacy projects in the Mojave include:

- Mojave Desert Vegetation Mapping Program
- Mojave Desert Terrain Analysis Database
- Mojave Desert Historical Resources Geographic Information System
- Mojave Desert Georeferenced Bibliographic Database

Our efforts in describing the landscape will involve synthesis and integration of existing data and new data being made available by these programs. We will also map, analyze, and assess land use, landscape pattern, and ecoregion degradation.

3.1.1 Map Vegetation.

The vegetation of the Mojave Desert has already been mapped by the California Wildlife Habitat Relations Program (Mayer and Laudenslayer, 1988) and by the California GAP Analysis Program (Thomas and Davis, 1996). Figure 5 shows the current GAP vegetation map. While the GAP vegetation map is a clear improvement on the WHR map with regard to both resolution and reliability (Thomas, 1996), ongoing work will result in a map with higher spatial resolution and with vegetation classified to the series level categories of Sawyer and Keeler-Wolf (1995). This new map will in turn enable higher resolution habitat modeling for vertebrates.

The vegetation of most of the California Mojave Desert is now being mapped anew by the Biological Resources Division (BRD) of the USGS, funded through the DoD Legacy program. This program will rely on 1:32,000 scale natural color high altitude photography in a 9" X 18" format flown by NASA in May of 1997. The mapping project integrates work conducted by the California Natural Heritage Program (operating within California's Department of Fish and Game) and other vegetation assessment projects. Dr. Kathryn Thomas, architect of much of the California GAP vegetation mapping work in the Mojave, is a co-Principal Investigator of the USGS BRD effort to produce the more detailed vegetation mapping project funded by DoD's Legacy program and supported by this project.Vegetation will be mapped at the alliance or series level (Sawyer and Keeler-Wolf, 1995) through the use of air photo interpretation of the 1:32,000 scale imagery augmented with an environmental model of predicted vegetation. A key element of the vegetation assessment relies on vegetation terrain modeling (Mouat, 1974). This involves determining vegetation terrain relationships, assessing the terrain through photo interpretation, existing soils, geomorphic, and topographic information, and predicting the resulting vegetation. USGS Digital Orthophotoquads (DOQs) will be used as the database for storage and rectification of the maps produced either through direct photo interpretation, or indirectly through terrain modeling. Where DOQs are not available, interpretations will be incorporated into Thematic Mapper Simulator imagery. Our SERDP investigation will work closely with the BRD work to ensure that spatial and thematic detail are adequate for habitat assessment. Vegetation information is of critical importance to the research. It will provide one of two key inputs into the assessment of wildlife habitat relationships (Section 4). The intensity of vegetation assessment (mapping and classification) will vary with the needs of the Biodiversity Response Team (Section 4). Vegetation associated with focal species in the focal transects (see Section 4) will be analyzed and assessed in greater detail than will the vegetation mapped and classified for the remainder of the Mojave. In order to intensify the effort (i.e., providing information at a 1 Ha resolution compared with the general mapping effort at 10 Ha resolution), the project will work with BRD to intensify those key areas. Their precise boundaries will be determined as information on focal species becomes clearer. More detailed vegetation information will be available to the project in mid-1998. The vegetation mapping project is not duplicative of our SERDP investigation, but rather is an input to it. We are coordinating work performed by the USGS BRD to ensure that its spatial and thematic detail is adequate for input into our habitat models.

3.1.2 Map Terrain.

Abiotic surface features play a much greater role in the assessment of habitat in arid areas such as in the California Mojave Desert than they do in other ecoregions. For some species, such as lizards and many small mammals, terrain information is the primary habitat determinant. Terrain features including erosional and depositional landforms, surface texture, structure and salinity, slope angle and aspect, elevation, surface lithology, and surface microtopography all combine to strongly influence habitat in the Mojave. A Terrain Mapping Project is being sponsored by the Legacy Program through the MDEI. This project will involve mapping of much of the terrain features mentioned at a fine level of classification developed by the U.S. Army Topographic Engineering Center. This effort will be coordinated with our project so as to ensure that appropriate terrain information is provided for both habitat and other landscape assessments. We will crosswalk surface lithology and geomorphic units with potential for land degradation in order to assess abiotic effects of stressors on habitat.

The Legacy Terrain Mapping effort will be accomplished by the U.S. Army Topographic Engineering Center in Fort Belvoir, Virginia, and Louisiana State University. This work will be accomplished through the analysis of Landsat Thematic Mapper, field verification, USGS topographic quadrangles, and other published maps and reports.

Additional terrain information will be acquired by the Landscape Team to provide a topographic data base within the Geographic Information System developed through the efforts of the Integration Team (Section 5). The Digital Elevation Models (DEMs) will provide key information toward the development of Wildlife Habitat Relationship models.

3.1.3 Map Land Use.

Landscape pattern can result from natural processes (i.e. climate, natural disturbance, other stochastic events) or directly and indirectly from human land use (i.e. urbanization, agriculture, recreation, etc.). Human-related patterns can be mapped just as 'natural' patterns are mapped. The patterns of human use on the landscape will be mapped using data from the County Governments, the BLM, the National Park Service, Landsat satellite imagery, aerial photography, and each of the military installations. As with the Camp Pendleton study (Steinitz et al., 1996) our primary job will be to create a consistent classification of land use categories across the entire study area. The final list of land use categories will be determined in consultation with other researchers and stakeholders. These categories will also be the ones available for the description of the Alternative Future Scenarios (Section 5). We will synthesize and integrate existing data, specifically Landsat satellite imagery, aerial photography, land use records and other existing data to create a current land use status map having a minimum mapping unit size of 1 Ha. This map will be input into the project GIS. This land use map will be the basis for analysis of current landscape condition and assessment of future changes as they relate to impacts on biodiversity. The structure and function of the Mojave Desert system may change significantly due to human related activities. Spatial representation of human related landscape pattern, and a supporting database, are fundamental elements for analysis of these changes. Consistency in this land use map is imperative to relate land use patterns with biodiversity across the entire Mojave study area.

3.2 Evaluate the Landscape

Having described the landscape we now ask following Steinitz (1990): How well is the landscape functioning? In particular, we seek to understand how the landscape has recently (the past 25 to 100 years) evolved in response to the anthropogenic stressors described in Section 2. We are also specifically concerned with the sensitivity and vulnerability of the system, and with the ability of the system to recover from adverse impacts. Research in the Mojave has shown that the landscape has been degraded by a wide variety of factors. These include mining, grazing, off-road recreational vehicle use, the introduction of exotic species, military testing and training, agriculture, development, and water diversion. Research in the United States, South Africa, Australia and elsewhere suggests that long term degradation results in a concomitant loss of diversity and productivity (Milton et al., 1994). A conceptual model of arid ecosystem degradation shows a change in the spatial and temporal arrangement of water, nitrogen, and other soil resources from a homogeneous to a heterogeneous redistribution of those nutrients (Schlesinger, et al., 1990). Severely degraded arid ecosystems may not return to their original state even when allowed to recover for decades (Westoby et al., 1989). We are concerned with both the short term and long term effects of current and future stressors on the Mojave Desert ecosystem and on the ability of the ecosystem to recover from these impacts. Specifically we are concerned with the sensitivity and vulnerability of the system and with the system's ability to recover from adverse perturbations. Our research seeks to provide an analysis of the effects of these stressors on patterns of biodiversity and related environmental issues of the region and in more detailed analyses.

We will evaluate the landscape in terms of its biodiversity potential by addressing two kinds of questions.

1. What are the patterns of land use and land cover across the landscape? By pattern we mean that pattern of connectedness and patch size of all of the categories of the landscape (Forman and Godron, 1986).

2. What can we say about the quality of the landscape in terms of degradation and what is the likelihood for recovery from negative impacts?

Historic records compiled by the State of California and available there as well as through other sources (e.g., universities, archives of government agencies such as the BLM, historical libraries, literature reviews) will provide a baseline picture of the Mojave at the time of European incursion (essentially, mid- 19th century). This information will be integrated with more recent mapping projects and a land use inventory we will produce based on 1970 high altitude photography available from the NASA Ames Research Center and from 1972 Landsat Multispectral Scanner (MSS) imagery. This will result in a 1970/72 land use map, produced at a 1 hectare resolution cell. Land use classes will include mining, transportation, agriculture, water, and urban development. Other land cover classes will come from those developed by the vegetation and terrain mapping efforts. A second land use map will be compiled using 1997 Landsat TM imagery and 1997 high altitude aerial photography using the same resolution cell and classes. Techniques for the generation of these maps are briefly described below. Analysis of the maps will allow us assess changes in landscape disturbance regimes as related to species habitat requirements in order to assess effects of stressors on biodiversity.

We know that the effects of abandoned agriculture, overgrazing, and mining in the past still have a profound affect on the present-day landscape and that recovery has been slow. Exacerbated by those historical activities has been an acceleration in the effects of more recent stressors on the landscape. We will compile and synthesize information from the georeferenced bibliographic database (Utah State University) and other sources on military and non-military stressors, including land use, water use changes, off-road vehicle use (both military and recreation), grazing, mining, and other, and evaluate and model the impacts of these stressors on landscape indicators of biodiversity. The latter will include surface soil condition, soil moisture, vegetation, and landscape pattern. The primary impacts of these stressors are through changes of the soil surface, especially through the effects of grazing and off-road vehicle use and in fragmentation of the landscape through changes in vegetation, transportation (including off-road vehicle use) networks, agriculture, and urbanization.

