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Presentation Abstracts
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URBAN EFFECTS / POLLUTION

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Management of the Mojave Desert has focused on knowing the distribution of threatened and potentially threatened species and protecting lands dedicated to their preservation. Increasingly, however, anthropogenic activity changes not only community composition but also broad-scale ecosystem functioning through direct soil disturbance coupled with indirect human activities. Two perturbations, exotic species invasions and nitrogen deposition pose a serious problem for conserving and restoring native communities because they alter ecosystem functioning. The resulting pattern with increasing urban development and highway traffic will likely be a shift in species from a shrub-dominated ecosystem to one dominated by exotic annual grasses and forbs. We postulate that this shift reflects a "third axis" of the teeter-tooter model between grassland and shrubland communities. Schlesinger and colleagues proposed that cattle grazing destroyed the grasses thereby resulting in nutrient loss. Under low nutrients, shrubs invaded forming "islands of fertility" and inhibited native perennial grasses from re-establishing. Currently, the composition of the west Mojave is predominantly shrubs that are widely spaced. Many native interspace annuals are N fixers or N scavengers. Today's perturbations are different than those a century ago. N deposition from automobiles and agriculture into the Mojave shrublands is increasing the available surface nutrients, particularly N. In addition, the increasing incidence of roads provides corridors for the invasion of exotic annuals that are largely nitrophilous. Based on observations we know that these shifts also change the saprobic and mycorrhizal composition. Thus, maintaining and increasing the species of concern will require not only land set-asides, but also an understanding of nutrient inputs and cycling patterns. This will require interactive research and careful integration of research and adaptive management.

AN OVERVIEW OF SPECIAL-STATUS PLANTS IN THE MOJAVE DESERT

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The remarkably diverse native flora of the Mojave Desert is steadily becoming less diverse as a result of habitat destruction, population depletion, and competition from introduced non-native species. In this presentation we provide a numerical assessment of the status of special-status taxa in the Mojave Desert, summarize the success of rare plant management programs, and recommend the most urgent needs for research and conservation. Our discussion will focus on the entire Mojave Desert with an emphasis on the California and Nevada portions.

While a published flora of the Mojave Desert is incomplete, approximately 2600 vascular plant taxa are known to occur in the Mojave Desert floristic province (excluding the higher elevations (> 2500 m) of the Spring, Sheep and Panamint ranges), representing one of the most diverse floristic regions in the United States. Based on number of taxa per area, the Mojave rivals the well-recognized California floristic province in terms of species richness. Approximately 230 taxa in the Mojave flora are, by our definition, considered "special-status" by state or federal listings, federal land management agencies, or by state heritage programs. Several interesting patterns emerge when analyizing the physical and chemical substrates that are associated with Mojave special-status plants. Based on categories of physical substrates, most taxa occur on gravel (25%), sandy (21%), and rocky (18%) substrates, while fewer are found on barrens (13%) and clays (6%). Carbonate substrates, such as limestone and dolomite are havens for rare and endemic species in the Mojave and makes up the most common chemical substrate (31%) that taxa are associated, followed by granitic (29%), alkaline (14%), and volcanic (8%) substrates.

The proportion of the Mojave flora comprised by special-status taxa is relatively low (10% of flora). By comparison, approximately 35% of California's flora is comprised of special-status taxa. Factors that contribute to the low proportion of special-status plants in the Mojave in comparison to the rest of California include: 1) lower levels of endemism; 2) a relatively less disturbed and unfragramented landscape; and 3) the Mojave is still a frontier for taxonomic discovery, having received less attention from academic and avocational interests during the past century. The latter factor illustrates an important management need. There is a growing misconception that we have completely documented the Mojave flora, that we now understand which taxa are rare and endangered, and that we are achieving our management goals to protect them. However, numerous mountain ranges and remote expanses of the Mojave have received only cursory field work at best. The vast majority of herbarium specimens collected over the past century from the Mojave Desert have been recorded along paved roads. New rare and localized endemics continue to be discovered, noteworthy range extensions are frequently reported, and distributional limits of common taxa are only generally understood.

Of the 230 special-status plants known to the Mojave, only about 25% have baseline status reports, and even these reports only minimally document known population distributions and perceived threats. Only about 10% of the taxa have received more extensive status reports, often

accompanied by management plans which summarize the results of cursory surveys and identify protection and research needs. However, even for these taxa we lack basic information about the distribution and biology of the taxa. For only a handful (2-3%) of the special-status taxa have we compiled baseline ecological data that includes population demographics, pollinator information, study of impacts from grazing, mining, or invasive species. And few of these have ongoing long-term monitoring programs. We provide a summary of research and management needs, and case examples of species for which we have waited too long to provide protection simply because critical information was lacking.

We are falling behind in meeting our conservation goals to document, understand and protect rare and endangered plants in the Mojave Desert. Agency programs are often bogged down at the management planning stage. As we move into the next century, agency managers, scientists and avocational groups will need to place greater emphasis on inventory, life-history studies and long-term monitoring as vital components of rare plant conservation programs. We strongly encourage planning efforts to include implementation of critical, comprehensive studies that are crucial for assessing and protecting special-status taxa.

LIVESTOCK GRAZING IN THE MOJAVE DESERT IN RELATION TO THE DESERT TORTOISE

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Like other ecological communities, desert communities are structured through proximate, historic, and evolutionary constraints that modify population dynamics of individual species, and potentially shape the interactions among species (Polis 1991). Desert plant associations are influenced by environmental factors such as timing and amount of rainfall, length of growing season, and ambient temperature. Species interactions, such as competition and herbivory, may also profoundly affect desert plant communities. Grazing and browsing are important selective forces in plant evolution and community structure, and large mammalian herbivores have had major influences on the evolution of defense mechanisms in vegetation (McNaughton 1979; Feeny 1992). Some grazing and browsing has occurred by native mammalian herbivores in the arid southwestern United States during the past 10,000 years (Jefferson 1989), but most recent herbivory by large mammals in the Mojave Desert has been by domestic sheep and cattle.

Domestic grazing by sheep and cattle has occurred on public lands in the Mojave Desert since the late 1500's, with stocking densities peaking at the turn of the 20th century (Hess 1992; BLM 1994). In addition to defoliation of vegetation, grazing by domestic livestock may have other effects of desert ecosystems. Grazing may change soil surfaces physically and chemically, and can change the form and structural complexity of vegetation (Rowlands et al. 1980; Marrs et al. 1989). These changes in turn can potentially affect species diversity of native animals and plants (Waser and Price 1981).

Grazing by livestock has been implicated in the decline of desert tortoise populations (Coombs 1979), yet until recently the effects of domestic livestock grazing has not been studied in a quantitative or scientifically rigorous manner. Earlier research did not investigate the effects of grazing on desert tortoise populations, and assumed that overlap of diet between domestic livestock and tortoises constituted evidence for food competition between the two species (Coombs 1979, Hohman and Omart 1980).

I conducted a two-year study to examine the spring diets of free-living desert tortoises in the Mojave Desert, in relation to cattle grazing. Also examined were year-round diets of free-ranging cattle, so that levels of dietary overlap could be determined between the two species. Unlike earlier studies, foraging was studied in relation to measured food availability. Evidence for interspecific competition was examined in early and late spring by comparing diets and foraging behavior of tortoises located in adjacent grazed and protected areas. In early spring the diet of tortoises was composed primarily of green annual forbs. As soil dried and annual plants senesced during late spring, tortoises reduced intake of annual plants and switched to cacti and other herbaceous perennial plants as their primary food. The diet of cattle showed surprisingly little change during the year and was predominantly made up of annual forbs and perennial grass. In early spring there was a 38% overlap in diets of cattle and tortoises when availability of fresh annual vegetation was greatest, but by late spring overlap declined by 16% because annuals had dried and tortoises shifted to eating cacti, which is not consumed by cattle. In spring of 1993 occurrence of cattle grazing altered the food habits of tortoises and possibly limited tortoise nutrition by causing tortoises to eat an exotic annual grass (*Schismus barbatus*) instead of a more preferred annual forb (*Malcothrix californica*). In addition, tortoises spent more time foraging than those in protected areas, further suggesting that cattle grazing altered the foraging behavior of tortoises. These findings are the first to show that diets of tortoises can be altered by the occurrence of cattle grazing, and provide evidence for diet competition between these animals under natural occurrences of food availability and typical stocking rates.

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DESERT TORTOISE RESEARCH PROJECTS IN THE MOJAVE AND COLORADO DESERTS OF CALIFORNIA: STATUS, TRENDS, DEMOGRAPHY, AND HABITATS

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Several inter-related research programs are underway on demographic attributes of tortoise populations, health, causes of mortality, the condition of the habitats and ecosystems they occupy, and sources of habitat degradation in California. The programs are designed to address critical issues for recovery and management of tortoise populations and the health of the ecosystems in which they live.

WEST MOJAVE POPULATIONS

In 1997 comprehensive surveys were conducted at a 7.8 km^2 study plot at the Desert Tortoise Research Natural Area interpretive center. The plot, established in 1979, was designed to address questions about effects of general recreation and the protective fence on tortoise populations and habitat. Part of the plot is inside the protective fence (4.5 km^2) and part is outside (3.2 km^2). In analyzing the data, I compared results of previous surveys conducted over an 18-year period. Overall, numbers of live tortoises continue to decline, from 593 individuals in 1979 to 77 in 1997. Between 1979 and 1997, densities of all sizes of tortoises declined 90% inside the fence and 93% outside the fence. For adults, the declines in adults have been 86% inside the fence and 94% outside the fence. More live tortoises still occur inside than outside the fence. Fewer tortoises were observed with moderate to severe clinical signs of upper respiratory tract disease (URTD) than in 1989 and 1993; all appeared active, robust, and in good flesh. Sources of mortality include raven predation, vandalism, disease, and vehicles. With 18 years of data, we have learned that existing management practices and the boundary fence are effective in protecting habitat but are not effective in reducing mortality of individual tortoises from raven predation or disease--two landscape-level sources of mortality.

