Mojave National Preserve

National Park Service
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Science Newsletter

Sweeney Granite Mountains Desert Research Center: an Interview with Director Dr. Jim André

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A significant factor in the amount of high quality research conducted in Mojave National Preserve is the Sweeney Granite Mountains Desert Research Center, part of the University of California Natural Reserve System. In this issue we interview its Director, Dr. Jim André. Dr. André is a research botanist who completed the Preserve's Vascular Plant Inventory for the National Park Service Inventory and Monitoring Program.

The Sweeney Granite Mountains Desert Research Center is located in Granite Cove at the base of the Granite Mountains.

The Sweeney Granite Mountains Desert Research Center (GMDRC) is one of 37 protected research sites operated by the University of California Natural Reserve System (UC NRS). This system of outdoor classrooms and laboratories makes relatively undisturbed examples of the state's diverse ecosystems available to researchers, teachers, and students with support facilities for long-term research projects and multi-week field courses. Established in 1978, the Sweeney Granite Mountains Desert Research Center encompasses 3,496 hectares (8,639 acres) of the pristine and rugged Granite Mountains in the East Mojave Desert ranging from piñon-juniper woodlands to creosote scrub bajadas. Housing, laboratories, and a conference room at the reserve can accommodate up to 12 researchers for long-term projects and field classes of up to 35 people. In 1994 with the passage of the California Desert Protection Act, the reserve was enclosed inside the boundary of the newly created Mojave National Preserve.

In this Issue:

Debra – *Some of the people who were instrumental in the formation of the UC Natural Reserve System, such as Ken Norris and Wilbur Mayhew, were very active in this area of the Mojave Desert. In fact one of the student camps is called Norris Camp. How did the Sweeney Granite Mountains Desert Research Center come to be and why did they choose this site?*

Jim – Before we get started, I wish to thank Debra Hughson for inviting me to this interview and for her continuing leadership in facilitating research and science education throughout the California Deserts. And to the Mojave National Preserve for the initiation of the

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This Science Newsletter:

The Mojave Desert is internationally known as a place to conduct scientific research on desert ecosystems. In fact Mojave National Preserve was designated in part to "retain and enhance opportunities for scientific research in undisturbed ecosystems" as stated in the California Desert Protection Act of 1994. Significant research is conducted through the Sweeney Granite Mountains Desert Research Center, part of the University of California Natural Reserve System, and the Desert Studies Center, operated by the California Desert Studies Consortium of California State Universities. Both are located in the Preserve.

The purpose of this newsletter is threefold. First, we would like to highlight some of the research being done by university scientists in the Preserve and to distribute this information to park staff and management. Second, this periodical will allow us to inform the public and research community about science being done by Preserve staff or funded through the National Park Service. And most importantly, we would like to build collaboration between scientists and resource managers so that scientists are made aware of the needs of managers and top quality science is brought to bear on the problems facing resource managers.

Our intention is to publish this newsletter twice per year, once in the spring and again in the fall; distributed in print at our Visitor Centers and electronically on the web. Articles will range from non-technical news stories to highly technical research reports. All material in this newsletter has been peer-reviewed by subject-matter experts. In each issue we will discuss a resource management issue or research need along with possible means of obtaining funding. The resource management concern highlighted in this issue is managing the effects of climate change.

Debra Hughson, Science Advisor

Science Newsletter, an effort that is strongly supported by the staff at the GMDRC, as well as many of our colleagues at the University of California. The Granite Mountains played a significant historical role in the development of the UC Natural Reserve System (NRS). Use of the Granite Mountains in the 1960s by UC professors Dr. Ken Norris (UCLA/UCSC) and Dr. Wilbur Mayhew (UCR) as a favorite destination for their natural history field courses helped spur the idea for the creation of the entire UC Natural Reserve System in 1965, which now includes 37 reserves located throughout California. Joined by Ken’s brother, Dr. Bob Norris (UCSB), and Dr. Mildred Mathias (UCLA), it was the enthusiasm of this prominent group of four professors that led to the University of California’s purchase of several sections of railroad lands and parcels of private lands in the eastern Granite Mountains. After several years of dogged persistence and diplomacy with land owners and a very supportive Bureau of Land Management, their efforts culminated in the establishment of the Granite Mountains Desert Research Center in 1978.