We will use the high resolution 1:32,000 aerial photographs acquired in FY97 by NASA along with Landsat Thematic Mapper imagery validated by field verification to assess the degree to which these stressors are responsible for landscape degradation. Two principal methods will be used to assess the degree to which these stressors are impacting the landscape leading to degradation. The first involves direct vegetation and terrain assessment as conducted by those teams (i.e., the vegetation mapping and terrain mapping teams). The scientists who are leading those efforts will assess the degree to which the present landscape, as evidenced in their mapping efforts has led to degradation. Changes of vegetation species composition and cover (toward less cover and a higher percentage of exotic species), removal of surface soil horizons, and increases in aeolian activity, are examples of evidence leading toward degradation. The second involves comparing vegetation types and soil surface condition occurring in homogeneous terrain assemblages (areas where the ecological potential as evidenced by similarities in terrain characteristics is relatively similar). Where, for example, grazing history can be seen to have influenced a vegetation type such that an area with little historical grazing has not appreciable changed while an adjacent area (within the homogeneous landscape element) shows deleterious vegetation change, we might assume that degradation change. The question then to be asked is "what effects do these changes have on biodiversity?" This question will be addressed in Section 4. We will examine broad scale terrain assemblages across the study area for evidence of these stressor-degradation relationships. Results will be incorporated within our GIS base containing the vegetation and terrain data bases.

High Altitude aerial photography acquired by NASA in May 1997 will be used for the vegetation mapping component. This imagery will be acquired by the Landscape Team for several purposes including providing field verification of land use mapping. Land Use will be mapped using Landsat Thematic Mapper imagery acquired by the Legacy Terrain Mapping Team for purposes of timeliness. It is anticipated that the TM imagery will come from the period 1994-1997. Our approach will employ an interactive supervised classification. This approach will make use of the analysts' field knowledge (verified by aerial photography) to provide training site identification as will as direct interpretation. Standard classification algorithms available (see, for example, Mouat et al., 1993 and Mouat and Lancaster, 1996) will be used in the land use mapping. Only urban and suburban development, agriculture, and mining will be mapped. Outputs will be incorporated within the Project GIS. Likewise, existing Landsat MultiSpectral Scanner imagery available for the California Mojave in 1972 (and supported by 1972 NASA aerial photography) will be used to provide an historical picture. Again, standard land use/land cover mapping techniques will be used. These assessments will be integrated with the biodiversity response team to evaluate the degree to which these changes have affected and are affecting patterns of biodiversity.

3.2.1 Assess Landscape Pattern

The major current hypothesis in landscape ecology is that measures of landscape pattern effectively capture enough of the functioning of the landscape to allow statistics derived from those patterns to estimate the richness of the biodiversity that the landscape can support. There is both support for and criticism of the hypothesis in the literature (Forman, 1995; Schumacher, 1996). If the hypothesis is true, the relative ease with which landscape pattern statistics can be calculated makes landscape pattern analysis an effective alternative to more detailed analysis of sets of species. As in the Camp Pendleton study (Steinitz et al., 1996), we will evaluate patch size distributions, connectedness, and corridors of the habitat types that are created through the combination of vegetation, terrain, and land use.

Spatial pattern is a measure of the distribution of individuals, groups of individuals, or resources across a landscape. While pattern can be regular, it is more often the manifestation of irregular distributions, or heterogeneity. Legendre and Fortin (1989) state, "The spatial heterogeneity of populations and communities plays a central role in many ecological theories, for instance the theories of succession, adaptation, maintenance of species diversity, community stability, competition, predator-prey interactions, parasitism, epidemics, and other natural catastrophes, ergoclines, and so on." Landscape patterns modify processes that regulate landscape structure (Milne, 1990). The result of process-pattern interactions are landscape mosaics of natural and human-related components. The composition and configuration of these components impact ecosystem function which influences or directly affects the attributes of those landscape elements. We are interested in the process-pattern relationships between the components of the Mojave Desert, and elements and attributes thereof, and stressors. The hypothesis is that in the wake of anthropogenic stress, landscape patterns of the Mojave Desert ecosystem will face serious alteration. This alteration has a cascading effect or sets into effect a chain of reactions beginning with changes in habitat structure and quality, habitat availability, food resources, and other requirements for diversity. Sooner or later through potentially complex interactions and landscape dynamics, the direct and indirect effects of landscape change are reflected in biodiversity.

We will assess landscape pattern, but the important aspect of these measures, or indices, to remember is that all measures of pattern are scale dependent. Landscape pattern indices can be as simple as calculating an average measure of patch size, perimeter, and frequency to estimate interior habitat versus edge habitat and habitat dominance (Griffiths and Wooding, 1988). Indices we will use include fractal dimension, diversity, dominance, and contagion.

The basic element of all these indices is a patch, defined as a contiguous area consisting of a common landcover (Turner and Ruscher, 1988). Patches were originally defined as clumps of vegetation but have since been expanded to apply to other areas, such as those with common soil characteristics, and now includes any place where the abundance of either resources or individual organisms is high or low relative to the surrounding area (Cullinan and Thomas, 1992).

Fractal dimension is a measure of a pattern which may or may not be self-repeating but which has an increase in variance with a decrease in scale (Cullinan and Thomas, 1992). Fractal dimension can be used to compare the geometry of landscape mosaics as a measure of the complexity of patch perimeters (Turner and Ruscher, 1988) and may be important measures of ecological diversity, stability, and function (Garcia-Moliner et al., 1990). Diversity, which can be calculated using a number of different indices, is a measure of the number of different cover types on the landscape (Robinove, 1986). Larger values indicate a more diverse landscape comprised of many different landcover types while smaller values indicate low heterogeneity in cover types. Dominance is the extent to which a single or many landcover types dominate the landscape. Large values of dominance indicate there are one or only a few landcover types on the landscape, while small values indicate the landscape is comprised of many landcover types in relatively equal proportions (O'Neill et al., 1988). Contagion is a measure of the degree of clumpiness of the landscape. High values indicate a landscape aggregated into a few large, contiguous patches while low values indicate a high degree of fragmentation, with many small patches (O'Neill et al., 1988). The results of these indices is a picture of the landscape quantified in terms of the composition and configuration of the physical elements of that landscape. These indices are used to quantify and describe the relationship of landscape elements and attributes within and among a given landscape. Interactions can be assessed using these indices as well. Inferences can be made linking the effects of the composition and configuration of a landscape directly and indirectly with factors which affect biodiversity. These factors might include resource availability, habitat quality and availability, species interactions or others. However, it will be beyond the scope of this project to study the exact mechanisms by which landscape patterns are related to biodiversity.

More advanced analytical indices of pattern include wavelet transforms, trend surface analysis, Fourier spectral analysis, and variography. The wavelet transform is used to analyze spatial pattern and time series data. It is similar to Fourier spectral analysis in that it 'looks for' a feature in the data to which the wavelet pattern is similar (Bradshaw and Spies, 1992). The wavelet transform performs a scale-by-scale decomposition of the data with a local filter, retaining location. The wavelet transform is particularly useful in hierarchical data, data which has a multi-scalar structure, or is non-uniformly distributed information (Garcia-Moliner et al., 1990). Fourier spectral analysis is a method which compares successive values in a dataset to a known wave-form pattern. This method and the wavelet transform are used to identify scales of repeated pattern in a dataset (Turner et al., 1990). Specifically, the frequencies and angular directions of known patterns are detected. The advantage of spectral analysis is that it can be used with anisotropic data, which is typically the case with ecological data (LeGendre and Fortin, 1989). Trend surface analysis tests the hypothesis that a spatial pattern results from a large-scale regional trend superimposed with small-scale local effects. Trend surface analysis is used to identify and separate broad regional patterns from smaller scale nonsystematic local variation (Turner et al., 1990). Variography typically refers to semivariograms and correlograms. Semivariograms and correlograms indicate the measure of spatial dependence (Turner et al., 1990). Variograms can be used to describe the structure function of the landscape elements which assists in understanding the structure of those elements in the context of the larger landscape (LeGendre and Fortin, 1989).

We will use these indices and others to quantify the pattern of the Mojave Desert landscape components. Because of the scale-dependence and specific assumptions of each method, we will select appropriate measures based on results of the land use classification and identification of key landscape components. Methods will be chosen to maximize complementarity for creating a holistic picture of the landscape and to maximize comparison across scales. It is not appropriate, *a priori*, to state the specific metrics to be employed, as these will be a function of the land use patterns actually determined.

3.2.2 Assess Landscape Degradation.

Most, if not all, arid ecosystem ecologists agree that land degradation is intimately related to the ecosystem's structure and function. That is, degradation moves the system into a state of lowered function. The implications of lowered function, of course, include lowered net primary productivity (see, e.g. Forman and Godron, 1986), but it also includes decreased biodiversity. That is, a close relationship exists between increasing degradation and measures of biodiversity. Our approach to land degradation assessment will be to locate test sites in areas of relatively homogeneous terrain (homogeneous in terms of landscape or ecological potential as measured by potential soils and vegetation and relative uniformity in terrain features). Test plots measuring, at a minimum, of 2.25Ha (i.e., a matrix of 5 X 5 Landsat TM pixels (or 150m X 150m) will be extracted from the Landsat TM data set. Sets of 3 test plots will each be located in areas considered to be of minimal, low, medium, and high disturbance regimes for a minimum of 12 test plots per homogeneous landscape or ecological site. Sites will be located in conjunction with field plots chosen by the Biodiversity Response Team, and by other researchers (including the test sites of researchers at California State University at Dominguez Hills and the University of California at San Diego. NASA High Altitude aerial photography will be used in conjunction with ground validation to verify condition status. Work done by Mouat et al. (1997) at the Jornada Long Term Ecological Research site has demonstrated that sets of satellite pixels extracted from data sets for separate homogeneous areas can discriminate ecosystem condition. This LTER study and other pilot studies suggest that vegetation composition and cover as well as soil surface condition as measured by satellite-derived indices provide the information required to develop status of land degradation (Lancaster et al. 1996).