CENTRAL MOJAVE POPULATIONS:
THE NATIONAL TRAINING CENTER, FORT IRWIN

Between 1996 and 1998, 20 tortoise plots were established within the National Training Center (NTC) at Fort Irwin. Research objectives were site- or region-specific and included: (1) characterization of demographic attributes of tortoises, (2) assessment of health and frequency of mycoplasmosis (URTD) and shell diseases, (3) evaluation of sites(s) for suitability for future translocation programs or head-starting neonates in predator-proof enclosures, (4) assessment of potential for critical habitat, and (5) testing summer survey methods. Demographic attributes and health of populations differed by site, and were dependent in part on such factors as geographic location, history of human use, and presence of disease. Two (2.25 km^2 each) of the 20 plots are within the Superior-Cronese critical habitat on the North Alvord Slope and have been protected from military vehicle use by a fence since 1994. They support densities estimated at 6 and 17 tortoises/km^2. On both plots, tortoises are less numerous near active and historic military maneuver areas. Subadult and adult tortoises plots experienced higher annual death rates (>5%) between 1993 and 1997 than reported for stable populations.

Three of the 20 plots are in military training areas (Tiefort Mountains, Eastgate 1 and Eastgate 2). The Tiefort Mountains plot (4.6 km^2 in size), the site with the most comprehensive population data, has a density of 28 tortoises/km^2 and experienced an annual death rate of 1.9% for subadult and adult tortoises between 1992 and 1997. The remaining 15 plots (1 km^2 each) are at the Goldstone Deep Space Communications Center (Goldstone). The sites are not used for military training. Densities were low, estimated at 1-5 tortoises/km^2 overall. A total of 17 live tortoises and 135 shell-skeletal remains were found on the 15 plots. Approximately 80 of the 135 shell-skeletal remains represent tortoises that died between 1994 and 1998.

COLORADO DESERT

One of the long-term study plots in the Colorado Desert, the Chuckwalla Bench, was established in 1977 and has been surveyed 7 times in 20 years. The plot is within critical habitat and is in an Area of Critical Environmental Concern. Tortoise populations have been declining since 1982, probably due to shell diseases (e.g., cutaneous dyskeratosis, Jacobson et al. 1994, Berry 1998, Homer et al. 1998). Data from the most recent survey in 1997 showed the same pattern: declining numbers of live tortoises, high mortality rates, and a high frequency of tortoises with active shell disease.

MULTI-DISCIPLINARY RESEARCH ON DISEASE AND TOXICANTS

Diseases, particularly URTD and shell diseases, appear to be important sources of mortality in some tortoise populations. The effects of diseases can be exacerbated by local weather conditions, climate change, or human activities on site or some distance away. Pathogenesis and epidemiology of URTD and shell diseases are high priority research topics for the desert tortoise (Fish and Wildlife Service 1994). In 1997 and 1998, we tested samples of tortoises from the NTC study sites for mycoplasmosis using three types of tests and clinical signs. None of the tortoises tested positive for *Mycoplasma agassizii* or *M. nov*. sp. at the North Alvord Slope, Tiefort Mountains, or Eastgate 1 and 2 using ELISA tests, polymerase chain reaction techniques, or cultures. In previous years, Jacobson et al. (1996) reported tortoises with positive ELISA tests (4 of 32 tortoises sampled) from the North Alvord Slope. In contrast, 20% of the tortoises tested (N = 8) at Goldstone were positive for one of the pathogens causing URTD. The low population numbers and recent high mortality rates in Goldstone may be due in part to URTD and/or shell diseases. Shell diseases were common in all the NTC populations.

Toxicants appear to be playing a role in tortoise health and disease. Elevated levels of heavy metals and other, potentially toxic elements (e.g., mercury, lead, cadmium, molybdenum) were recorded in the tissues of tortoises salvaged from throughout the desert (Jacobson et al. 1991, Homer et al. in prep). Tortoises with elevated levels of toxicants appear to be more severely ill than control animals. To learn more about the role of potential toxicants, I formed a multi-disciplinary research team that includes a veterinary pathologist (B. L. Homer) and reptilian disease expert (E. R. Jacobson), geochemist (M. Chaffee), lead isotope expert (G. Haxel, J. Wooden), and surficial geologist (B. Houser). We are testing efficacy of new techniques for analyzing tissues of live and dead tortoises, including bone and scute; exploring sources of the toxicants in the environment by testing soils and forage plants; and comparing soil, plant, and tortoise tissue data bases on a site-by-site basis. We recently completed a pilot project on soils and plants from the West Mojave (Desert Tortoise Research Natural Area, Rand Mountains, and Johannesburg), Goldstone, and Chuckwalla Bench.

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SUBSIDIZED PREDATORS IN THE MOJAVE DESERT

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Many natural processes occur in the desert and they are often altered by human activities. Predation is one natural process that results in mortality to desert tortoises (*Gopherus agassizii*) and other animals. To determine the necessity and nature of management actions, it is important to know the levels of mortality and the effect predation has on population viability. Knowing details of the demography of the prey species is essential to understanding the consequences that predation has on the prey population. The probability of mortality from predation and the age at which most mortality occurs are important considerations for evaluating population viability. Furthermore, the geographic extent of predation should be considered in any potential management program.

Subsidized predators are species whose populations survive and often thrive on resources (e.g., food, water, safety, etc.) provided by humans. Common ravens (*Corvus corax*) are an excellent example of a subsidized predator. Their populations have grown precipitously in recent years as a result of the proliferation of human activities in the desert. In a multi-year survey, significantly more ravens were found at landfills and sewage ponds than at other human-dominated and natural areas. Ravens prey on juvenile desert tortoises, a Federally-listed threatened species, much of the tortoises' range. However, not all ravens prey on tortoises, and few appear to prey on them in large numbers. It is not known if raven predation is high enough to prevent tortoise recovery rangewide, but it is likely high enough in some areas to alter success of recovery efforts. Removal of selected ravens known to prey on tortoises will likely aid short-term recovery in some areas, but such efforts should be coupled with aggressive reductions in anthropogenic resources (e.g., garbage) made available to ravens.

ECOLOGY AND MANAGEMENT OF EXOTIC ANNUAL PLANT SPECIES

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Exotic plants comprise a relatively small proportion of the Mojave Desert flora, but a few species dominate many plant communities and have negatively affected or threaten to affect ecosystem integrity. The most studied exotic plant species in the Mojave Desert is the riparian perennial, *Tamarix* spp. While riparian habitats comprise less than 3% of the entire region, the remaining upland area is often dominated by exotic annuals. Because annuals are currently the most widespread and common exotic plants in the Mojave Desert, and because the effects of *Tamarix* spp. are discussed elsewhere in this symposium (Stan Smith), we focus on the ecology and management of exotic annual species.

Widespread and common exotics include four species that are dominant in plant communities throughout the Mojave Desert. *Bromus madritensis* ssp. *rubens* [*Bromus rubens*] is recognized as a potential wildland pest, but relatively little is known about its ecology. It has increased in dominance in the Mojave Desert since the 1970s, and is likely limited in dominance by rainfall and soil nitrogen in the Mojave Desert. *Bromus tectorum*'s ecological effects are well documented in the Great Basin Desert, but not in the Mojave. Its distribution is generally confined to higher elevations above 5,000 feet, yet encroachment into lower elevations has been observed throughout the Mojave Desert. Its ecological effects are virtually unstudied in the Mojave Desert, but they are likely similar to those observed in the Great Basin. Stands of *Bromus* likely deplete soil moisture in spring and create a more competitive environment with native species. *Schismus* spp. (*S. arabicus* and *S. barbatus*) are recognized as potential wildland exotics but very little is known about their ecology in North America. *Schismus* is not invasive in it home range, but it is well-adapted for arid conditions and is not limited by low water and nutrient levels in the Mojave Desert. *Erodium cicutarium* is widespread and has been shown to outcompete native annual plants in the Mojave and Sonoran deserts.

Locally common exotic annuals include seven species that are dominant in plant communities in certain regions or habitats. *Brassica tournefortii* became dominant in cis-montane southern California during the 1980s. It is currently spreading north and east into the Mojave Desert, and since 1995, it has spread away from roads into wildland areas. *Hirschfeldia incana* [*Brassica geniculata*], *Descurania sophia*, *Sisymbrium irio*, *Sisymbrium altissimum*, and *Salsola* spp., are often locally abundant along roadsides, livestock watering sites, and off-highway vehicle staging areas. *Bromus trinii* appears to be ecologically similar to other brome grasses, and where it is abundant, it can fuel the spread of fires and may compete with native. Other exotic annuals are either very limited in their distributions or are confined to urban or agricultural areas.

Despite the ubiquitous nature of many of these exotic annuals in the Mojave Desert, research is necessary to determine the relationships between exotic annuals and native plants. Direct effects of exotic annuals may include competition with natives and alteration of the seedbed environment. Indirect effects of exotic annuals include alteration of fire regimes and biogeochemical cycles. The characteristics and effects of these fires are discussed elsewhere (Rich Minnich, Todd Esque).

We identify several research goals important to the control and management of exotic annuals in the Mojave Desert: 1) document the distribution of exotic species using data collected by state and federal agencies and university researchers, and consolidate information on a public domain database, 2) identify the soil, vegetation and climate attributes that are associated with exotic invasions, 3) determine the common physiological and ecological characteristics of exotic annual species that facilitate their invasiveness, 4) prioritize the most vulnerable habitats that should receive immediate protection from exotic plant invasion and prioritize the exotics of greatest concern based on their invasive attributes, and 5) conduct experimental control of exotic species and restoration of degraded habitats through well-designed, fully-replicated experiments.

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COMPARATIVE ECOLOGY OF DESERT BIGHORN SHEEP AND FERAL BURROS

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The comparative ecology of desert bighorn sheep and feral burros demonstrate how competitive interactions and system disturbances occur when an exotic herbivore is introduced into the habitat of a native herbivore. Desert bighorn sheep evolved their adaptation strategies within desert ecosystems in the United States while feral burros evolved in deserts of northern Africa. A comparison of these adaptation strategies and their consequences comprises the message of this presentation.

Desert bighorn sheep and feral burros are medium-sized ungulates; feral burros weigh about 1.5 to 2 times as much as the largest desert bighorn ram, and 3 to 4 times as much as a bighorn ewe. Bighorn sheep and feral burros are among the largest animals in the Mojave Desert system, and both have large home ranges. During summer months both species restrict movements to remain close (1-2mi.) to permanent water sources, but range farther from water when not under water stress. Both species have life expectancies of 10-15 years in the wild, and longer in captivity.