Debra – *The UC Natural Reserve System is available for use by institutions outside of the University of California. What proportion of researchers and students come from out of the state and what do you think brings them here to Granite Mountains and the Mojave Desert?*

Jim – Perhaps more than any NRS reserve, the GMDRC sustains a very diverse array of research from scientists who come from all parts of the world. Of the more than 350 research projects that have been conducted at the GMDRC in the past 30 years, about 40% were by UC scientists, while roughly one-third were by scientists from outside of California. Presently, we support more than 155 active research projects, including studies in microbiotic soil crust development, taxonomy and evolution of insects and plants, population ecology of large mammals such as the desert bighorn sheep, and studies of landscape-level processes, such as erosion dynamics of alluvial surfaces. A number of projects at the GMDRC focus on long-term processes, such as global climate change, soil disturbance recovery monitoring, or the survivorship of long-lived shrub species. By design, such studies may span decades, if not centuries.

As a hub of research activity in the Mojave Desert, the question of why researchers seek the GMDRC and the eastern Mojave Desert in general is one that has drawn our interest, and probably requires a more lengthy discussion than we have room for here. But every reserve is unique in its capabilities and what it emphasizes in its mission. What the GMDRC offers to visiting researchers and classes, as much perhaps as any field station in the western U.S., is access to a tremendous natural area—pristine, wild, and expansive. The 9,000-acre GMDRC is located within a region of unparalleled biological and geological diversity in California. And while the facilities and staff here are vital to its operation, it really is the quality of this natural area that represents the single greatest asset of the field station. Embedded within millions of acres of federal wilderness, including the Mojave National Preserve, ecological processes are still functioning here. The GMDRC provides not only a quality setting to researchers, but a site that will be protected over the long term. For visiting students, the Granite Mountains and surrounding region represents not only an outdoor classroom, but an adventure into a frontier. Here visiting students can make observations that contribute significantly to our knowledge base, inspiring discovery and appreciation for the complexity of our natural world.

Debra – *Research projects tend to build on each other. The reserve makes this* *possible and also enables projects to be designed to go on for decades. How can researchers new to the area tap into this body of work? Is it primarily through the published literature, or are there mechanisms for sharing data internally within the reserve system?*

Jim – Over the past 30 years the GMDRC has supported more than 350 academic research projects that have generated over 450 publications. But one of the great surprises for me in my tenure as resident director for the past 15 years has been the near exponential growth of our research program. It took 20 years to reach 50 active research projects. Today, just 10 years later, the number of active research projects has tripled.

Many factors have contributed to this rapid growth in research, including the addition of lodging and laboratory space, collaboration with agencies, staff expertise, organization of workshops and symposiums, and the protected lands – some of the only lands protected for research in the 25 million-acre Mojave Desert. But the single most important factor that stands out more than any other is the phenomena of building a body of research. Like stepping stones, over time one research project builds on the previous one. For example, a site becomes especially interesting to a plant physiologist after a soil scientist has mapped the age of the surfaces there. Some research is only made possible by the data collected by a prior investigation. This nurturing process takes time to evolve, but after 30 years we are beginning to cultivate and sustain an active research program at GMDRC because we have developed a body of research. Plant a seed and it will grow.

As a member of the NRS and national Organization of Biological Field Stations (OBFS), the GMDRC has several mechanisms for storing data collected by researchers and making it available to future investigators. The NRS maintains a website (http://nrs.ucop.edu) that includes a Research Database, where research applications, metadata, and bibliographies are accessible to the public. In addition, OBFS (http://www.obfs.org) offers a Data Registry, where a variety of datasets and protocols are made available. Finally, we do house a small collection of dissertations, reports, and datasets from projects completed here at the GMDRC; you can also see a list of current research and publications on our website (http://granites.ucnrs.org/).