The purpose of the detailed site analyses performed in the previous task is twofold: 1) to provide for a regional assessment of land degradation as a function of measured aspects of the environment to be performed by the vegetation and terrain mapping, as coordinated by the Landscape Team, and 2) to provide a type of sensitivity analysis with which to compare future assessments. In future scenarios, we may make an assumption that, for example, a given stressor (for example, a change in surface disturbance) will cause an area to move from a moderate to a high level of degradation. Our present data layer of relative degree of degradation will allow us to evaluate the status (or provide a future assessment) of that degradation.

The Mojave landscape is different from other ecological systems because of its fragility. Ecosystems are often characterized by vegetation structure and function, climate, and productivity. By these standards, desert systems are difficult to characterize because vegetation is sparse, climate is severe and highly variable in the case of the Mojave, and productivity is comparatively low. These considerations influence how land use is defined in that activity intensity, frequency, and density directly affects the impact on the landscape itself.

Degradation in the Mojave may be a direct or indirect result of development, agriculture, grazing, exotic species, vehicle based recreation, water redirection and/or military activities. The effects of each of these activities is manifest as changes in the landscape in time and space. Specifically, we can evaluate the impact of these activities directly from aerial imagery or indirectly from indices of landscape pattern. Activity effects are scale dependent. We will be able to assess the scale at which impacts from the specific activities occur and the relative impact of these activities over areas of variable size with the use of multiple resolution, multitemporal data. For example, some activities may produce local effects which have a significant impact on ecosystem function or biodiversity in localized areas, while other activities may produce effects which impact the entire region and have a much broader scope of influence on the Mojave Desert. The identification of local versus broad-scale processes will also provide an opportunity for assessing cumulative impacts for the larger region. In other words, given a set of localized activity effects we can ask questions regarding the sum impact of those effects, determine the interdependency of landscape elements across scale, and assess or predict biodiversity response to current or changing conditions.

Intensity, frequency, and density of activities directly influence degradation of the landscape and these three factors often occur together in some combination. Intensity of an activity relates to the level of direct impact on the landscape. For example, armored tank maneuvers involving shelling or testing of heavy artillery will likely have a more intense impact on the landscape than a mountain bike. However, daily rides by one hundred mountain bikers for one year will likewise have a more intense impact than an occasional single mountain biker. Frequency is the temporal indicator of the effects of a given activity and relates to the number of occurrences of an activity. For example, an agricultural field planted and irrigated every third year will exhibit different temporal and spatial patterns in terms of system functioning and suitability to maintain biodiversity than an agricultural field intensively farmed annually. Density is a spatial indicator of the amount of an activity per unit area. Density can indicate either the activity itself, such as the number of cattle per hectare, or can indicate a secondary effect of an activity, such as number of roads or streambeds per given area. These three activity descriptors are the basis to rank effects of activities which can be used to assess landscape degradation. Severe degradation would be expected in an area which had a heavy intensity, high frequency, and relatively dense activity, where little degradation would be expected in areas relatively unaffected by human related activities. There are other components to this equation which will have a direct effect on the amount of landscape degradation: system vulnerability and recovery.

The Mojave Desert is a fragile ecosystem as a whole, yet exhibits variability in its resilience to anthropogenic stressors within its boundaries. That is, the Mojave is not uniform in its ability to resist the impacts from human related activities nor is it homogenous in its ability to recover from these impacts. Some areas may not be highly affected by certain activities, where other systems within the Mojave landscape may be highly vulnerable to effects from the same activities. Even within the areas which are more vulnerable to stressors than others, certain levels of intensity, frequency, and/or density of any given activity may be required to cause irreconcilable changes. We can assess the vulnerability and resilience of a landscape and make predictions about the future of landscape function, and consequential response of biodiversity, with the direct and indirect measures of landscape pattern and an understanding of the pattern-process relationships. Degradation can be measured as the cumulative effect of the intensity, frequency, and density of an activity on a system which has an inherent ability to resist and recover from those levels of the particular activity. In this sense, degradation is measured in space and time.

The specific causes of degradation and our methods for estimating them are listed below. The list of stressors and issues follows those presented in Section 2.

1. *Development: residential, industrial, commercial, infrastructure*. Changes in development can be detected and quantified using standard change detection techniques of remotely sensed data (Jensen, 1996; Lillesand and Kiefer, 1994; Avery and Berlin, 1992). Physical structures such as buildings, roads, parking lots and railroad tracks can be directly identified by shape, size, and spectral reflectance. Features can be detected by both physical and spectral characteristics such as power lines, which are linear features and which typically exhibit very different spectral response from neighboring vegetation due to management (i.e. suppression) of vegetation along the path of the lines themselves. Other features of development can also be directly identified spectrally such as lawns and swimming pools. Grass and trees are very apparent and easily distinguished from surrounding asphalt or desert vegetation and soils. Water absorbs almost all energy in the infrared part of the spectrum and is easily distinguished from surrounding arid conditions. Development features themselves exhibit significantly different spectral responses than vegetation or bare soils because of the difference in reflectance properties. Materials such as asphalt, tar, shingles, and gravel have compositional differences which absorb or reflect wavelengths differently from soils of variable substrate composition, mineral, and water content. The physical shape of the component materials also has an effect on spectral response. The effects of development can be direct, in physical removal of vegetation habitat and/or individual animals, or indirect as non-point source pollution or redirection of water from one area to another. Effects of development can be local at the source, such as replacement of habitat with a mall and parking lot, local removed from the source, such as loss of water to other areas from water redirection, or regional, such as the cumulative effects resulting from development and consequential population expansion. We will assess development through analysis of Landsat TM imagery and the recently acquired aerial photography.

2. *Agriculture.* Agriculture in the Mojave Desert involves irrigation. Just as lawns are readily apparent spectrally, crops which are irrigated exhibit very different spectral responses from non-irrigated surrounding areas. Shape is also a recognition feature used to discriminate agricultural areas. Irrigation is done in a circular or other regular pattern which is very apparent on the landscape. Seasonally there are much larger fluctuations in landscape (i.e. vegetation) conditions for agricultural crops than for non-agricultural areas. Crops are planted, irrigated, grow relatively quickly and are harvested at the end of the season. This pattern can be captured in the spectral response of the vegetation over time as phenology. The direct effects of agriculture include vegetation and species loss, salinization, alkalinization, and erosion such as dust. Indirect effects of agriculture include effects from water redirection and change in nutrient and soil properties. The recent Landsat imagery and NASA acquired aerial photography will be used as a basis for estimating agriculture.

3. *Grazing.* The effects of grazing are less straightforward to detect and map. BLM grazing allotments and Animal Unit Months (AUMs) data are available and we will work with BLM scientists on this component. Grazing causes a redistribution of soil resources, alters vegetation composition, changes the pattern of vegetation on the landscape, and creates surface disturbance. Changes in vegetation may be detected spectrally from imagery and aerial photographs and texturally in aerial photographs. The redistribution of soil resources and changes in vegetation composition will be reflected in landscape pattern indices. Surface disturbance can be direct, such as creation of animal trails or compaction around water, or indirect with redistribution of resources from animal droppings and compaction. Grazing is a direct contributor to desertification and can severely alter the 'normal' function of a healthy arid or semiarid system. We will estimate the effect of grazing as a function of vegetation and soil condition.

4. *Exotic species.* Exotic species will not be dealt with in general, but some species, such as the common raven, may be chosen as focal species by the Biodiversity Response Team (see Section 4.2.1).

5. *Vehicle based recreation.* Some effects of off highway vehicle activity both by civilians and the military are detectable from remotely sensed data. In fragile desert soils, trails and unofficial roads are easily etched into the landscape by compaction and erosion. These trails may remain obvious features on the landscape for years after use has ceased. The direct result of these trails can include mineral, water, and other soil resource distributions which in turn may result in accelerated desertification and consequential changes in vegetation composition. These changes may directly affect biodiversity by such means as loss of habitat and reduced prey-base. The effects are therefore long lasting in that effects from fragmentation and change in landscape pattern may continue far beyond the life of the trail. Other potential effects of vehicle based recreation are the direct loss of individual species from being squashed or otherwise run over. The BLM has devoted considerable effort to estimate these effects and we will work closely with them on this issue. The military bases also have developed considerable information on the effects of their off highway activities.

6. *Water redirection.* The effects of water redirection are local at the source, local removed from the source, and regional. Water redirection can be identified by an increase in vegetation, such as from irrigated agriculture or the creation of riparian zones along canals. Likewise, water redirection can be identified by a decrease in vegetation from downstream loss of water, a lowering of the water table, and changes in geomorphology. Remnant features of water can be detected as geomorphic features, in soil compositions, and for a short time after removal or decrease in water availability, in vegetation. The alteration of water from its former course or reduction in groundwater changes the landscape which no longer receives water or receives reduced water. Changes to the downstream landscape may include changes in vegetation composition and consequential redistribution of soil resources. These changes have implications for habitat issues which affect biodiversity, and also affect the physical properties of the substrate itself. Loss or change in vegetation and soil resources contribute to desertification and increase erosion and dune movement.

7. *Mining.* It is unlikely that we will be able to develop spatially explicit estimates of the effects of mining activity.

8. *Noise.* The effects of noise on biodiversity is mediated through species-specific effects. Each species responds differently to different noise patterns. This issue is therefore also beyond the scope of the present research. While biodiversity issues related to noise are beyond the scope of the present research, the issue of noise in the context of the juxtaposition of land use with military activities will be addressed.

The implications of degradation on biodiversity are considerable. Recent work performed by Morafka and Adest (1996) shows that, for example, significantly disturbed areas exhibit lower plant biomass, densities, species diversity and cover than comparable low disturbance and control (or pristine) sites. Furthermore, they state that as few as a dozen key species (combined) of flowering plants, birds, lizards, and rodents may provide effective measures of disturbance.

3.3 Create Tools for Evaluating Alternative Futures.

By synthesizing the results of the pattern and degradation analyses in to GIS coverages and models we will create two of the tools to be used for the evaluation of Alternative Futures described in Section 5.