Space use is directly related to body weight, and space requirements can be estimated based on scalar relationships to weight. Large herbivores use relatively large amounts of space in their daily and seasonal movements; this causes home ranges of larger herbivores to overlap with more individuals of their own species than is the case with small mammals. Large herbivores also tend to be more social than small animals, probably as an adaptation to these spatial realities.

The amount of food an animal requires is another important scalar relationship. Small herbivores, such as rodents, rabbits, squirrels, and hares, have high metabolic rates compared to large herbivores, and require much higher intakes of nutrients and protein. For example, 500kg of small herbivores, such as mice, would expend about 10 times the amount of energy that 500kg of large herbivores would expend to maintain a constant biomass. Thus, a given energy supply will support a much smaller biomass of mice than of burros or bighorn. As a consequence, any degradation of the available plant resources (i.e. energy supply) will impact the smallest herbivores in the system long before the larger herbivores are affected. We found twice the number and twice the biomass of rodents in a lightly used burro area compared to a heavily used burro area. Similar findings have been reported for burro use areas in the Grand Canyon by Carothers et al.

Bighorn sheep are ruminants; they have a 4-chambered stomach and are able to extract high percentages of nutrients from their forage species. The down side of being a ruminant is that forage must be processed into fine particulate size before it can be broken down by the rumen micro-organisms and passed through the system. Thus bighorn must select the most highly nutritious parts of plants because processing time is longer than for a non-ruminant. Conversely, burros have a monogastic digestive system that is not limited by particle size nor as much by processing time. Burros have a large caecum in which fibrous plant materials are broken down, but this arrangement is not as efficient as that of ruminants. Burros, however, can vary their rate of gut clearance and can process more forage by eating more. They can thereby subsist on poorer quality forage that bighorn can. Our studies demonstrated that in Death Valley burro and bighorn diets had a 65% overlap of selected forage species. Overgrazing by burros in the Panamint Mountains of Death Valley has caused changes in the vegetative composition of some plant communities, with favored browse species being reduced in size and number and some species being removed.

Both bighorn and burros have conservative reproductive strategies, and have one young per birth. Generally both species give birth in their third year; however, if forage conditions are good, yearlings may breed and reproduce at two years of age. Gestation periods are about 6 months for bighorn and 12 for burros. Breeding in bighorn is confined to autumn months with births in the spring. Burros breed mostly during summer months when they are congregated near water sources, then give birth the next summer. However, burros are polyestrous and some young may be seen throughout the year.

Lamb survival is a boom or bust phenomenon in the desert. In years having ample precipitation to generate new vegetative growth, and growth of annual plant species, ewes are able to obtain the nutrition needed to produce enough milk to wean healthy lambs. In years having poor precipitation ewes may not conceive, or may have to terminate nursing before the lambs are able to obtain adequate nutrition from forage species. If lambs must be weaned early, they have a slim chance of survival because their nutrition requirements are higher than any other animals in the population including lactating ewes. In the River Mountain herd in Lake Mead National Recreation Area, lamb survival in October-November has averaged about 40 lambs/100 ewes and has varied from 8 to 76 lambs/100 ewes over the past 20 years. Our experience with feral burros is that very few foals die before they are a year old. This agrees with the findings of other investigators in the western United States, and in Australia. This has a profound effect on potential population growth. Bighorn sheep must have about 25 lambs/100 ewes surviving to yearling status in order to maintain stable population numbers. Because burros can survive on poor quality forage and lose very few foals they may have population growth of as much as 20% per year. While bighorn populations frequently struggle to maintain their numbers, burro populations may double in size within 3.5 years.

Burro impacts to bighorn habitat include soil compaction of trails, dust bath areas, and areas around springs. Compaction of burro trails can equal the compaction of long-established dirt roads, which creates an unsuitable site for plant growth. Burros eat many of the same plant species as native herbivores, and have been shown to negatively affect the composition of plant communities by removing native bunch grasses, churning the soil surface and thereby reducing soil crusts and soil moisture and promoting growth of weeds. Small mammals decrease in numbers and diversity in areas used by high densities of burros. Because of their larger body size and digestive system, burros eat more than bighorn sheep, and can not only survive on forage with low nutrient content by adjusting their intake rate, but they can successfully nurse foals to weaning under poor forage conditions. Burros require significantly more water per unit body weight than bighorn sheep because their urine is more dilute than that of bighorn, and their feces has higher water content. Burros also congregate and remain for extended periods of time at water sources. Monitoring with time-lapse cameras and camcorders showed that desert bighorn did not approach water sources when 3 or more burros were in the immediate vicinity.

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MANAGING FIRE AND INVASIVE PLANTS IN THE MOJAVE DESERT: DEFINING AN INTEGRATED RESEARCH PROGRAM TO ADDRESS KNOWLEDGE GAPS

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Incidence of fires and their spread have recently increased, at least in localized areas, throughout desertscrub habitats in the Mojave Desert. These increases are often attributed to alien annual plants increasing fuel loads and fuel continuity, coupled with increased human use of desert habitats. Greater human contact in formerly wild areas causes disturbances, augments invasive species introductions (Brooks 1995) and increases ignition sources (Fish and Wildlife Service 1994). This scenario promotes a positive feedback process known as the grass/fire cycle (D'Antonio and Vitousek 1992). The Mojave Desert fire problem is an invasive plant issue. The primary invasive species that fuel desert wildfires in the upland habitats of the Mojave Desert are *Schismus barbatus* and its close relative *S. arabicus*, as well as, *Bromus madritensis* ssp. *rubens*. Other alien plant species probably could fill this niche if the current species were reduced in abundance, eliminated by manipulations, or simply out-competed (Young et al. 1992).

The grass/fire cycle has dramatically altered some localized areas in the west Mojave Desert at Opal Mountain and Stoddard Mountain near Barstow, California (Fish and Wildlife 1994, Brooks 1998); the east Mojave around the Goodsprings Mountains in Nevada; and in the northeast Mojave in the Pakoon Basin, Arizona. Recent observations in some of these areas suggest that episodic burning reduces the survival of native perennial plants dramatically. But what is the likelihood that the grass/fire cycle will become more widespread, and what are the long term implications for biodiversity in the Mojave Desert? These are some of the challenges of managing biotic reserves in the Mojave Desert today. Currently we have few answers for these important questions, but researchers are working to fill knowledge gaps about Mojave Desert fire and invasive plant ecology in a variety of ways. Unraveling these questions about habitat change will require understanding the complex interactions between fire and plants and animals.

Effects of fires on desert plants and animals can be categorized as direct and indirect effects (Whelan 1995). Direct effects result in damage or death to plants and animals because of excessive heat and smoke. Indirect effects of fire result from habitat changes that affect growth, survivorship, and recruitment for plants and animals. The direct effects of fire on perennial plants has been quantified in the Colorado Desert (O'Leary and Minnich 1981, Brown and Minnich 1986) the west Mojave Desert (Brooks 1998) and the northeastern Mojave Desert (Esque et al. Unpublished Data). Some information will be presented from postfire transects to find animal mortalities, however the direct effects of fire on animals are difficult to quantify using observational studies. Little empirical information exists about the indirect effects of fire disturbances on plants and animals in the Mojave Desert (Esque et al. In Prep. a).

Most of the information about responses to fire by plants and animals in the Mojave Desert are from observational experiments. Although observational experiments can be a powerful method to describe patterns, their primary drawback is uncertainty about conditions prior to disturbances. Thus we are often left wondering if the patterns we observe are due to a source of variability that was not accounted for in the study. One alternative to observational experiments is manipulative experiments. The focus for such manipulative experiments include biogeochemistry, plant physiological ecology, plant/plant interactions, plant/ animal interactions and disturbance/restoration ecology. Manipulative experiments can be used to predict the outcome of natural or anthropogenic disturbances, and provide information used to develop or modify management practices. One of the most powerful means of solving questions about environmental change is to combine observational and manipulative experiments into an integrated research program. This approach has been used to answer questions about fire and community ecology in the western Mojave (Brooks 1998), and is also being used in the northeastern Mojave. In 1998, a multi-agency group was organized to consider the need for fire ecology/restoration research in the Mojave Desert. A proposal was developed for a desert fire ecology/restoration program that would be replicated in several vegetation associations throughout the Mojave Desert.

How can we use what we know about fire disturbance in the desert to conserve natural resources in the Mojave Desert now? What information do we need to manage the deserts for biodiversity and other management mandates?

There is still a lot to learn about managing fires and alien plants in the Mojave Desert. Following the tenets of restoration biology, "first do no harm" (Meffe and Carroll 1997). When fires occur in Mojave desertscrub habitats, it is generally agreed that they should be suppressed, aggressively. Fire suppression activities can be managed to minimize disturbances that are inherent in fighting fire, however, the management prescriptions should be tailored to specific habitat types (Duck et al. 1997). Anthropogenic activities that encourage habitat disturbance and increase ignition sources should be curtailed through education and management prescriptions (Brooks 1995). Alien plant populations should be identified, contained and controlled aggressively (DeFalco and Brooks -- this symposium). Finally, we need an integrated research program to help fill knowledge gaps about fire effects, habitat recovery, restoration, and weed abatement.

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DESERT RESTORATION: DO SOMETHING OR WAIT A THOUSAND YEARS

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UNDERSTANDING DISTURBANCE

Impacts to the desert can be loosely divided into local and widespread impacts. There is rarely a complete distinction between the two but in general the local impacts include such things as mining, pipelines, roadways, off-highway vehicle impacts, military operations and localized ranching impacts. Widespread impacts to the Mojave Desert include overgrazing, feral animal grazing and trailing, the invasion of non-native plant species, urbanization and its related affects, and the atmospheric deposition of nitrogen from pollution related dryfall. It is unfortunate, but adverse impacts usually lead to further impacts. For example, the increase in surface nitrogen on the desert's surface favors the establishment of exotic plant species, and exotic plant species may increase fire frequencies and intensities with very detrimental effects on native plant communties.

While historical photos, written descriptions and air photos can provide a good first look at above ground disturbance patterns, some of the most important impacts of human activities are the often unseen effects at and below ground level. There are physical, hydrologic, chemical and biological changes after disturbance which make conditions much less favorable for soil microbes and plants. These changes include reduced infiltration and fertility, increased compaction and soil strength, increased erosion and reduced biological activity.