As is the case at all reserves in the NRS, it has in fact been a great challenge to obtain raw data from researchers who are wary to part with it prior to completion of their analyses and publications. And because data management can be time-consuming, the GMDRC may select certain datasets over those with low probability of being used again. Thus, most of the projects that build from previous projects do so through the personal correspondence and cooperation among individual researchers. The GMDRC has been successful as a conduit for linking researchers with similar academic interests, and that has likely been our greatest active influence on this stepping-stone process.

Debra – *Your own research interests include the flora of the Mojave Desert. In your floristic inventory for the National Park Service Inventory and Monitoring Program you added 85 new taxa to the known 831 species of vascular plants in the Preserve, including several that are new to science, and 885 occurrences of special-status plants. What makes this region so floristically diverse?*

Jim – There is a broad misconception by the public and even by some scientists that the California deserts lack botanical diversity, and perhaps an even bigger misconception is that the desert has already been well documented, that there are few remaining taxonomic discoveries left for science. Nothing could be farther from the truth. The California deserts collectively make up 28% of California's landmass, yet contain 37% of its native plant taxa. Some of the mid-elevation zones of the eastern Mojave support 60 to 70 species of shrubs per hectare—some of the highest shrub diversity found in North America! New species are being discovered every year. I estimate that 6 to 9% of the California deserts flora is presently undescribed. So next time you're out and about looking down at those desert plants, do not assume they all have names!

I was immediately drawn to the Mojave National Preserve by its geographical position and high-elevation linkages. The Preserve lies at the hub of the Mojave, Great Basin and Sonoran Deserts with lowland and mountain corridors interdigitating in all directions. And while these corridors promote a dynamic long-distance flux of genotypes into the region, the complex local topography, soils, and geomorphic diversity found in the Preserve create niches where species may persist on the margin of their range, or act as isolating mechanisms where speciation may be facilitated. Additionally, in contrast to the west Mojave, the eastern Mojave Desert flora is significantly influenced by summer monsoonal precipitation. There exists a whole suite of plant species (mostly summer annuals) in the Preserve's flora that occur nowhere else in California. These are species that rapidly germinate, flower, and set seed in a matter of weeks following summer rain events.

My work on a Flora of the Mojave National Preserve and surrounding areas has been ongoing since 1994 when I first arrived at the GMDRC. I wish to again thank NPS and the Inventory and Monitoring Program for the financial support of this project several years ago. The three-year grant helped fund a major push in the botanical inventory of the

Preserve by bringing in additional field assistance for the surveys. Though we continue to add new vascular plant taxa (*1*) to the overall park list (total number of known taxa in the Preserve stands today at 928), the rate of new finds has slowed down considerably. Still, additional spring surveys in remote areas and during fall following summer rains will likely add an additional 15-20 taxa to the overall list.

The floristic effort at the Preserve underscores two significant truths: 1) the Mojave National Preserve is indeed floristically diverse with a high concentration of rare and endemic species, and 2) the Preserve lies within a region of California where taxonomic inventory is far from complete. With the near completion of the flora, the Preserve now represents one of the few areas in the California Deserts that has been well-documented. The only other recent and comprehensive floristic inventories are at the Whipple Mountains (*2*) and at Joshua Tree National Park, led by GMDRC scientist Dr. Tasha La Doux. One does not need to go to New Guinea or the Brazilian rainforest to make important botanical discoveries, as 90% of the California Deserts remain a floristic frontier ripe for taxonomic discovery.