3.4 Development of Wildlife Habitat Data.

Data and models on land use, vegetation, and terrain will provide input to the Biodiversity Response analyses described in the Section 4. In particular, the work of the Landscape analyses will be used to help identify habitat for the vertebrates.

4.0 Biodiversity Response

The results of the Landscape Change (Section 3) will be used as input for models for the maintenance and distribution of vertebrate biodiversity. As with the Landscape Change studies, research will focus on multiple scales. In particular, we will focus on three taxonomic scales. These scales are:

1. Single Vertebrate Species: the desert tortoise, *Gopherus agassizi.*

2. Focal Vertebrate Species: approximately 12-15 resident or breeding terrestrial vertebrates.

3. Total Vertebrate Species: all resident or breeding terrestrial vertebrate species.

The overall plan is to characterize the tortoise very well, the focal species well, and all species adequately. Thus we are working at three points on a continuum between a single species and all species, trading off much knowledge for one species against a little knowledge for many species. Ideally we would create models of population viability for each species that could be used to evaluate alternative future scenarios. However, such analyses are expensive and time consuming. We will be able to construct such an analysis only for the desert tortoise. For the other species we focus on overall diversity, and not on the viability of any single species, relying on the power of statistical sample size.

Each group will be studied on different spatial scales as well. Three scales will be applied to the tortoise and the focal species and two scales to total diversity. The three scales are:

1. Point Localities. For tortoise and focal species

2. Focal Transects. For tortoise and focal species. Two focal transects

3. Mojave Wide. All species

The size of the California Mojave Desert (74,000 km^2) and the magnitude of even the vertebrate diversity (approximately 349 resident or breeding terrestrial vertebrates) make a detailed study of either the entire area or all species practically impossible. In addition, logistical difficulties posed by the desert environment make acquisition of new data expensive and difficult. On the other hand, a great deal of data are already available. Therefore our primary strategy will be one of synthesis. New data will be collected only for part of the study - the focal species on the focal transects.

The current state-of-the-art for estimating biodiversity from landscape characteristics in the Mojave Desert is the California Statewide Wildlife Habitat Relationships System (CWHR). First published in 1988, the CWHR is a database system that is continually being updated and is available from the State of California Department of Fish and Game in electronic form. This database covers all of the vertebrates of California, including those in the Mojave Desert. The database consists of a vegetation map of the state and a lookup table that associates each vertebrate species with the vegetation types in which it is known to occur. Maps of the predicted range of each species can then be created. While the CWHR is an impressive overall achievement, its resolution in the Mojave Desert is not as great as we would like. The lack of resolution is partly due to the lack of data on many of the vertebrates of the Mojave Desert, but it is also due to the use of vegetation classes as the model of the environment to which species are matched. There are approximately 50 types recognized for the entire state with only about 22 types given for the Mojave Desert. In our work we propose to create a new concept of habitat for the Mojave Desert based on a combination of substrate variables and vegetation (Figure 6.) This new concept of habitat recognizes that in the Mojave Desert vegetation cover is very sparse and frequently virtually absent, and that many (but by no means all) species are more sensitive to variation in substrate than to variation in vegetation cover. By "substrate" we mean surface lithography, soils, and microterrain. Measures and classifications of substrate will be associated with vegetation and the two in combination will be used to characterize vertebrate habitats. This new concept of habitat also has implications for remote sensing on account of the limited vegetation and high lithologic response. The spectral examination of surface lithography and concomitant assessment of habitat strengthens the use of remote sensing in the Mojave.

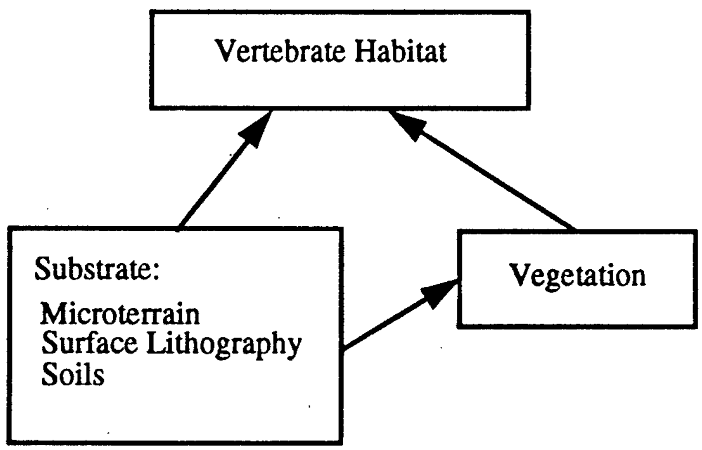


Figure 6. A concept of vertebrate habitat for deserts

Developing new habitat models for the approximately 349 terrestrial vertebrate species Mojave wide will be done using available literature and data. Higher resolution habitat models will also be developed independently for the focal species. Therefore, each of the focal species will be modeled twice, once at the same resolution as all of the other vertebrate species and once at a higher resolution. The predicted distributions generated by these two models for the focal species will then be compared to assess the accuracy of the lower resolution models. The lower resolution models for all vertebrate species will not be directly validated as validation for that many species would be prohibitively expensive. Rather, we shall analyze the entire group as a statistical ensemble relying on the large sample size to make up for defects in any one species model in the manner of White et al. (1997).

With the habitat models in hand for all species we will then investigate the degree to which protecting the habitat of one species (or a small group of species) will provide habitat for all other species. In the sense of Kiester et al. (1996) we will ask how well one species or group of species sweeps all others.

The models will also provide the basic mechanism for the Biodiversity Evaluation of Alternative Futures. Each alternative future will specify spatially explicit changes in the landscape which will be described as changes in the substrate and vegetation. These new patterns of substrate and vegetation in turn will be used to estimate the pattern of vertebrate biodiversity that would be expected.

A combination of sweep analysis and evaluation of alternative future will also be used to evaluate alternative management strategies for the tortoise. The idea here is that, given that the tortoise must be managed under the requirement of the Endangered Species Act, we should be able to chose that strategy for managing the tortoise that simultaneously meets the requirements of the ESA for the tortoise and minimizes the chance of any other species becoming listable. Management of the tortoise is naturally defensive and reactive, but it can be combined with a proactive strategy to prevent the listing of other species in the first place.

4.1 Desert Tortoise.

This is the flagship species of the ecosystem. It is a Federally Threatened Species. It will be studied in detail and its relationship to focal species and then total vertebrate biodiversity carefully studied. A great deal of information is available on the tortoise so our approach will be one of integration and synthesis of existing data and information followed by two modeling efforts.

Few animals now are as well studied as the desert tortoise: Grover and DeFalco (1995) present a bibliography for the biology of this species with over 700 citations prior to 1992. Among the most important works are Woodbury and Hardy (1948) who produced the first major population study on this species (and one which is still extremely valuable as their population is still being studied), Desert Tortoise Recovery Team (1993) who present the recovery plan for the listed Mojave populations, Bury and Corn (1995) whose volume contains several articles, Herpetological Monographs Number 8, 1994, contains 12 articles summarizing work done in the eastern Mojave, and Morafka (1995) who attempts to synthesize all management relevant knowledge of the species. The ongoing investigation of the desert tortoise at Fort Irwin is described at http://curly.tec.army.mil/mojave/mojave.html.

Our work will consist of 6 tasks:

4.1.1 Literature review.

Our first task will be to review the current literature. Much of the literature on this species is unfortunately not readily available being in the form of various reports. Nonetheless we will attempt to accumulate as much of this work as possible. A preliminary synthesis will be written to help guide further work on this project.

4.1.2 Point locality mapping.

We will attempt to acquire as much as possible of the available point locality data for the California Mojave Desert. Most of the current data is held by various government agencies and the Recovery Team. We will work with these agencies to synthesize all data into a point coverage with dates attached to the points if possible. We will have to develop agreements with each agency as to protocols for data sharing. There is concern that if known localities are published that information may be used by poachers intent on illegally capturing tortoises for food or the pet trade.

4.1.3 Mojave wide habitat model.

Several local studies have attempted to determine the habitat preferences of the tortoise in particular study areas. Watts and Anderson (1997) have produced a sophisticated CART model for a single tortoise population on the southern edge of Ft. Irwin. CART is a nonparametric exploratory data analysis tool for uncovering the structure in a data set (Breiman et al., 1984; Efron and Tibshirani, 1991; Clark and Pregibon, 1992). CART recursively partitions the *observations* by binary divisions of the variables until either all the nodes are homogeneous or some stopping criteria is reached (e.g., the nodes contain a certain number of observations). The explanatory variables can be categorical or numeric. The analysis can be used to produce accurate prediction or to obtain a more parsimonious description of the data's structure (Clark and Pregibon, 1992). Watts and Anderson's response variable was local tortoise density and their predictor variables included vegetation data, geologic data, soil type, soil composition data, and topographic data derived from a DEM. The CART model indicated that tortoises prefer creosote bush scrub vegetation, on soils derived from granitic or granitic conglomerate parent materials, and avoid steep rock areas and calcareous soils with cemented layers. We will expand these studies to create a Mojave wide habitat model relating tortoise localities to habitat requirements as estimated from both remote sensing and ground data. That is, we will model tortoise presence-absence using variables similar to those used to model density by Watts and Anderson and others. Various scales of remote sensing will be used. In particular, we will compare aerial videography on the focal transects, the 1:32000 color aerial photography, and SPOT panchromatic imagery to the known localities developed above. Variables identified as significant by this procedure will be used in the dynamics models described next.