Physical Changes

Construction activities, equipment operation, agriculture, animal trampling and off-road vehicle operation can remove soil surface armor including crusts and gravel mulches. This can dramatically increase wind and water erosion. These activities also degrade soil structure. Even minimal activity can have significant adverse effects on soil structure. Loamy soils are more sensitive to compaction than sandy soil and wet soils are much more vulnerable than dry soils. The strength of soils that have been compacted increases much more quickly than undisturbed soil as the soil dries out. Penetrometer resistance, a measure of soil strength, is as much as 155% higher in single tank tracks than in adjacent, undisturbed soils, and most desert military camp roads from WWII remain extremely compacted even after 40 years. This increase in soil strength inhibits root growth and limits water and air exchanges at the soil/air interface.

Increasing soil strength reduces root growth and survival and adversely affects soil microbes. The changes in soil structure can reach much deeper than might be expected. Significant adverse changes were observed at 25 cm depth from as little as three passes with a four wheel drive vehicle over moist soil. In some cases soil strength can be significantly increased by one pass, but more commonly the soil strength increases with repeated passes. Values of soil strength after

10 passes of a four wheel drive vehicle on one test day all exceeded 67 kg/cm2, more than three times the minimum amount causing serious reduction in root growth.

Hydrologic Changes

Compaction leads to the destruction of larger soil pores with related, detrimental changes in infiltration. Compaction and tracks also reduce surface storage and often increase the rate of runoff and gully initiation. Soil compaction and modification of the ground surface by tracked vehicle movement and roads leads to long-term changes in drainage patterns and infiltration. Infiltration rates were reduced 56% in a former vehicle parking lot at one desert military camp after more than 30 years.

The removal of vegetation can also reduce infiltration as the plant mediated infiltration benefits (stem flow, litter, etc.) are eliminated. Infiltration in dry creosote bush soil was double that of dry bare soil and infiltration in wet creosote bush soil was almost five times higher than wet bare soil. During intense summer rains these changes in infiltration are accentuated. Areas with good plant cover may hold and save much of the rain that falls in intense storms while areas that have been disturbed experience sheet flow, flash floods and severe erosion. This suggests that fine soil particles and organic matter accumulating beneath the plant canopies improve the water and nutrient retention capacity of desert soils.

Disturbance most commonly limits water infiltration into the soil, reduces surface roughness and surface retention, reduces soil moisture storage for water that makes it into the soil and increases runoff intensity and flood frequency. These can increase gully or stream cutting and lower water tables over extensive areas. Disturbance that removes plants affects soil development and changes soil moisture and structure for soil microbes and plants.

Chemical Changes

Disturbance can also dramatically change soil chemistry. Construction activity or severe erosion can remove the often very thin layer of fertile topsoil, leaving subsoil that is nutrient limited. Disturbance can also add nitrogen, changing the competitive balance between perennials and annuals, exotics and native species. These, in turn, affect soil microbes.

Chemicals that are poisonous to many species may also be introduced. Contamination of agricultural soils and illegal dump-sites with biocides is common. Farmlands may also have excessive nitrate levels. Available phosphorous and other biologically mediated nutrients may be depressed by disturbance and this may limit establishment and growth.

Biological Changes

Disturbance commonly decreases soil organic matter. In plowed field agriculture, repeated tillage, increased soil temperatures and added nitrogen tend to burn off soil organic matter. Less dramatic but equally important changes occur with lower intensity disturbance. Disturbance also eliminates or reduces populations of soil burrowing organisms. Ants, burrowing lizards and mammals may be particularly important for recovery of degraded areas. Compaction and disturbance can also reduce soil organism populations. Total numbers of fungi, bacteria, nematodes and arthropods are much lower on compacted soils. Pathogens were common on the compacted soils and rarely isolated on control plots.

Removal of plants can remove symbiotic soil organisms critical for plant survival. Compaction can also limit infection by mycorrhizae which are unable to extend hyphae into the compacted soil. Changes in soil moisture caused by reduced infiltration and lower moisture holding capacity may make nodulation by rhizobia difficult or impossible. Changes in soil structure and elimination of soil burrowing organisms can limit movement of inocula in the soil.

Surface disturbances also remove cryptobiotic crusts which, when in place, reduce wind and water erosion and evaporative water loss. Crusts also form catchment sites for seed and safe-sites for seedling establishment.

UNDERSTANDING RECOVERY

Extreme temperatures, intense solar radiation, limited moisture and the low fertility of desert soils combine to make natural recovery of disturbed desert sites very slow after disturbance. In addition, conditions for plant establishment are rare and it may take 60 years to reach predisturbance biomass and 180 years for reasonable recovery of species diversity on non-compacted soils. Recovery times for compacted and severely disturbed soils may reach 1000 years or more.

RESTORATION DECISIONS

Often the most difficult step in restoration is removal of the source of the impact. This often means changes in current land use patterns and can include the removal of feral animals, grazing restriction or removal, route designation for off-highway vehicles and road closures.

Once the source of the impact has been removed, site rehabilitation can proceed. However, tough choices have to be made in most desert restoration projects. The cost of comprehensive rehabilitation including site preparation, seed collection, plant propagation and care, outplanting and site maintenance may well exceed $10,000 per acre. This far outweighs the value of the land ($300/acre). Except in rare cases, the best that can be done is a modest rehabilitation to facilitate natural recovery. This would typically include decompaction, adding weed free compost to some spots, it may also include pitting and surface roughening, seeding with site collected seeds, and very limited container planting with tree shelters and supplemental deep pipe irrigation (as a future seed source and resource island). For $500 - $2000 an acre these strategies can improve visual appearance and speed recovery.

Other restoration strategies include removal of exotic species with the use of herbicides and/or fire and visual restoration using an artificial surficial coloring compound. However, it should be recognized that with all rehabilitation efforts, even the most limited is costly, labor intensive and time consuming. It is also true that even after site rehabilitation is complete it may still take decades or longer for a site to recover all of its components and functions. For these reasons, it is always better to prevent disturbance than to attempt to restore a damaged site.

CHALLENGES IN RESTORATION

Many organizations in the Mojave Desert have demonstrated the desire and ability to restore damaged lands. However, desert restorationists face several significant challenges. First, there is no complete understanding of the extent and type of disturbances that exist in the desert. Without this information, it is difficult to assess the highest priority restoration needs. Second, there is very limited funding available for restoration projects. Third, there are currently only a few skilled restoration specialists in the desert either in private industry or in government employment. Fourth, the most affective and cost efficient restoration techniques have not been determined. Lastly, there is only a limited supply of appropriate seed and plant material for restoration projects. Two regional working teams, the Desert Lands Restoration Task Force and the Southern Nevada Restoration Team, are working collaboratively and across management boundaries to address these restoration needs.

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SURFACE PROCESSES AND LAND MANAGEMENT ISSUES IN THE MOJAVE DESERT ECOSYSTEM

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The present physical condition of the Mojave Desert ecosystem results in part from landform changes of the recent past. Historic-age (i.e. within the past 100-150 years) changes in alluvial and eolian geomorphic systems have altered large portions of the landscape. For example, alluvial channels widen, deepen, and refill; portions of alluvial fans aggrade and downcut by debris flow and streamflow; and inactive sand dunes destabilize and active dunes fields become stable. Informed land-management decisions require understanding the natural variability of surface processes obtained through analysis studies of recent landform changes and historic climate variation.

In the case of alluvial and hillslope systems, this recent, short-term landform evolution is driven directly by hydrologic processes. The rate and amount of landform change is affected by climate variation and human activity, such as grazing, mining, military operations, and recreational use. Establishing patterns of historic-age climate variation and recent landform development are crucial for understanding the present physical condition of the ecosystem, for evaluating the affects of human activity, and for understanding rates of landscape recovery. Knowledge of the spatial and temporal distribution of these young landforms enhances vegetation maps, complements existing surficial geologic maps by elaborating details of recent alluvial activity, and contributes directly to regional mapping of the ecosystem by remote sensing. Land management agencies need this information to unravel the affects of natural variation and human activity on desert landforms and to estimate the rate of surface recovery following disturbance.

An important hydrologic aspect of the ecosystem with an historical component is the frequency of surface runoff. Frequency of runoff is critical to understanding landform evolution because sediment movement by water is one of the principal processes effecting geomorphic change. For this reason, recoverability of low-relief desert landscapes from human disturbance is affected largely by runoff frequency. Sediment movement during runoff eventually removes or covers the disturbance in a time span that depends on the frequency of overland flow. In addition, runoff frequency is useful for modeling the availability of surface water, recharge of shallow aquifers, erosion, sediment yield, and surface stability.

Geologic information about runoff frequency is in the deposits of artificial impoundments, which develop on the upslope side of railbeds and other linear features where they cross alluvial fans and piedmonts. Railroads (most are now abandoned) were constructed in much of the Mojave Desert around the turn of the century. Alluvial deposits in the impoundments record the number of times water and sediment entered the impoundment, which is the number of times that rainfall produced substantial overland flow in the past 90 years or so. This information allows one to calculate average runoff-recurrence interval and in certain cases to calculate surface erosion and sediment yield of individual runoff events.

As part of the USGS Mojave Desert Ecosystem Science Program, we have begun analysis of historic-age climate and field studies of artificial impoundments. These studies are producing results that should be useful for addressing a variety of land management issues. Work on the historic aspects of surface runoff is ongoing in Valjean Valley 40-km north of Baker, California. The Tonopah and Tidewater Railroad was constructed here in 1906 and abandoned in 1940. Since 1906, up to1 m of sediment has accumulated on the upslope side of the railbed wherever it crosses active washes. Sedimentologic and stratigraphic analysis of these deposits indicate that runoff large enough to cause deposition of sediment happened only 15 times since 1906. The average runoff-recurrence interval is 5–6 years for the 87-year period 1906–1993.

This result, although preliminary, has practical application for Valjean Valley and other areas of similar climate. For example, it may take 5–6 years before runoff occurs that is large enough to eliminate or reduce vehicular tracks and trails on alluvial fans and in washes. Likewise, substantial recharge of shallow aquifers from surface runoff probably occurs only about this often.