Debra *– Threats to rare plant assemblages in Mojave National Preserve include local factors such as cattle grazing and fire and larger global issues such as climate change. How do you think the National Park Service could best protect these populations? Are there specific management actions that could be developed into project funding requests?*

Jim – Inventory of the botanical resources is obviously critical to this management mission, as we can only protect what we know exists. While the inventory of the Preserve has focused initially on developing a park species list, we are now working to map many hundreds of rare plant populations as well as unique plant assemblages throughout the park. It will be important to assess the needs of each of the approximately 120 special-status plant species that occur in the park, starting with the rarest and most imperiled taxa and developing detailed management guidelines for each. Often threats are obvious, such as those caused by the direct impacts of vehicles or livestock trampling. Yet other threats are more cryptic, requiring fairly sophisticated biological research (population genetics, demography, reproductive biology) or modeling/long term monitoring (climate change, soil nutrient, hydrological alteration) before remedial actions or protection measures are taken. It is human nature to feel compelled to take action to heal the wounds of an impact, but actions must be tempered with the very risks they pose and be based upon the best science. For example, removal of invasive alien plants using either mechanical or herbicide applications may or may not adversely impact rare plant populations, but should be carefully assessed prior to implementation.

Considerations for the long-term viability of native plants in the Preserve extend well beyond its borders. With the increasing fragmentation of the eastern Mojave Desert by energy and other development, the long-term viability of many populations within the park cannot be sustained without the preservation of external corridors and trans-boundary processes such as dispersal of pollen by pollinators and the movement, or colonization, of plants through seed dispersal. As large as the Preserve is, it will require collaboration with neighboring agencies to develop regional conservation strategies.

Debra *– Controlling invasive non-native weeds, such as Sahara mustard, is a high natural resource management priority for the Preserve. Although we are fortunate compared with much of the rest of the Mojave Desert, at times this seems like a Sisyphean task. If you were to lead an effort to prevent biological invasions into Mojave National Preserve, how would you go about it?*

Jim – This is a very difficult question, and one that often leads to a lively discussion in some circles of conservation biology. And being tasked with the job of preventing biological invasions into Mojave National Preserve is like trying to prevent drinking at Burning Man, one is doomed to fail. The management of invasive plants usually comes down to a triage decision that balances the likelihood for success with available resources (budget, labor force, available expertise). In the case of Sahara mustard, we have a superstar weed that disperses at extraordinary rates, can colonize undisturbed desert, and has already structurally altered millions of acres of lowland sandy habitats. Many millions of dollars are being spent on both herbicide and mechanical removal in an attempt to stem the tide. Optimists believe there is still an opportunity to control this species from spreading further into the California Deserts. The unfortunate reality, however, is that it has already entrenched itself throughout much of the Mojave, and control of its spread is probably only worthwhile, or possible, in localized cases to protect unique or rare habitats and populations. We actually know very little about the life history and ecology of Sahara mustard (e.g., tolerance to drought, seed bank and dispersal ecology, impacts on soil nutrients, etc...). Given that there is little we can do to control the spread of the species on the landscape level, I would recommend that a higher proportion of the management funds be directed towards research into the biology of Sahara mustard, as we have a lot to gain by improving our understanding of its impacts to our natural systems. And perhaps we might identify weak links or stages in its life history that might be helpful to our management.

As you know, there are many other invasive species that pose existing or future threats to the Mojave National Preserve. Some of these, such as *Erodium cicutarium* (storksbill), have been here for decades and have naturalized into the native vegetation. Unless a very sophisticated control mechanism is developed, such naturalized invasives are here to stay. The point here is that as difficult as it is to prevent invasions, it is far less an option to eradicate aliens once they have become established. Thus, it is vital to develop a coordinated multi-agency monitoring program that detects invasions early on when eradication is still a feasible option.

Finishing this discussion on a more positive note; although invasive alien plants pose perhaps the greatest threat to native ecosystems throughout California, the eastern Mojave Desert remains the least impacted region of the state. While invasive aliens comprise 15 to 35% of the species in any given subregion throughout cismontane California, they make up only 7 to 9% of the California Desert flora.