4.1.4 Dynamic model of tortoise populations.

Several models of tortoise population dynamics have been developed to study the viability of the species. Gilpin (in Desert Tortoise Recovery Team, 1993) analyzed the population near Goffs using demographic methods. Doak et al. (1994) used data averaged from several sites to construct a population viability model for the western Mojave Desert. Neither of these models is spatially explicit. Hannon et al. (1997) have constructed a spatially explicit model for a population on Ft. Irwin. Our approach will be to combine a more sophisticated two-sex demographic model including demographic and environmental stochasticity and catastrophes (as per Caswell, 1989 and Lande, 1993) with a more realistic spatial model based on movement and dispersal using Kiester and Slatkin (1974) and Kiester (1985). These spatial models will recognize that tortoises move about in response to both food resources and conspecifics and that the sex of the conspecifics encountered matters in the determination of movement pattern. The model will characterize the environment in each spatial grid cell using the variables identified above and measured with remote sensing. This model will be run under different management scenarios and will produce as output spatially explicit polygons of tortoise habitat occupancy.

4.1.5 Sweep analysis.

A sweep analysis (Kiester et al., 1996) will relate the presence of tortoises to the chosen focal species at the focal scale, and to all vertebrate species at the Mojave wide scale. This sweep analysis will be computed by comparing the polygons created by the tortoise habitat and population dynamics models to the estimated polygons of occurrence of the focal and total species. Management strategies which produce the richest sweeps will be evaluated as preferable. See also Section 4.2.6.

4.1.6 Synthesis.

The model of population dynamics will represent one form of synthesis of the known information on the biology of the tortoise. However, the model will require explication in great detail so that its strengths and weaknesses can be evaluated. This written synthesis will also provide general guidance on the managemnt of the tortoise, especially as it relates to other species.

4.2 Focal Vertebrate Species.

Approximately 12 - 15 species will be studied in detail on two focal transects. Work will be both synthetic and involve new field studies. We divide the work on these species into 7 tasks:

4.2.1 Choose the focal species.

We will use the following criteria of choice to pick the focal species: tractability (we must be able to acquire enough data in the time available to say something useful about the species), diversity of representation, likelihood of becoming listable, and charisma. Table 3 lists the Candidate Focal Species from which we will choose.

TABLE 3. Potential focal species (numbers are page numbers from the California Wildlife Habitat Relations documents).

135 Swainson's Hawk	185 Rosy Boa
153 Chukar	191 Spotted Leaf-nosed Snake
167 Gambel's Quail	225 Western Shovel-nosed Snake
189 Snowy Plover	231 Lyre Snake
317 Yellow-billed Cuckoo	241 Sidewinder
319 Greater Roadrunner	245 Mojave Rattlesnake
327 Great Horned Owl	25 Desert Shrew

TABLE 3. Potential focal species (numbers are page numbers from the California Wildlife Habitat Relations documents).

333 Burrowing Owl	89 Desert Cottontail
345 Lesser Nighthawk	127 White-tailed Antelope Squirrel
363 Costa's Hummingbird	139 Mojave Ground Squirrel
387 Ladderbacked Woodpecker	165 Little Pocket Mouse
419 Say's Phoebe	175 Long-tailed Pocket Mouse
421 Vermillion Flycatcher ?	179 Desert Pocket Mouse
465 Common Raven	193 Chisel-toothed Kangaroo Rat
475 Verdin	211 Desert Kangaroo Rat
487 Cactus Wren	207 Panamint Kangaroo Rat
531 Bendire's Thrasher	223 Cactus Mouse
537 LeConte's Thrasher	245 Desert Woodrat
543 Phainopepla	289 Kit Fox
567 Lucy's Warbler	297 Ringtail
601 California Towhee	357 Mountain Bighorn Sheep
617 Black Throated Sparrow	125 Desert Collared Lizard
659 Scott's Oriole	127 Long-nosed Leopard Lizard
73 Red Spotted Toad	131 Desert Spiny Lizard
93 Bullfrog	139 Side-blotched Lizard
109 Banded Gecko	141 Long-tailed Brush Lizard
113 Desert Iguana	151 Desert Horned Lizard
115 Chuckwalla	159 Desert Night Lizard
117 Zebra-tailed Lizard	169 Western Whiptail
123 Mojave Fringe-toed Lizard	

Several of the species on this list are listed by either the Federal Fish and Wildlife Service or the California Department of Fish and Game. These species are clearly important. However, their rarity may prevent our being able to acquire much information during the course of this study.

4.2.2 Set up focal transects.

The focal species will be studied along two transects roughly defined as follows:

1. Joshua Tree - Twentynine Palms - MCAGCC. This is a North-South transect that covers the Marine Corps facility north of Twentynine Palms, Twentynine Palms itself which is one of the most rapidly growing areas in the Mojave Desert, and Joshua Tree National Park which contains some of the most pristine wilderness in the Mojave Desert. In a space of less than 50 miles this transect covers the range of land cover and land use seen in the Mojave Desert. See Figure 7.

2. China Lake Naval Weapons Center (Argus Range) - Fort Irwin - Mojave National Preserve. This transect will begin in the Naval Weapons Center, China Lake, at Maturango Peak in the Argus Range, angle down to the southeast through the Naval Weapons Cen-

ter, China Lake, Mojave Range B and the Army's Fort Irwin National Training Center, then turn to the east to end in the Mojave National Preserve. Thus this transect compares military installations with the Preserve and with intervening private and BLM land. Its length is approximately 120 miles. See Figure 8.

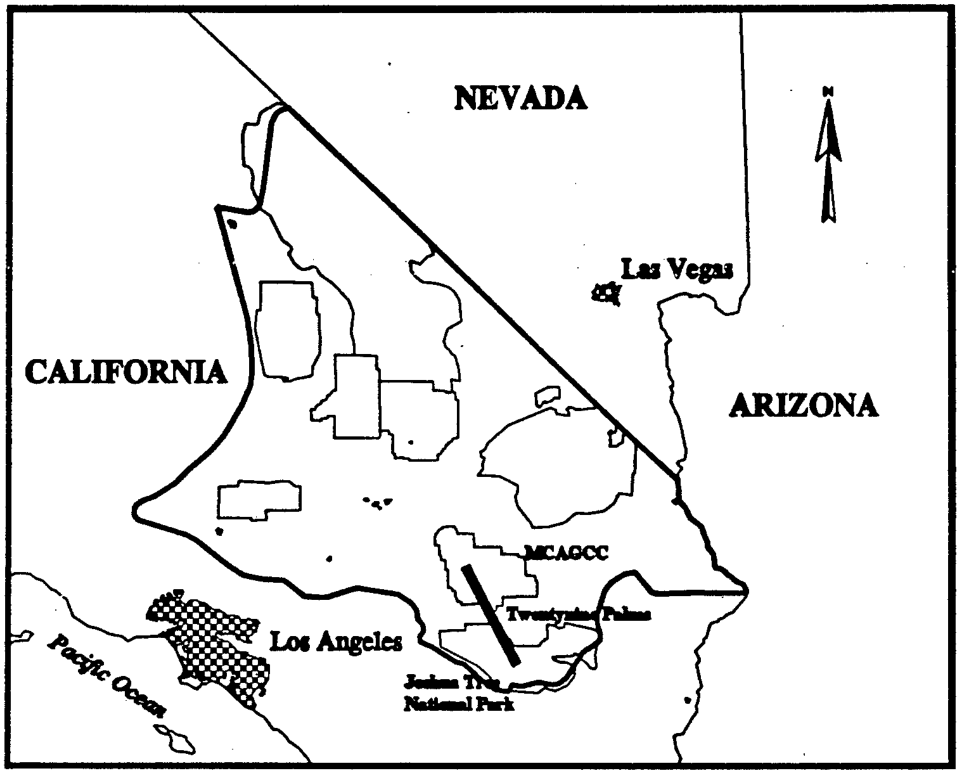
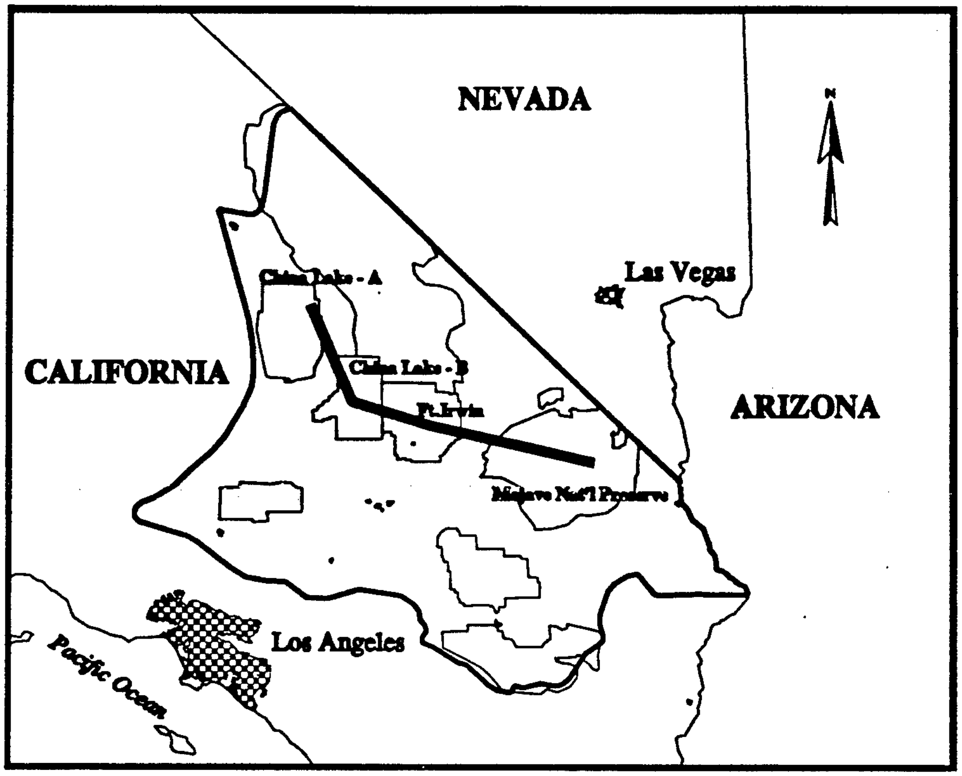


Figure 7. Southern Focal Transect.