To assess the variability of historic-age climate in the Mojave Desert, we compiled a database of daily precipitation and temperature from 35 weather stations over the period 1897–1996. The precipitation data were analyzed station-by-station for total annual precipitation, seasonal precipitation, days of precipitation annually and seasonally, and precipitation intensity as expressed by 24-hour rainfall totals. These analyzes were averaged using a standardized index to form regional time series of precipitation variability. The results are preliminary, but they suggest that precipitation in the Mojave Desert has varied substantially over the period 1897–1996. For example, from 1944–1978 precipitation was generally below normal across most of the desert regardless of season. In addition, the number of days with measurable precipitation has increased over the period; this is coincident with a decrease in precipitation intensity. The below normal precipitation during 1944–1978 was evidently related to global climate variation. Sea-surface temperature was low and atmospheric pressure was high over the eastern Pacific Ocean at this time; these conditions would suppress precipitation.

This climate variability has important, although presently untested, implications for both the biologic and physical environment of the desert. For instance, the present density, cover, composition, and distribution of vegetation may reflect this recent climate variability. Surface runoff was probably less frequent during the 1944–1978 period of reduced precipitation. Less frequent runoff should result in diminished recharge of shallow aquifers. Relatively infrequent runoff could increase in-channel alluviation of major washes because of fewer destructive floods and increased riparian vegetation. Finally, the recovery rate of surface disturbances was probably slower during the period of reduced precipitation, as there was less movement of water and sediment.

RIPARIAN VEGETATION ALONG THE MOJAVE RIVER

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INTRODUCTION

Assuring an adequate water supply for the remaining native riparian vegetation along the Mojave River is an important element in the court's recent decision regarding water rights in the Mojave River basin (City of Barstow versus City of Adelanto, 1996). As part of the judgment, California Department of Fish and Game proposed "target" ground-water depths to sustain the native vegetation in several critical areas. However, even with the target depths specified in the judgment, many questions remained. How accurate were the target water-table depths, and how important is soil moisture? An inventory of the riparian vegetation (areal extent, density, and diversity) was needed in order to define current vegetation conditions. An estimate of the amount of water transpired by the vegetation was needed in order balance sub-basin water budgets and to determine the amount of water that would be required to maintain current vegetation. And finally, there was a need to quantitatively define the hydrologic conditions necessary to maintain healthy and reproducing native vegetation.

In 1995, the U.S. Geological Survey, Mojave Water Agency, and California Department of Fish and Game agreed to conduct a cooperative study of riparian vegetation along the Mojave River, which would include an inventory of vegetation and an estimate of its water use. The results of that phase of work are published (Lines and Bilhorn 1996). Although much work had been completed to define markedly different hydrologic conditions along the Mojave River (Lines 1996), its relation to health and reproduction of vegetation was still poorly understood. In 1997, the U.S. Geological Survey, in cooperation with Mojave Water Agency, began work to define the health and reproduction of native riparian vegetation and to quantitatively define its relation to hydrologic conditions.

PLANT INVENTORY

The extent and areal density (percent canopy area) of riparian vegetation, including both phreatophytes and hydrophytes, were mapped along the 100-mile main stem of the Mojave River from Forks Reservoir to Afton Canyon (Lines and Bilhorn 1996). Mapping was aided by vertical false-color infrared and low-level oblique photographs taken during 1995. However, positive identification of plant species and stress required field examination. The predominant native riparian species along the Mojave River include Fremont cottonwood (*Populus fremontii*), Black willow (*Salixgooddingii*), and Honey mesquite (*Prosopis glandulosa*). Native plant communities that were mapped included cottonwood-willow woodland, monotypic cottonwood woodland, mesquite bosque, a willow-baccharis streamside community, and hydrophytes. Desert willow (*Chilopsis linearis*)grows along the driest ephemeral reaches of the Mojave River and, although it is a xerophyte, it was mapped to document its extent during 1995. Saltcedar (*Tamarix ramosissima*), the most widespread and prevalent plant in the Mojave River riparian zone, was also mapped in order to document its extent. The plant communities were mapped using the following areal densities: 1-10, 11-40, 41-70, and 71-100 percent.

During 1995, there were about 10,000 acres of riparian vegetation and about 2,700 acres of desert willow (areal densities greater than 1 percent) along the Mojave River main stem. A total of about 12,000 acres of the riparian zone had been disturbed, mainly for agricultural and residential uses. The total area of cottonwood-willow woodlands was about 2,600 acres, including about 420 acres showing signs of water stress. There was about 620 acres of monotypic cottonwood woodland, about 120 acres of streamside willow-baccharis, and about 40 acres of hydrophytes.. There were about 1,100 acres of mesquite bosque, but most of the mesquite showed signs of water stress. Saltcedar was the dominant species in about 5,200 acres.

CONSUMPTIVE USE

The consumptive use of water by different areal densities of riparian plant communities was estimated using water-consumption data from a select group of studies in the southwestern United States (Ball et al. 1994. Bowie and Kam 1968. Lines 1996. Weeks et al. 1987. U.S. Bureau of Reclamation 1995). Estimates of water consumption were considered for use if they were obtained using water-budget, streamflow-depletion, or micrometerological techniques and if the estimates were representative of fairly large areas of a flood-plain environment. Tank-lysimeter studies and plant-specific physiological techniques, such as stem-flow gauges, were not used because converting water use of isolated plants was problematic when estimating water use in a complete woodland environment . Another criteria used for acceptance of water-consumption data was the documentation of the areal densities and species of plant studied. Many factors define an area's climate, but free-water surface evaporation is an excellent indicator of the climatic variables that also partly control transpiration of plants, such as solar radiation, air temperature, and wind. Thus, results of previous studies were considered transferable if annual free-water surface evaporation was within about 10 percent of that along the Mojave River, which ranges from about 60 to 85 inches. Distinct communities of riparian vegetation grow in distinct hydrologic niches along the Mojave River and in these same niches throughout the southwestern United States (Meinzer 1927) and, in the author's opinion, results of select studies are transferable.

Based on the above studies, maximum annual water use of cottonwood-willow woodland, monotypic cottonwood woodland, and the streamside willow-baccharis community was assumed to be 4.1 feet for the density range of 71-100 percent. The maximum annual water use was assumed to be 1.4 feet for mesquite and 2.8 feet for saltcedar. Hughes (1972) and van Hylckama (1974) both found that a density reduction from 100 to 50 percent reduced water use of saltcedar only about 10 percent. Therefore, in estimating water use for each mapped plant community, it was assumed that there is a 10-percent reduction in water use between the mapped density ranges of 71-100 percent and 41-70 percent. Water use was assumed to decrease linearly for the mapped density ranges of 1-10 and 11-40 percent. The species/plant-density/water-use model was verified on the basis of seasonal depletion of base flow (natural ground-water discharge) by riparian vegetation at Afton Canyon (USGS gaging station 10263000 on the Mojave River). Seasonal depletion of base flow averaged about 600 acre-feet per year, and 600 acre-feet was the estimated annual water use of riparian vegetation using the above model.

Total consumptive water use by the 10,000 acres of riparian vegetation was estimated at about 17,000 acre-feet during 1995. About 12,000 acre-feet was consumed by native riparian species and about 5,000 acre-feet by saltcedar. Barring major changes in the riparian vegetation along the Mojave River, the estimated consumptive use during 1995 should represent fairly accurately consumptive use during most years.

PLANT HEALTH AND REPRODUCTION

Vegetation and hydrologic data were collected, mainly during the growing seasons of 1997-98, at three instrumented sites in cottonwood-willow woodlands and at two instrumented sites in mesquite bosques along the Mojave River. The instrumented cottonwood-willow sites included a healthy and reproducing woodland in a "natural" setting, a water-stressed and non-reproducing woodland, and a severely stressed woodland with extremely high mortality. The mesquite study sites included a healthy and reproducing bosque and a severely stressed bosque with no reproduction. In addition, vegetation and limited hydrologic data were collected periodically at another 16 synoptic sites in order to include a widespread distribution and a wide range of hydrologic conditions.

At the instrumented sites, shallow piezometers were used to monitor the water table, access tubes were used for neutron logging in order to determine volumetric soil moisture, psychrometers were installed at various depths in order to determine soil-water potentials of "dry" soils, and tensiometers were used to determine soil-water potentials of "wet" soils. Leaf-water potentials and leaf-area indices (LAI) were monitored periodically. In addition, plants within 20x60 meter plots were inventoried at each study site. Tree growth characteristics measured or noted in each plot included: species, diameter at breast height, tallest tree, areal density (percent crown area), percent live crown volume, percent survival, density of trees, and recent reproduction. At selected sites, analyses of stable hydrogen and oxygen isotopes were performed on soil water, ground water, surface water, and tree water in order to determine the source(s) of water utilized by the plants. A backhoe was used at six cottonwood-willow sites (both healthy and stressed) to dig trenches to the water table in order to examine tree-root distribution and its relation soil moisture and ground water.

Comparison of leaf-water potentials and soil-water potentials indicate that cottonwood-willow woodlands and mesquite bosques probably rely on both soil water and ground water. The shallowest available ground water is in the capillary fringe (a zone of aeration), which is in contact with both the water table below and the belt of soil moisture above (Meinzer 1923). Water is removed at the top of the capillary fringe and from the belt of soil moisture by plant absorption and evaporation. The capillary fringe is replenished with moisture at the bottom where it is in contact with the water table. Except during infrequent periods of heavy surface wetting, soil moisture is replenished by upward movement of water from the capillary fringe. Although the vegetation may utilize some soil moisture, observations of tree-root distributions in trenches and the stable-isotope data indicate that they mainly rely on ground water.

Because of low (more negative) soil-water potentials near land surface in most areas, it was concluded that only in extraordinary conditions could seeds germinate and young seedlings be sustained by soil moisture until roots reach the capillary fringe. But, instead, the trees usually reproduce by root sprouting. This was supported by field observations.

Regression analysis of the data from both cottonwood-willow woodlands and mesquite bosques indicate that there is a strong relation between depth of the water table and LAI. There also is a strong relation between water-table depth and recent reproduction from root sprouting. However, relations of water-table depth to other measured tree-growth characteristics were not statistically significant. Nevertheless, ground water has been identified as the main source of the water utilized by the trees, and health (LAI) and reproduction was found to be strongly dependent on the depth of that source.