Debra – *The Hackberry Complex Fire in 2005 was quite possibly the most dramatic natural disaster in this area in some decades. But in your rare plant report on that fire you identified a number of other threats to rare plant populations besides fire. Would you care to elaborate on these and perhaps prioritize them in terms of the most immediately needed management actions?*

Jim – I agree that the Hackberry Fire event was dramatic and natural, but the term disaster does not necessarily apply in describing its impacts upon rare plant populations. Most plant ecologists agree that fire regimes are in flux, but the role of fire and its effect upon native vegetation and rare species in the eastern Mojave Desert is complex and remains poorly understood. We know that several dozen rare plant species were impacted by the Hackberry Fire, and that each species endured and responded to the event differently, depending upon their individual life-history characteristics. Because we lacked sufficient pre-fire information (distribution, population sizes, etc…) for the majority of the rare species, our assessment of impacts was limited to a post-fire snapshot.

We observed that with the sudden release of nutrients into the soil and the sunlight gaps that were opened among previously dense shrub and tree canopies, many of the rare herbaceous perennials and/or annuals showed a very positive initial response (e.g., Cima milkvetch). Rare plants that were most adversely affected by fire were those lacking the ability to survive the burn (e.g., woody such as Thorne's buckwheat), poor re-sprouters, or not likely to regenerate quickly from the seed bank. In the Hackberry Fire report I provided a general discussion of other potential threats that pertain to these particular species (*3*). Examples of these threats included grazing/trampling, road maintenance, and invasion of alien species that may or may not be related to post-fire management or processes.

Rather than focus on the Hackberry Fire, however, I believe your question relates to the Preserve's entire rare plant management program and the development of management priorities for rare plant protection in general. Many of the 120 or so rare plant species in the Preserve are being threatened by a variety of factors. In most cases, threats are associated with human actions of some sort, which implies we can often take action to remove or adapt these actions to reduce the threat. However, for many threats it is difficult to understand how they ultimately affect the viability of specific plant populations or metapopulations, to untangle their interaction with other threats, and to come up with effective methods to alleviate them. For example, habitat fragmentation caused by developments along I-15 between the Clark Range and the Ivanpah Range impacts numerous rare plant populations, but how? If we assume that larger populations that are broken into smaller ones leading to restricted exchange of pollen or seed, then this has important genetic and demographic consequences. But fragmentation also creates edge effects and deterioration of habitat quality. It may alter plant-pathogen and plant-herbivore dynamics. Due to lack of time, funding or available expertise, the full range of demographic- versus genetic-stochasticity parameters are rarely integrated into a population viability analysis. Until such detailed analyses become available, managers must work with scientists to maintain natural ecological processes and provide the best natural conditions for populations and metapopulations to persist, while delineating the most likely threats for each species and minimizing or eliminating them where possible.

In general, threats come in three types: *1)* threats imposed by changes in the environment, either by natural or human causes, *2)* threats resulting from disturbance of important interactions with other species, and *3)* genetic threats. Although the Preserve and its surrounding lands are considered well-protected, environmental threats are, in fact, considerable. These include climate change (e.g., altered precipitation and fire regimes), habitat fragmentation (e.g., roads), direct disturbance (e.g., livestock trampling, hydrological alterations, deposition of atmospheric nitrogen) and exploitation (e.g., cactus collecting). Disturbance of biotic interactions might include destruction of key pollinator guilds, altered pathogen and herbivore interactions, and hybridization with introduced natives (e.g., CalTrans revegetation programs).

Despite the complexity and multitudes of threats, there are a number of options for reducing their effect on rare plant populations in the Preserve. Some of these need to be implemented on the landscape level and require cooperation from adjacent land owners, for example, maintaining large expanses of unfragmented habitat, increasing connectivity, creating buffer zones, and restoring original hydrological conditions. In other cases, managers must act more on the local scale by providing protection from livestock trampling, invasive species, or recreational activities. And perhaps most important of all, lack of information can be one of the greatest threats to rare species. In order to prioritize management of rare plants in the Preserve, we must first know something about their distributions, life-history attributes, and identify any threats to their viability. Finally, conservation management for rare plants should always take place in the context of the key processes of their ecosystem (i.e., practices developed in the Nebraska prairies may not be appropriate in the California deserts).