Figure 8. Northern Focal Transect.



The widths of the transects will be approximately 200 meters. Remotely sensed images will be constructed for each transect using all scales of imagery. In particular we will compare aerial videography, the 1:32,00 high altitude color photography, and SPOT panchromatic images. TM and MSS data will be used to define wider (1000 m) versions of the transects for comparative purposes.

4.2.3 Synthesize information for each species Mojave wide.

A complete literature review will be done for each focal species. Particular attention will be paid to information about the habitat relations and population dynamics.

4.2.4 Point locality mapping.

All known current and historical locality data will be mapped for each focal species Mojave wide. These point coverages will then be overlaid on remotely sensed imagery to estimate habitat associations. A comparison of current and historical data will enable the estimation of how well the species is known across the Mojave.

4.2.5 High Resolution Habitat Occupancy Models (HRHOMs).

Habitat models for all focal species on the focal transects will be constructed from a combination of literature and field work. The first part of this effort will be to determine a list of habitat variables (vegetation and substrate) that can be measured for each species. Once the environmental variability can be characterized, a quantitative study will be undertaken to associate each species with its measured habitat. This part of the study will primarily involve two kinds of subtransects laid out at intervals within each of the two overall transects. The first kind of subtransect will be a ground survey methodology using standard design and analysis methods (Laacke et al., 1993; Buckland et al., 1993). Similar transect surveys have been done for some of the candidate focal species in the Mojave Desert (Morafka and Adest, 1997) and appear to work well. One of the great advantages of working in an environment such as the Mojave Desert is the great visibility afforded by the lack of dense vegetation. The second subtransect methodology will use pitfall trap arrays. Our designs will follow the method developed by Case and Fisher (Department of Biology, University of California at San Diego) and applied with great success in the California Coast Range. Each pitfall trap is a 5 gallon bucket sunk flush into the ground. Seven buckets are arranged into an array of three 10 m arms set at 120 degrees to each other. A drift fence made of greenhouse cloth connects the buckets on an arm. Inside each bucket is a collection of items such as food, water and shelter designed to ensure survival of any organism that falls into the trap. Traps will be checked daily. Some modification of the system will be needed to have the traps functional effectively in the hotter desert environment. These modifications will involve the addition of an evaporative cooling system. The arrays will be placed in a linear arrangements to form subtransects within the focal transects. The length of the subtransects and the density of arrays along the subtransect will be determined through a pilot study which will utilize radiotracking of individuals of prospective focal species to determine the effective area that a single array samples. This work will be undertaken in collaboration with Dr. Robert Fisher and Dr. Ted Case of the University of California at San Diego.

Each subtransect will be characterized by all scales of remote sensing. In particular, the higher resolution aerial videography and the 1:32000 color aerial photography will be used to construct complete images which will then be compared to SPOT and TM subscenes. The aerial videography acquisition and analysis will be undertaken by Dr. Charles Rosenfeld, Dr. Mary Santelmann, and Jill Heaton of the Department of Geosciences at Oregon State University.

4.2.6 Sweep analyses with tortoise and total vertebrates.

Mapped occurrences of the focal species will then be used to sweep the tortoise and the set of all vertebrate species. That is, we will compute in spatially explicit manner the amount of habitat of the tortoise that is covered when the various focal species are protected. Separately we will compute the total vertebrate diversity that is covered by the focal species. Note that sweeping is not symmetric. The degree to which protecting tortoise habitat will protect focal species habitat or total vertebrate habitat is not simply the reverse of how protecting focal vertebrate habitat will cover tortoise habitat or total vertebrate habitat. So we will compute all possible pairs of sweeps.

4.2.7 Synthesis: Indicator Species?

A synthesis of the work on the focal species will be an evaluation of the degree to which a set of focal species can be used as indicator species for total vertebrate diversity. This synthesis will provide quantitative guidance to managers wishing to use an indicator species approach. The sweep analysis will provide a quantitative estimate of the efficiency of any candidate indicator species and allow selection of optimal indicator species.

4.3 Total Terrestrial Vertebrate Species Richness.

This group includes all species of amphibians, reptiles, birds, and mammals that breed in the Mojave Desert. These number approximately 349 species. This number is estimated from the California Wildlife Habitat Relations documents and includes peripheral species. As the research progresses some peripheral species may be dropped from the analysis as not really belonging in the Mojave ecoregion. We will determine to drop species from the Mojave list on a case by case basis for those species whose ranges only barely enter the Mojave. This total diversity is one of the major endpoints of the entire study.

We divide our efforts into 4 tasks:

4.3.1 Create new set of habitats.

The first task will be to extend the existing California WHR system from one based on relatively few vegetation cover types to a system which uses both substrate (surface lithography, soils, and microterrain) and vegetation variables. These variables will have to be estimatable from a combination of SPOT Panchromatic and TM imagery and the vegetation and terrain maps provided by the Landscape Team (Section 3). The habitat will be further calibrated by reference to the 1:32000 color aerial photography and the detailed maps produced by the focal species studies. As described in the introduction to Section 4, these models will not be directly field validated.

4.3.2 Create Habitat Occupancy Model (HOM) for each species Mojave wide.

Once a new set of habitat variables has been identified and statistically characterized using different resolutions of remotely sensed data, a habitat relations table will be constructed for each species using best available information. At this time we are reasonably confident that all vertebrates with the exception of the bats can be done to a degree of accuracy comparable to other studies of this type (e.g. the Monroe County study, White et al., 1997).

4.3.3 Calibrate HOMs with high resolution HRHOMs from focal species.

After each species range has be modeled at this scale, that model's predictions for the focal transects will be compared to the higher resolution models produced specifically for the transects. This comparison completes the set of cross-scale comparisons that, taken together, constitute the basis for final accuracy assessments. With this associated accuracy assessment, the models for total diversity become one of the major tools for evaluating alternative future scenarios.

4.3.4 Assess risk of becoming listable.

Each species status under current conditions will be evaluated in two ways. First, the range of each species will be intersected with the wilderness areas and other areas in the Mojave Desert managed for the long term protection of biodiversity. This procedure will estimate the number and size of the habitat polygons for each species and provide a GAP analysis (Scott et al., 1993, Kiester et al., 1996). Second, the size and distribution of all habitat polygons will be combined with information on area requirements for each species to produce a risk assessment following the method of White et al. (1997). These tools for assessing risk of listing will also be used to evaluate alternative future scenarios.

5.0 Integration and Alternative Future Scenarios

The purpose of this component of the research project is to integrate information on landscape status and change (Section 3) and concomitant biodiversity responses (Section 4) and to use this synthesis to assess and effectively communicate to decision makers the consequences of alternative management strategies for the Mojave region. To achieve this goal, we will complete five major tasks:

1. Analyze and interpret data on Mojave stakeholders to better understand and characterize what people value about the Mojave (both use and non-use values) and how these values affect and constrain management options.

2. Synthesize the implications of existing and planned land uses for 2020.

3. Develop a set of realistic, spatially-explicit alternative futures for 2020 that reflect the range of stakeholder values.

4. Evaluate the likely effects of each of these alternative futures using the pattern and degradation analysis of the landscape and the three measures of biodiversity given in Section 4, as well as in terms of constraints on land use and human activities.

5. Create the framework for a Decision Support System for manipulation and assessment of Alternative Future Scenarios. Communicate the framework to interested stakeholders and decision makers and to implementers of the Decision Support System.

These five tasks are described in greater detail in the subsections that follow.

5.1 Stakeholder Characterization

The term "stakeholder" refers to any individual or group that has a "stake in" or reason to care about how the Mojave region is managed. It is often useful to subdivide stakeholders into what are referred to as "communities of place" and "communities of interest" (Shannon and Antypas 1996). Communities of place are residents of the Mojave and include the military installations, Native American communities, civilian settlements, ranchers, miners, local recreational users, and city and county planners and elected officials. Communities of interest are those who have a stake in decisions made about the region but do not reside in that region. They include non-resident military planners and advisors, urban recreationists, environmental interest groups, resource extractors, and, for Federally owned lands, all citizens of the United States.

We are interested in characterizing what people value about the Mojave not as an end in itself, but as input to designing a set of realistic and inclusive alternative futures (Section 5.3). For example, the Mojave is valued by some for recreational use of off-road vehicles. To be helpful in designing management options responsive to that value, we need to know what locales and landscape characteristics provide particularly high quality off-road vehicle experiences. Others value the Mojave for the isolation and wilderness experience it can provide. Are there particular sites or particular features most important to this experience? Significant portions of the Mojave have been set aside for military use and are of critical importance for military training and testing activities. How large an area and what types of terrain are needed for these purposes? Environmental groups want to protect the unique natural features and biota of the Mojave. Are there certain types of features and biota with which the Mojave is most strongly identified? As human populations grow and expand beyond the Los Angeles basin, the Mojave is increasingly valued as a locale for new housing developments. Are there particular areas most likely to be developed in the future? What amenities and characteristics determine what areas are most desirable? Answers to these and a host of similar questions will characterize the variety of stakeholder values. This characterization will be broad-brush and, as we have emphasized, be used to help formulate the range of alternative scenarios. We will not therefore attempt to quantify human values, in terms of either proportions of groups that value "x" as opposed to "y" nor in terms of "willingness to pay" for "x".

Our basic approach will be to rely on the many ongoing studies of stakeholder values in the Mojave Desert. Our primary point of contact with these numerous efforts will be the Desert Managers Group (DMG). The DMG consists of high ranking representatives of all federal and state land management agencies within the California Desert (e.g., Commanding General or designee from each military installation, National Park Superintendents, BLM District Land Managers). We will meet routinely with the representatives of the DMG, and on a less frequent basis report back to and interact with the DMG itself.