The riparian vegetation is heavily dependent on ground water in the capillary fringe just above the water table, and the vertical distribution of roots (observed in trenches) allows for seasonal water-table fluctuations of 2 to 3 feet. However, sustained water-table declines and associated declines of the capillary fringe of only a few feet can cause high mortality of riparian vegetation. Along one reach of the Mojave River, channel incision and lowering of the water table in the flood-plain aquifer by 5 feet resulted in mortality of 60-95 percent in the cottonwood-willow woodland. Where the water-table decline was less than 5 feet, stand mortality was 7-13 percent; however, trees exhibited significant loss of leaf area (Auble et al. 1998).

Along another reach of the Mojave River where water-table depths are normally 10 to 15 ft below land surface, sustained water-table declines (caused by ground-water pumping) of about 10 feet have resulted in mortality of 70 percent in a mesquite bosque; declines of about 20 feet have resulted in stand mortality greater than 95 percent. In areas where the mesquite mortality was greatest, the surviving mesquite now grows as small plants 1 to 3 feet tall and probably is relying on meager soil moisture for survival. Similar declines in mesquite (*Prosopis valutina*) stature have been observed in Arizona where pumping also has lowered the water table (Stromberg 1991). The mesquite bosques have been transformed from a riparian plant community to a xeric community.

FUTURE STUDIES

Study plots in which various tree-growth characteristics were measured afford the opportunity to quantitatively monitor future vegetation changes along the Mojave River. Measurements of LAI and water-table depth are key factors, as well as observation of reproduction.

The relations between water-table depth and plant-growth characteristics (LAI and reproduction) will be tested on a regional scale during the next three years as part of the U.S. Geological Survey's southwestern ground-water program. Species to be studied include Fremont cottonwood (*Populus fremontii*), Narrowleaf cottonwood (*Populus angustifolia*), Black cottonwood (*Populus trichocarpa*), Honey Mesquite (*Prosopis glandulosa*), and Velvet mesquite (*Prosopis velutina*).

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A BRIEF HISTORY AND SYNOPSIS OF USGS RESEARCH ON THE DESERT TORTOISE

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The desert tortoise (*Gopherus agassizii*) has the widest latitudinal distribution of any of the four species of North American tortoises, extending from southwestern Utah to northern Sinaloa State in Mexico, a range of 1,100 kilometers. Across this vast range the tortoise occupies a staggering diversity of plant communities from tropical deciduous thorn scrub in Mexico, across the Mojave and Sonoran Deserts, to the edge of the Great Basin Desert and the Colorado Plateau (Ernst and Lovich, 1994).

Despite the broad distribution of the desert tortoise, some biologists reported widespread population declines in portions of the Mojave and Sonoran Deserts in the 1980's. Although no one knows how many tortoises there were prior to the arrival of humans in the southwest, they were assumed to be plentiful by some, but not all, biologists (Corn, 1994; Bury and Corn, 1995). However, widespread alteration of the desert by overgrazing, off-highway-vehicle use, military training activities and urban development has generally been detrimental to the tortoise and other desert wildlife (Lovich and Bainbridge, in press). As a result, tortoise populations in the western Mojave Desert and southwestern Utah have experienced significant declines.

In partial recognition of the problem, the United States Fish and Wildlife Service listed the tortoise population on the Beaver Dam Slope in Utah as threatened in 1980 under the authority of the U.S. Endangered Species Act. In 1989, the Fish and Wildlife Service used an emergency listing to declare populations north and west of the Colorado River as endangered. The next year formal listing for the "Mojave" population was established as threatened.

The history of research on the desert tortoise is closely tied to the evolution of its conservation status. Prior to the 1970's, little was know about the distribution or ecology of desert tortoises and published literature on the species was largely anecdotal. During the 1980's, the perception of widespread declines by some scientists precipitated a new era of desert tortoise research. Fear of listing under the Endangered Species Act prompted land management agencies to fund research to determine the distribution and abundance of desert tortoises, especially in California. Much of the voluminous literature produced during this period was in the form of government reports that were not subjected to rigorous peer review by the scientific community (Germano and Bury, 1994).

The final listing of the desert tortoise in 1990, the publication of the Recovery Plan in 1994, and designation of Critical Habitat in the same year heralded a new era in tortoise research. Critical summaries of existing information (Bury and Germano, 1994) and significant new research (Spotila et al., 1994) were published soon after the listing. Coincident with this new phase of tortoise conservation, was the creation of the National Biological Survey (Service) in 1993 consolidating research scientists from other bureaus of the U.S. Department of the Interior including the Bureau of Land Management, Fish and Wildlife Service, National Park Service into one organization. This reorganization brought together a core of desert tortoise expertise that had not existed previously under one roof. The National Biological Service was short-lived and in October of 1998 was merged with the U.S. Geological Survey as their Biological Resources Division.

Recognition of the need to conduct coordinated research on the desert tortoise led to the creation of the Desert Tortoise Research Project (DTRP) within the National Biological Survey in 1993 and its continuation in the USGS. Current membership in the group includes: Drs. Hal Avery, Bill Boarman and Jeff Lovich at the Canyon Crest Field Station; Dr. Kristin Berry, Box Springs Field Station; Dr. Chuck Douglas, University of Nevada, Las Vegas Field Station; Mr. Todd Esque and Ms. Leslie DeFalco, St. George Field Station; Mr. Phil Medica, Las Vegas Field Station; and Dr. Cecil Schwalbe at the Sonoran Desert Field Station.

The Coordinator of the DTRP, Jeff Lovich, works with the Chair of the Technical Advisory Committee (TAC) to the Management Oversight Group (MOG) for the desert tortoise to schedule, develop the agenda for, and co-chair meetings between the TAC and the DTRP. Meetings occur on an semi-annual basis to present updates on ongoing and completed research and to discuss future research priorities. As funds and personnel are available, the DTRP responds to the high priority research needs identified by the group.

The MOG is composed of representatives from Regional offices of the Fish and Wildlife Service, the Bureau of Land Management, and state fish and game agencies within the range of the desert tortoise. The MOG was formed based on the recommendations of a BLM report on desert tortoise habitat management, published in 1988. The overall goal stated in the report is "...to manage habitat so as to ensure that viable desert tortoise populations exist on public lands." The TAC includes representatives from various agencies, organizations, and groups with special knowledge of tortoises and their habitats.

Numerous research projects have been, or are being, conducted that will assist state and federal land managers who are trying to encourage the protection and recovery of desert tortoise populations. Projects include investigations of reproductive ecology, surveys of population density, feeding ecology, competitive interactions from livestock for food plants, transmission of disease, and predator ecology. A complete listing of USGS research projects and summaries is available through the Science Information System at http://cristel.nal.usda.gov:8080/star/brd.html. Readers interested in details beyond the brief summaries presented below should visit that web site and search on the keyword "tortoise."

Jeff Lovich is one of three Research Managers for the USGS Western Ecological Science Center and he supervises the majority of scientists in the USGS who conduct research on the desert tortoise. Jeff is the Principal Investigator (PI) of an ongoing study of geographic variation in reproductive output of the desert tortoise (for details see http://www.werc.usgs.gov/cc/reprod.htm). Co-PIs include Hal Avery, Phil Medica and Todd Esque. Preliminary data show vast differences in reproductive output of tortoises from year-to-year and site-to-site. In wet years more females reproduce and they produce more clutches of eggs. Jeff is also interested in behavior and habitat selection by tortoises in disturbed areas, and the ecology of western pond turtles (*Clemmys marmorata*) in the Mojave River. The following research summaries pertain only to the scientists Jeff supervises.

Hal Avery is interested in the physiological and nutritional ecology of reptiles with emphasis on the desert tortoise. He is the PI on studies to assess impacts of livestock grazing on desert ecosystems and foraging ecology of desert tortoises in particular.

Bill Boarman's interests include behavioral ecology and conservation biology. He is the PI of two multi-agency projects. The first focuses on raven ecology, with emphasis on the ecology and management of ravens and their impacts on desert tortoises. The second is examining the effects of roads and roadside barriers on mortality in, and fragmentation of, vertebrate populations.

Although more familiar for his research on bighorn sheep, Chuck Douglas is conducting a major study of desert tortoise survivorship at Lake Mead National Recreation Area. Data collected from his study suggest that local variation in annual plant abundance has a strong influence on mortality rates, with tortoise survivorship decreasing significantly when annual food plants do not germinate.

Lesley DeFalco is currently a Ph.D. student at the University of Nevada, Reno. A member of the Saint George Field Station in Utah, Lesley conducts research on the competitive effect of the introduced annual grass *Bromus madritensis* ssp. *rubens* on native Mojave Desert perennials after wildfire, and has studied the influence of cryptobiotic soil crusts on winter annual plants and the foraging movements of desert tortoises.

Todd Esque, also of the Saint George Field Station, is working on his Ph.D. at the University of Nevada, Reno too. Todd has studied the diet, diet selection, and feeding behavior of the desert tortoise in southwestern Utah. His doctoral research focuses on the effects of alien plant invasions and fire on native plants and animals in Mojave Desert scrub and Sonoran Desert scrub communities.

Phil Medica is one of the best known desert ecologists in southern Nevada. He has several large projects including: 1) a project looking at the survivorship and movements of translocated tortoises; 2) a study looking at how movements, behavior, reproduction and survivorship differ under varying tortoise densities; 3) studies to evaluate the efficacy of distance sampling for tortoises in the Piute/Eldorado Desert Wildlife Management Area (DWMA); and 4) the longest running study of individual tortoise growth in the world at Rock Valley on the Nevada Test Site.

Research priorities of the Desert Tortoise Research Project are established through regular meetings with the Technical Advisory Committee mentioned above. Research needs identified in the Recovery Plan for the desert tortoise include: 1) collection of data on tortoise densities in and out of DWMA's; 2) development of comprehensive models of demography, including information on recruitment, survivorship and population structure; 3) epidemiological studies of diseases; 4) studies of sources of mortality; 5) measurement of impacts associated with grazing, roads, human use, etc.; 6) evaluating the effectiveness of protective measures; 7) evaluating responses of tortoise populations to climatic variation; 8) continued studies of nutritional and physiological ecology; and 9) continued studies of reproductive ecology. These priorities are used to direct ongoing and future research of USGS/BRD scientists working in the Mojave Desert. The objective is to make our research relevant to the needs of the client agencies and to facilitate recovery of the desert tortoise.

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STRUCTURE AND FUNCTION OF RIPARIAN ECOSYSTEMS IN THE MOJAVE DESERT

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The importance of riparian zones in the arid Southwest as wildlife habitat and as recreational resources has led to a considerable amount of recent research and management efforts that seek to identify the structural and functional attributes of this critically important ecosystem type. There have been numerous descriptive inventories of riparian vegetation and animal communities, and recently studies have begun to link ecological processes with hydrogeological variables. For example, studies of the relationships between the population biology of riparian plants and stream discharge dynamics have helped to clarify the essential role of flooding in the recruitment of trees in floodplain communities. Studies of diverted streams in the western U.S. have shown that curtailment of annual flooding results in long-term senescence of riparian vegetation and succession to more drought-tolerant types, often resulting in a physiognomic shift from gallery forest to a more xeric shrub/thicket community.

Riparian plants have been classified as "drought avoiders" due to their access to an abundant subsurface water supply. Recent water relations research that tracks water sources of riparian plants suggest that many plants in the riparian zone use groundwater rather than streamwater, and not all riparian plants are obligate phreatophytes, but may occasionally be dependent on unsaturated soil moisture sources. A more thorough understanding of riparian plant water relations must include water source dynamics and how those dynamics vary over both space and time.

Many rivers of the Mojave Desert region have been invaded by the exotic shrub *Tamarix ramosissima* (saltcedar). Our studies of *Tamarix* invasion into habitats formerly dominated by native riparian forests of primarily *Populus*, *Salix* and *Prosopis* have shown that *Tamarix* successfully invades these habitats because of its: (1) greater tolerance to water stress and salinity; (2) status as a facultative phreatophyte, enhancing its ability to recover from droughts and periods of groundwater drawdown relative to obligate phreatophytes; (3) maintenance of extremely dense canopies with high leaf area, which in turn apparently results in superior competitive ability in closed communities; (4) stimulation of a fire cycle and superior regrowth after fire; and (5) lack of herbivore pressure. As *Tamarix* invasion occurs on floodplains, *Tamarix* progressively desiccates and salinizes floodplains due to its salt exudation and high transpiration rates, and also appears to accelerate fire cycles, thus predisposing these ecosystems to further loss of native taxa. Management efforts aimed at maintaining native forests on regulated rivers and slowing the spread of *Tamarix* invasion must include at least partial reintroduction of historical flow regimes, which favor the recruitment of native riparian species and reverse long-term desiccation of desert floodplains.

Efforts to counteract *Tamarix* invasion in the region are faced with severe obstacles. Because of its density and high biomass, mechanical clearing of *Tamarix* is extremely labor intensive and has shown only moderate success. Because of its stimulation by fire, burning of *Tamarix*-invaded stands will in most cases favor *Tamarix* over the natives. Recently, APHIS has been authorized to release several biological control vectors from Eurasia that may reverse *Tamarix* invasion and dominance in the region. If these releases indeed occur, they will provide important management challenges and research opportunities as we track the response of riparian ecosystems to herbivore-induced *Tamarix* removal.

There are many research challenges available to scientists interested in the structure and function of riparian systems in the Mojave Desert region. These include improving our understanding of successional processes and patch structure in floodplain communities, and functional relationships between floodplain (riparian) and upland (desert) ecosystems. Our research group at UNLV and DRI is particularly optimistic concerning the use of remote sensing technology to answer many functional questions about these remarkably complex ecosystems.

ENVIRONMENTAL RESEARCH ON MILITARY INSTALLATIONS IN THE MOJAVE DESERT: SUCCESS AND THE DESERT TORTOISE

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The U.S. military has several installations in the Mojave Desert and has spent millions of dollars on environmental research related to activities on these installations. Because we cannot truly defend the Nation without also defending its environment the military is committed to maintaining a viable Mojave Desert Ecosystem while carrying on the mission of national defense. The National Training Center, Fort Irwin; Naval Air Weapons Station, China Lake; Air Force Flight Test Center, Edwards Air Force Base; Marine Corps Air Ground Combat Center, Twentynine Palms; and Marine Corps Logistics Base, Barstow have conducted research on ravens, integrated training area management, exotic species control, inventories, and desert tortoises. In addition, the Department of Defense Legacy Program and the Strategic Environmental Research and Development Program have made substantial investments in environmental research in the Mojave Desert. The Mojave Desert Ecosystem Program supported by DOD Legacy has compiled and integrated a very large database on the desert. Other Legacy programs have also made important progress in understanding the desert ecosystem. These programs have helped the military to manage the desert for sustained use. However, little progress has been made in obtaining sufficient understanding to manage the desert tortoise on military lands or elsewhere in the Mojave Desert.

The desert tortoise is the flagship species of the Mojave Desert. The decline of the tortoise is one of the key warnings that this ecosystem is in danger. Millions of dollars have been spent on studies of this species, but after several years we know little more than we did when the tortoise was listed as a threatened species. This is because federal agencies have not been addressing the right questions. For example, what good do tortoise surveys do? Even modern techniques that have been reported in peer reviewed publications (distance sampling) at best give density estimates. Most past attempts at surveys gave unrepeatable results. Nevertheless, installations are required by their biological opinions to conduct surveys. Do surveys tell us anything about the status of a tortoise population? Do they tell us if the population is declining, stable, or growing? Do they tell us if tortoises are reproducing? Do they tell us if eggs are producing males or females? Do they tell us if hatchlings survive? No, No, No, No, No!

The URTD disease is blamed for the demise of the desert tortoise, but no data are available to indicate whether URTD affects growth, reproduction, or survival of desert tortoises under natural conditions. Is it lethal or is it the flu? How many tortoises do managers kill each year because the tortoises test positive for URTD by ELISA? And how many tortoises do managers permit Fort Irwin to kill in its training activities each year? Shouldn't this be a priority for research?

It is clear from the peer reviewed biological literature that to understand the dynamics of a population of long lived vertebrates such as the desert tortoise we need to understand its life history, that is its demography and the mechanisms that define its demography. How many tortoises are there and of what ages on an installation? How many males and females are there? When are they active? What factors affect activity and growth? What do the tortoises eat? Do the tortoises reproduce? Is that reproduction successful? What are the sources of mortality for young and adults? What are growth rates? What do demographic models tell us about the future of the population? These are the questions that need to be answered. We can do all the surveys we want to in the next 20 years and we will have no more ability to predict the impact of military activities on tortoises than we do now. That is not much at all.

Because we do not know enough to manage desert tortoises in the Mojave Desert military installations are faced with increasing restrictions on their missions and are constrained from expanding them. For example, Fort Irwin faces difficulties in carrying out its primary mission daily due to current restrictions and its future is affected as well. Are these restrictions justified? Is there some research that can be done to clarify the effect of training activities on the desert tortoise? Is training bad for tortoises? In a battle between a tank and a tortoise the tank usually wins. However, that is the wrong proposition to test. Of course tanks modify habitat. Yet why is Fort Irwin one of the few places with URTD free tortoises? Why are there so many tortoises on Fort Irwin? What is being done right? We will never find out from surveys.

The Army is a national leader in environmental and natural resource stewardship and is committed to maintain and improve sustainability and biological diversity of terrestrial and aquatic ecosystems. While there is a concern that the presence of an endangered species on an Army base will have negative effects on the Army's ability to support present and future training and testing requirements, the Army has taken a proactive approach to protecting tortoise populations on Fort Irwin. By a combination of innovative research and conservation activities and changes in training procedures the Army has been able to achieve both its primary mission of defending the nation and its goal of maintaining viable tortoise populations. Fort Irwin has a viable desert tortoise population in areas used for training. Current research and conservation programs and tortoise set aside areas protect this population. Future expansion is needed. This provides a good opportunity to break the mold of "survey biology" and replace it with a comprehensive program of research and conservation that will answer many of the questions posed above.

The Army is willing to partner with other military installations, the USFWS and BLM to develop a comprehensive research program that will provide the long-term demographic information on desert tortoises. This should involve studies of the biology of diseased and disease free tortoise populations, in areas of training and no training, and control populations on and off installation. We can maintain a viable desert tortoise population on Fort Irwin while conducting realistic training and can contribute to developing an understanding of the biology of the desert tortoise so that it can continue to survive and perhaps thrive in the Mojave Desert of the 21st Century. Changing the paradigm is necessary if research is to do more than throw money at the desert tortoise problem in the Mojave Desert.

MOJAVE DESERT ECOSYSTEM PROGRAM: MOJAVE VEGETATION MAPPING PROJECT

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Land and resource managers and desert scientists frequently need require knowledge of the vegetation types in a particular area. Ecosystem level approaches to land and biodiversity management requires a regional view of vegetation that has been standardized, well documented, and represents vegetation at a minimum mapping unit that is salient to management and research needs. Large scale maps (small area) of Mojave vegetation types have been developed using the Holland classification system or a system unique to the project. Small scale maps of the entire Mojave have been developed by CalVeg (Matyas and Parker 1980), Kuchler (1977), and for California Gap Analysis (Thomas 1996, Davis et al. 1998). Only the Gap Analysis map uses a published classification system, the Holland (1996) system. Problems have arisen in the application of the small scale maps due to the coarse minimum mapping unit and the apparent lack of accuracy assessment and consequent updates. Similarly problems have arisen in the application of the large scale maps because of the limited area in which the map is applicable, inconsistencies in classification, and lack of accuracy assessment.

The Department of Defense Legacy-funded Mojave Desert Ecosystem Program has the goal of sponsoring the development of scientifically based data for the Mojave ecoregion. The Desert Managers group identified the need for up-to-date vegetation mapping as a high priority. In late 1995 the US Geological Survey's Biological Resources Division (USGS/BRD then National

Biological Survey) was asked to head the development of such a map. Vegetation mapping of the central section of the Mojave ecoregion, as defined by Bailey (1995), began in 1996. The final products are scheduled for completion in late 1999.