Existing public forums and stakeholder involvement processes, such as town or county planning meetings, can provide significant insight regarding stakeholder values and conflicts, the major stakeholder groups and principal representatives, and existing community networks. The National Park Service (NPS), Bureau of Land Management (BLM), and U.S. Fish and Wildlife Service (USFWS), in particular, have substantial ongoing stakeholder interactions in conjunction with development of management plans for federal lands in the Mojave (Dennis Schramm and David Moore, NPS, Northern and Eastern Mojave Planning Team, personal communication; Alden Sievers and Bill Haigh, BLM, West Mojave Plan, personal communication). Activities include widely advertised public meetings, open to all interested parties, "working groups" consisting of representatives from each interest group, smaller focal groups discussing specific topics in greater depth, and public rating sheets for establishing priorities, distributed at open meetings and through the mail. Information obtained though these processes will be of great value to us, both in terms of stakeholder values tied directed to the federal lands within our study area as well as stakeholder views regarding the Mojave in general.

For our purposes we will group data on stakeholder values obtained from these studies into three groups:

1. Elected officials and town and county planners with responsibilities that extend to privately owned lands in the Mojave.

2. Representatives from public and private interest groups, including environmental interest groups, mining interests, ranchers, and recreational interest groups.

3. Representatives from the five military installations within the study area, to obtain detailed information on their specific needs, primary concerns, and ongoing and planned activities.

Our own direct interactions will take place with Group 3, representatives of the military installations.

The literature is another source of extant data on stakeholder values, particularly for the broad community of interest. Types of information available range from studies of human values as they relate to the environment or biodiversity in general (e.g., Kellert 1996, Kempton et al. 1996) to anecdotal information about the Mojave specifically (e.g., Darlington 1996) and possibly formal studies dealing with issues and areas sufficiently similar to those in the Mojave to be directly applicable to our needs. We will search the literature for relevant information and utilize the results, as appropriate, in design of the management options.

Results from these diverse sources of information on what people value about the Mojave region will be organized and delivered to the group developing the Alternative Futures.

5.2 Synthesize Existing Plans.

Based on our experience in the region of Camp Pendleton (Steinitz et al., 1996) we expect to find that most land in the Mojave Desert already is the subject of an existing plan. As with Camp Pendleton we will synthesize the implications of these plans into a land use map which represents the future that they imply. This will be one of the alternative futures for the year 2020 which we will evaluate. It is different from those described in the next Section in that it is a calculated rather than a designed future.

5.3 Develop Alternative Futures.

Our approach for designing and selecting a set of alternative management scenarios (termed "alternative futures") for the Mojave study area will be based on prior experience with similar efforts in the Poconos region of Pennsylvania (Steinitz et al. 1994, White et al., 1997), Camp Pendleton, California (Steinitz et al. 1996), and Muddy Creek watershed in Oregon (Freemark et al. 1997), which were described in Section 2. As in these studies, we expect to design several alternative futures, ranging from a "high conservation" to a "high development" alternative, each of which will incorporate a suite of specific management decisions (e.g., where housing developments will occur, where off-road vehicle usage will be allowed, what areas will be set aside for protection of native plants and animals or cultural resources, etc.). In some ways, these "futures" represent assumptions, i.e., we assume, for the sake of illustration, that a specific management decision is implemented. Other aspects are projections, or estimates of what the future will look like given current trends (e.g., human population growth rates in the area) and our understanding of how those trends might be influenced by management actions (e.g., land use planning decisions to concentrate growth within certain areas). Important inputs to the design of these alternative futures are ideas from existing plans and projections for the multiple jurisdictions (towns, counties, federal and state lands) that occur within the study area.

There are many planning activities ongoing in the Mojave (e.g., the NPS, BLM, and USF-WS planning efforts for federal lands discussed earlier). The value we add is the broader view - looking across jurisdictions (multiple ownership, multiple land uses) within a fairly large geographic area (see Figure 1). Thus, for example, decisions about how best to manage lands within a given military installation or given other political unit can be evaluated within the context of plans and projected trends within the larger surrounding area. This broader view is of particular importance for analyses of species viability and sustainability of biodiversity, for which land ownership boundaries have little meaning. Considering the larger context can impact management decisions within individual jurisdictions in two ways: (1) actions to protect species and biodiversity in one area may make similar actions in other areas less critical or unnecessary or (2) the adverse effects of a single action, when considered in isolation, may appear minimal, but when evaluated as a component of the cumulative effects of multiple actions within the region may be severe and, thus, unacceptable.

This portion of the research project will be conducted by investigators that have not yet been selected. A Request for Assistance (RFA) will be prepared and openly competed in FY98. Proposals received will be evaluated by an independent peer review panel. The assistance agreement awarded will include

1. Incorporation of all sources of information on human values.

2. Design of the alternative futures (i.e., selection and design of the management options that reflect stakeholder values).

5.4 Evaluate Alternative Futures

The data and models developed as part of the Landscape and Biodiversity Response research components, described in Sections 3 and 4, will be applied to evaluate the ecological consequences of the alternative futures on the five primary endpoints:

1. Landscape pattern indices.

2. Landscape degradation extent and intensity.

3. Population distribution and viability of the desert tortoise.

4. Population distribution and viability of the focal species.

5. Terrestrial vertebrate species richness

The investigators who develop these data and models will work together with the investigators who develop the alternative futures (Section 5.3) to conduct these integrated analyses. Thus, there will not be a separate "integration team" although there will be additional analytical support. Results will be displayed in a spatially explicit format as well as in tabular and in graphical form (see examples in Steinitz et al., 1996), whichever most effectively conveys the major findings. Projected future conditions will be compared to present-day conditions, as the primary reference or baseline. Available information on historical conditions in the Mojave (see Sections 3 and 4) will be summarized qualitatively, to provide context for interpretation of current conditions and future trends.

Two further questions will be addressed as part of evaluation of alternative futures:

1. To what degree do management scenarios designed to protect single species, such as the desert tortoise, also adequately protect other species and terrestrial vertebrate biodiversity overall, and vice versa? Land owners and managers are, by law, required to avoid actions that would harm species currently listed as threatened or endangered. It is highly desirable that management plans implemented to protect the desert tortoise also prevent the listing of other species in the future as well as protect important habitats and landscape features required to sustain biological communities unique to the Mojave region. We will explicitly address this question, both specifically for management plans being developed for military installations as well as for the entire Mojave study area.

2. What types of management actions, and where, are most effective to achieve long-term management goals and a balance among conflicting values within the Mojave? Can we target specific locales or ecosystem classes (e.g., habitat types or riparian areas) as particularly important for protection or restoration?

In addition to assessing the effects of each alternative future on ecological endpoints, we will characterize each future in terms of the constraints on land uses and human activities associated with that future or management strategy. Our budget is not sufficient to conduct formal, quantitative analyses of the economic and social impacts of each option, but the results will be presented in a manner that would facilitate such interpretations.

Our analyses will represent state-of-the-science understanding and analytical techniques, but will still have significant uncertainties. Some components of this uncertainty we can and will quantify, for example, classification errors in landscape characterization (Section 3) and the limitations of our current understanding of species-habitat requirements, which will be assessed by collecting more detailed information on a subset of species (Section 4). Those that cannot be quantified we will describe qualitatively. A key research issue, which we will explore, is how can we best communicate these uncertainties to decision makers in a manner that is constructive, that is, conveys appropriate uses and misuses of the data and results but does not allow the uncertainties to overwhelm the value of the major conclusions.

5.5 Develop the Framework for a Decision Support System and Transfer Technology.

We will be successful only if we can present our results in a manner that is useful to the military. They must inform public debate and be understandable and useful in the decision making process. Therefore we will produce a summary document written specifically for decision makers and stakeholders in the Mojave (in addition to publications in the scientific peer-reviewed literature).

The number of analyses we can conduct and alternative futures we can examine is limited. Thus, another important component of technology transfer is to ensure that others can readily access the data and analysis tools we develop, as an aid to future decision making or to evaluate additional management options. The primary target for this technology transfer are the military installations within the Mojave, with the environmental resource group at the Marine Corps Air Ground Combat Center at Twentynine Palms as our designated lead contact.

We cannot, however, take "research grade" models and data, deliver them as is, and expect them to be useful in management applications. Thus, we also plan to develop the specifications for a decision support system with user friendly interface and appropriate documentation. The actual coding and testing of such a decision support system will not be undertaken by this project as writing DoD complaint code is beyond our scope. However, preparation of a detailed specification for such a system will make construction of the system by others straightforward.

6.0 Research Organization and Management

We have organized our research effort into four major components (Figure 9):

Project Management - responsible for overall management of the research.

Landscape Status and Change - characterizing current landscape conditions and landscape changes in response to human activities.

Biodiversity Response - evaluating how landscape changes and human activities affect biodiversity and the viability of selected species of special concern (e.g., the desert tortoise).

Integration and Alternative Futures - using the information and methods developed in components 1 and 2 to assess the effects of alternative land use scenarios and developing approaches to effectively communicate our results and transfer the information and analytical techniques to interested users.

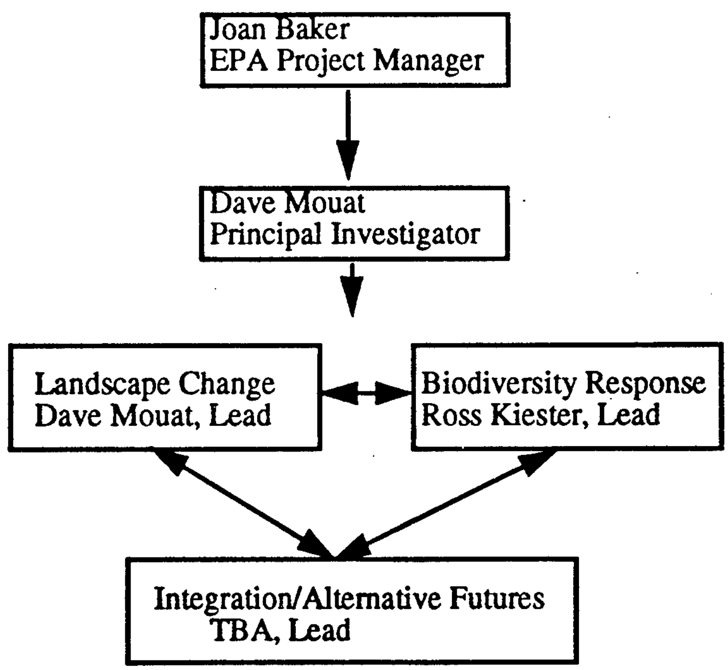


Figure 9. Research project organization and lead scientists.