The Mojave Vegetation Mapping Project has the goal of developing a set of digital databases for part of the Mojave desert with supporting metadata, documentation on methodology, recommendations for database use and update, and a revised Mojave vegetation classification system. The digital databases (called maps in the remainder of this paper) consist of geographic information system (GIS) developed spatial data (map data) with accompanying tabular databases (tabular data). The core map to be developed is that of actual vegetation. A map of special features and of plot locations will also be developed. The actual vegetation map will use the National Vegetation Classification System and will identify vegetation types to the alliance level thematic resolution. Spatial resolution will be to a 5-hectare minimum mapping unit. The initial study area is a 12.5 million-acre area in the central portion of the Mojave ecoregion.

DEVELOPMENT OF THE MOJAVE VEGETATION DATABASE

The Mojave Vegetation Database is being developed by four teams. The delineation/predictive modeling team, headed by Dr. Janet Franklin in the Department of Geography at San Diego State University, is performing the cartographic and GIS work for the actual vegetation database. The classification team, headed by Dr. Todd Keeler-Wolf of the California Department of Game and Fish, is classifying field plot data and updating the Mojave vegetation classification system. The field and data management teams, and overall project management, are headed by Drs. Kathryn Thomas and Peter Stine of the Biological Resources Division.

Plots Database

A database of field plot observations is being developed to provide data for vegetation classification and creation of the actual vegetation map. Data has been collected on vegetation composition, cover and structure and on site environmental factors for 1130 plots in 1998. Plot locations were allocated by stratified sampling throughout the study zone. A GIS grid of environmental types was developed as a sampling frame. This environmental type grid was developed by overlaying four climate grids (developed for the project) with a generalized grid of geology types. Additional field data collected in 1999 will be added to the database. The database also contains geo-referenced data from previous field studies conducted throughout the study area.

Actual Vegetation Database

A preliminary map has been developed that consists of delineated vegetation polygons labeled by life form. The polygons on the preliminary map were delineated on satellite imagery (Landsat Thematic Mapper) using 1:32,000 aerial photography as an interpretation guide. True color aerial photography was acquired for all of the California Mojave in late spring through early summer 1997.

A predictive map of vegetation alliances is being developed. The map shows the probability of alliance occurrence as a function of select terrain variables. Known locations of alliances, as found in the plot database, are used as the response variable in statistical procedure known as decision or regression tree analysis. Decision tree analysis determines the probability of an alliance (the response variable) occurring as a factor of explanatory environmental variables. Explanatory variables that are being examined are terrain (elevation, slope, aspect, potential solar radiation, topographic moisture index, and hillslope position), substrate (bedrock geology, landform) and climate (winter precipitation, summer precipitation, winter temperature, summer temperature). The relationships between alliances and explanatory variables will be used to develop a set of "rules" that allow the predictive map to be developed in a GIS environment.

The draft actual vegetation map is developed by combining the preliminary map and the predictive map. Alliance labels for each map polygon will be derived by assigning the alliance type predicted for that polygon to the preliminarily labeled polygon. Where the predicted alliance type is not compatible with the preliminary label, field investigation will be undertaken to verify labeling. Where multiple alliance types are predicted for one preliminary polygon, the aerial photography and TM imagery will be reevaluated.

Validation will be conducted to finalize the actual vegetation map. Validation will be conducted using three data sources: 1) directed site visits where alliances are assessed using a project developed field key to identify vegetation alliances, 2) plot data from previous studies that were not used previously in the study and assigned an alliance type, and 3) existing large scale (small area) maps. The map will not be formally accuracy assessed as part of this project, but a work plan for future accuracy assessment will be provided.

Special Features Database

The actual vegetation map does not map vegetation features less than five hectares size. However, some alliance types are typically small in extent. The scope of the mapping project does not allow full mapping of these types. To initiate documentation of the location of alliances that occur in limited areas, the special features database is being developed. The special features database is a GIS point coverage that shows locations of known alliances or probable locations of alliances that typically have small coverage. It is being created by compiling existing digital coverages that map the locations of wetland, riparian and spring areas; landforms that support special alliances; and known locations of special alliances. The special features map serves as a template for more detailed mapping at the locations shown.

The National Vegetation Classification System (NVCS) has been adopted by the Federal Geographic Data Committee (FGDC 1997) as the recommended standards for vegetation classification, description, and mapping in the United States. The NVCS is a hierarchical system that provides several potential levels for vegetation mapping. The Mojave Mapping Project is using the alliance level to describe vegetation. Preliminary alliance types were obtained from the Manual of California Vegetation (Sawyer and Keeler-Wolf 1995). The collected 1998 and 1999 field data are being analyzed using classification software to revise and update these alliance types. The plot data is allowing fuller description and supporting documentation of the alliance types in the Mojave.

THE FINAL PRODUCTS

The USGS-BRD is publishing a technical report documenting this project. The documentation will present several topics: methods for developing the databases and the revised classification; the Mojave alliance classification including keys and descriptions of the types; recommendations for accuracy assessment and recommendations for use and update of the databases. The technical report will be available in late fall of 1999. Digital maps and accompanying metadata will be available through the Fort Irwin Mojave Desert Ecosystem Program website after the completion of the project. Contact the authors listed above for additional information about the Mojave Mapping Project.

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DEEP HISTORY OF THE MOJAVE DESERT

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In the early 1960's, Philip V. Wells and Clive D. Jorgenson discovered a hard dark juniper-rich packrat (*Neotoma* spp.) deposit in a plant survey of the Spotted Range on the Nevada Test Site in southern Nevada. A radiocarbon date of more than 10,000 years launched the discipline of packrat midden analyses (Wells and Berger 1967), and began the 'rush' to use fossils from the deserts to reconstruct the history of vegetation and climate of the last 40,000 years for many of arid and semiarid areas in the western United States and northern Mexico (Van Devender and Spaulding 1979; Betancourt et al. 1990). Well-preserved plant remains documented woodlands in the modern lowlands of the Mojave Desert in the late Wisconsin prior to 11,000 years ago (Spaulding 1990; Van Devender 1990). Desertscrub dominated by *Larrea divaricata* (creosotebush) without woodland communities was only present below about 300 m elevation in the lower Colorado River Valley although important Mojave Desert dominants such as *Yucca brevifolia* (Joshua tree), *Coleogyne ramosissima* (blackbrush), and *Salvia mohavensis* (Mojave sage) extended far to the southeast in Arizona in ice age woodlands (Van Devender 1990).

In the southern Mojave Desert, the late Wisconsin vegetation at sites such as the Lucerne Valley, Robbers Roost and the Turtle Mountains in southeastern California and the Newberry Mountains of southern Nevada was a woodland dominated by *Pinus monophylla* (singleleaf pinyon), *Juniperus osteosperma* (Utah juniper), *Quercus turbinella* (shrub live oak), and others (see summary in Spaulding 1990). In the northern Mojave Desert in southern Nevada (Wells and Jorgenson 1967) and in the Grand Canyon in northwestern Arizona (Cole 1990), a more xeric woodland with *J. osteosperma* associated with various shrubs was present. The paleozonation was directly from juniper woodland to mixed-conifer forest without the modern *Pinus ponderosa* forest zone. Higher elevations in southern Nevada supported open forests of *P. longaeva* (Great Basin bristlecone pine), *P. flexilis* (limber pine), *Abies concolor* (white fir), and *J. scopulorum* (Rocky Mountain juniper), in some cases in anomalous associations with desert shrubs such as *Atriplex confertifolia* (shadscale; Spaulding 1990 and elsewhere). At higher elevations in the Grand Canyon, *Pseudotsuga menziesii* (Douglas fir) and *Picea engelmannii* (Engelmann spruce) were in the mixed-conifer forest (Cole 1990).

The structural dominants of the woodland and forest communities were relatively stable through the late Wisconsin (ca. 11,000 to 20,000 yr B.P. [radiocarbon years before 1950]) although shorter lived associates were more variable (Cole 1990). In contrast, Holocene communities have been much more dynamic. The early Holocene (ca. 8000 to 11,000 yr B.P.) was a transitional period as *Pinus monophylla* and other mesic woodland species retreated from the southern Mojave Desert lowlands about 11,000 yr B.P. Mixed woodland and desertscrub communities persisted in many areas for several thousand years. In the lowest areas in Death Valley and along the Colorado River, desertscrub without *Juniperus* formed but differed in composition from the modern communities in those areas. *P. monophylla* soon dispersed into southern Nevada (Wells and Jorgenson 1967), beginning its gradual migration into the Great Basin (Thompson 1990). For species like *Yucca brevifolia* that were widespread in the modern Sonoran Desert in the late Wisconsin and expanded into southern Nevada later, their maximum distribution was in early Holocene. *Larrea divaricata* migrated out of the lower Colorado River Valley, reaching the Lucerne Valley after 8,000 yr B.P., and the Eureka Valley in the northern Mojave Desert perhaps 4,000 years later. In the Sonoran Desert in Arizona, *Carnegia gigantea* (saguaro) and *Encelia farinosa* (brittlebush) reached the Puerto Blanco Mountains in Organpipe Cactus National Monument by 10,500 yr B.P. although modern desertscrub did not form until about 4500 yr B.P. with the arrivals of *Cercidium microphyllum* (foothills palo verde), *Olneya tesota* (ironwood), and *Stenocereus thurberi* (organpipe cactus). Unlike the winter rainfall southern Mojave Desert, the Holocene vegetational climatic sequence in biseasonal rainfall areas such as this was more complicated, notably in a middle Holocene peak in summer rainfall.

Thus the vegetation of the last 40,000 years recorded by the packrat middens has changed dramatically tracking changes in global climates. Communities such as pinyon-juniper woodland in the Grand Canyon and ponderosa pine forest in Arizona only developed in the Holocene. Species ranges have changed dramatically migrating north and south, up and down mountains. Porter's (1989) analysis of the various proxy records suggested that the climate, and thus woodlands in the Mojave and Sonoran desert lowlands, of 12,000 years ago was typical of the entire Pleistocene. Relatively modern desertscrub communities similar to those of the late Holocene were only developed for about 10-20% of the 2.4 million years of the Pleistocene (Porter 1989; Winograd et al. 1997). Similar successional stages likely occurred during each of 15-20 interglacials. Individualistic responses to climatic changes on time scales from millennia to hours ensured that communities likely did not achieve equilibria at any time.

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