Each of these components is led by a senior researcher. Dave Mouat is the principal investigator for the project and leads the Landscape Change component. Dr. Mouat is an arid lands geobotanist with Desert Research Institute currently assigned to the EPA research laboratory in Corvallis, Oregon, via an Intergovernmental Personnel Action. Ross Kiester leads the Biodiversity Response Team. Dr. Kiester is a Mathematical Statistician with the U.S. Forest Service, Pacific Northwest Research Station in Corvallis where he is the Global Biodiversity Team Leader. Dr. Kiester is also Director of the Biodiversity Research Consortium with extensive experience in the scientific and policy analysis of biodiversity. Resumes for Drs. Mouat and Kiester, are included in Appendix A. Administratively, the research project is the responsibility of Dr. Joan Baker of EPA's Western Ecology Division of NHEERL and falls within the Ecorisk Team of the Regional Ecology Branch.

The research leads are responsible for defining the objectives and basic approach, conducting some portions of the research, and ensuring the successful and timely completion of their respective research components. The research will be carried out, however, by a larger team of scientists. Some of these cooperating scientists, and their specific contributions and roles, are identified within appropriate sections of the research plan. Other research tasks will be openly competed, consistent with EPA's policy to openly compete extramural research elements whenever possible. Research activities that will be openly competed are also identified within the research plan.

The research management effort will also include a senior military person from the environmental staffs of one of the Mojave bases. We intend to identify a person who can act both as an advisor to the management group and a liaison to the military bases in the Mojave. Identification of this person will take place in FY 1998.

A Quality Assurance Project Plan will be produced in accordance with the specifications used by EPA's Western Ecology Division.

7.0 Budget

The Mojave project is designed as a four-year effort with total funding of $1.65M. The allocation of funds by year, to be provided by DoD/SERDP, and proposed distribution among the major project components is presented in Table 4.

TABLE 4. Project Budget ($K) and Proposed Distribution by Year and Project Component

Project Component	1997	1998	1999	2000	Total
Project Management	75	50	25	25	175
Landscape Change	125	200	125	50	500
Biodiversity Response	50	200	200	50	500
Integration / Alternative Futures		100	200	175	475
TOTAL	250	550	550	300	1650

8.0 Expected Schedule

Details of the schedule will depend on the awarding of the cooperative agreement for the Alternative Futures Scenarios component of the project. The following schedule is tentative and gives start and completion dates.

3 Landscape Status and Change

Staff and collaboration agreements in place: 8/98

3.1 Describe the Landscape

3.1.1 Map vegetation: 10/97 - 6/99

3.1.2 Map terrain: 10/97 - 6/99

3.1.3 Map land use: 10/97 - 6/99

3.2 Evaluate the Landscape

3.2.1 Assess Landscape Pattern: 5/98 - 3/00

3.2.2 Assess landscape degradation: 5/98 - 6/00

3.3 Create Tools for Evaluating Alternative Futures: 6/99 - 1/00

3.4 Develop Wildlife Habitats: 10/97 - 6/99

4 Biodiversity Response

Staff and collaboration agreements in place: 8/98

4.1 Desert Tortoise

4.1.1 Literature review: 10/97 - 6/98

4.1.2 Point locality mapping: 10/97 - 6/98

4.1.3 Mojave wide habitat model: 5/98 - 6/99

4.1.4 Dynamic model of tortoise populations: 1/99 - 1/00

4.1.5 Sweep analysis: 1/99 - 1/00

4.1.6 Synthesis: 10/99 - 6/00

4.2 Focal Vertebrate Species

4.2.1 Choose the focal species: 10/97 - 8/98

4.2.2 Set up and run focal transects: 10/97 - 9/99

4.2.3 Synthesize information for each Species Mojave wide: 8/98 - 10/99

4.2.4 Point locality mapping: 8/98 - 9/99

4.2.5 Develop High Resolution Habitat Occupancy Models (HRHOMS): 6/99 - 6/00

4.2.6 Sweep analyses with tortoise and total terrestrial vertebrates: 10/99 - 6/00

4.2.7 Synthesis: 10/99 - 6/00

4.3 Total Terrestrial Vertebrate Species Richness

4.3.1 Create new set of habitats: 10/97 - 6/98

4.3.2 Create Habitat Occupancy Model (HOM) for each species Mojave wide: 6/98 - 6/99

4.3.3 Calibrate HOMs with high resolution HRHOMs from focal species: 10/99 - 6/00

4.3.4 Assess risk of species becoming listable: 10/99 - 6/00

5 Integration and Alternative Future Scenarios

RFA released: 4/98; RFA awarded: 9/98

5.1 Interactions with Stakeholders: 12/96 - 9/00

5.2 Synthesize Existing Plans: 12/98 - 4/99

5.3 Develop Alternative Futures: 4/99 - 9/99

5.4 Evaluate Alternative Futures" 9/99 - 3/00

5.5 Develop Framework for Decision Support System and Transfer Technology: 6/98 - 6/00

6 Final Synthesis and Report: 9/00

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Appendix A. CVs of Principal Investigators

DAVID A. MOUAT, Ph.D.

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U.S. Environmental Protection Agency
National Health and Environmental Effects Research Laboratory
Regional Ecology Branch/Western Ecology Division
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Education:

1969-1974	Ph.D.	Geoecology, Oregon State University, Corvallis, Oregon
1968-1969		Geomorphology, McGill University, Montreal, P.Q., Canada
1966-1968	M.A.	Physical Geography, Kent State University, Kent, Ohio
1962-1966	B.A.	Physical Geography, University of California, Berkeley, CA

Professional Interests:

Dr. Mouat is an arid lands geoecologist and remote sensing specialist with over 25 years experience as a research scientist. Pioneering techniques in using terrain correlation to discriminate vegetation and habitat (the subject of his dissertation) he has applied this hypothesis to land capability and condition assessment, vegetation and habitat mapping, and land degradation assessment. He has made extensive use of remote sensing systems including Landsat TM and the Airborne Visible and Infrared Imaging Spectrometer (AVIRIS). Most recently, he managed the interagency Biodiversity Research Consortium (BRC) investigation involving "Biodiversity and Landscape Planning at Marine Corps Base Camp Pendleton and its Context Region" and is the principal investigator of "Analysis and Assessment of Military and Non-Military Impacts on Biodiversity: A Framework for Environmental Management on DoD Lands Using the Mojave Desert as a regional Case Study". He serves on a number of remote sensing symposia committees and is a reviewer of papers and proposals for journals and government organizations.

Professional Experience:

1994-Present	*Senior Environmental Scientist*, U.S. EPA NHEERL, Corvallis, OR (on IPA assignment from the Desert Research Institute)
1988-Present	*Associate Research Professor* Biological Sciences Center, Desert Research Institute, Reno, NV
1988-1994	*Associate Director* Cooperative Institute for Aerospace Science and Terrestrial Application, Desert Research Institute, Reno, NV
1986-1988	*Senior Research Associate* Mackay School of Mines, University of Nevada, Reno, NV
1984-1985	*Visiting Scholar* Department of Applied Earth Sciences, Stanford University, Stanford, CA
1981-1984	*Research Geoscientist* NASA/Ames Research Center, Moffett Field, CA

1974-1981 *Assistant Professor, Research Fellow, and Director*
Applied Remote Sensing Program, Office of Arid Lands Studies,
University of Arizona, Tucson, AZ

<u>Selected Recent Publications:</u>

Mouat, D., J. Lancaster, T. Wade, J. Wickham, C. Fox, W. Kepner, and T. Ball. 1997. Desertification evaluated using an integrated environmental assessment model. *Environmental Monitoring and Assessment,* 48:139-156.

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EDUCATION:

Ph.D. 1975. Harvard University. Biology.

1967 - 1968. Rockefeller University.
Studied biochemistry, population genetics, animal behavior, mathematics.

A.B. 1967, with honors. University of California, Berkeley. Zoology.

PROFESSIONAL EXPERIENCE:

1989 - present. Supervisory Mathematical Statistician.
USDA Forest Service - Pacific Northwest Forest Experiment Station.

1994 - present. Professor (Research), Courtesy
Department of Geosciences, Oregon State University

1990 - present. Professor (Research), Courtesy.
Department of Zoology, Oregon State University.

1986 - 1989. Mathematical Statistician.
USDA Forest Service - Pacific Northwest Forest Experiment Station.

1985 - 1986. Mathematical Statistician.
USDA Forest Service, Southern Forest Experiment Station.

1984 - 1985. Associate Professor.
Department of Biology and Center for Latin American Studies, Tulane University.

1982 - 1984. Assistant Professor.
Department of Biology and Center for Latin American Studies, Tulane University.

1975 - 1982. Assistant Professor.
Department of Biology, University of Chicago. Committees on Evolutionary Biology, Conceptual Foundations of Science, Latin American Studies.

1972 - 1975. Junior Fellow.
Society of Fellows, Harvard University.

SELECTED PUBLICATIONS

Kiester, A.R.
1997
Terrapene carolina, the Common Box Turtle.
In: Pritchard, P.C.H.; A.G.J. Rhodin (ed.s). The Conservation Biology of Freshwater Turtles.
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