Debra – *One of the attractions of Sweeney Granite Mountains Desert Research Center is its setting in a fairly expansive region of federally protected public land and designated wilderness areas. In fact a number of the researchers who come to the reserve do much of their work in Mojave National Preserve. The Preserve, in turn, benefits from the work of these researchers and the scientific expertise concentrated at the reserve. Knowing that this relationship is built for the long term, what kind of policies and practices would you have in place for optimizing this relationship?*

Jim – The continuing development of our collaboration is perhaps the most important goal of the GMDRC and, indeed, ranks as one of the highest priorities of the UC Natural Reserve System. I truly believe this is a match made in heaven as our missions are, if not compatible, highly complementary. Numerous successful collaborations already exist between the UC NRS and NPS. The UC Santa Cruz Island Reserve collaborates with NPS Channel Islands to facilitate research and teaching on the island. More recently, Yosemite National Park has been working with the NRS to establish a similar relationship at the UC Merced Wawona Field Station.

As a hub for research throughout the eastern Mojave Desert, the GMDRC functions within this concept of a “gateway reserve” where it impacts a much larger area than what is contained within the GMDRC boundaries. And as you alluded to, the success of the University of California alliance (via the GMDRC) in the eastern Mojave depends largely upon the extraordinary quality of the ecosystem found in this region. Thus, we greatly appreciate the opportunity to work with NPS, the leader among federal land management agencies in preservation, research, and ecosystem management.

Over the past 15 years the GMDRC and Mojave National Preserve have teamed up to facilitate over 100 academic research projects, developed and supported student research grants, engaged the media and public about important desert issues, collaborated on a number of programs, including the Inventory and Monitoring Program (e.g.Vital Signs Workshop, NPSpecies certification), rare plant inventory and monitoring (e.g. after the Hackberry Fire), and we have collaborated to organize several regional workshops and symposiums.

There are a number of directions I hope to see our collaboration continue to evolve. We can develop a more structured protocol of information and data sharing. We can exchange expertise and resources to enable specific projects and programs to occur. We can develop broader long-term commitments to events and conferences that advance communication about research and education. We can re-energize our MNP science group that includes the California State University Desert Studies Center and meet on a regular basis to share ideas. And we can jointly participate in national programs such as the National Science Foundation’s National Ecological Observation Network (NEON) or a Long Term Ecological Research network (LTER). These are just a few thoughts. The sky is the limit.

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Reptile Diversity Following the Hackberry Fire

Kirsten E. Dutcher[1]

The Hackberry Complex Fire in Mojave National Preserve stimulated research on seed banks (*1*), small mammals (*2*), and effects on reptile diversity (*3*). Changing fire regimes in the Mojave Desert is an ongoing land-management issue. Much attention is given to the relationship between fire and invasive annual plants. But fire regimes can also be exacerbated by precipitation variability, which may become more prevalent in the future. The work by Dutcher presented here provides managers with information on how reptile diversity was affected by a major fire.

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During the summer of 2005, lightning caused numerous wildfires in the Mojave National Preserve, California. The fires burned 287 km^2 and created a mosaic of unburned patches surrounded by burned vegetation. This study examined the effects of these wildfires in 2006 and 2007 on reptile diversity by conducting transect surveys at unburned patches and along the fire perimeter in burned and unburned habitats. Temperature and vegetation cover data were also recorded at each site. These surveys showed that average environmental temperatures were higher in burned areas as compared to unburned areas. Unburned areas also showed a greater vegetative cover two years after the fires. Burned and unburned habitats had comparable reptile diversity, and *Uta stansburiana* was the most abundant reptile recorded. The numbers of individuals and species recorded during this study suggest that the wildfire negatively impacted the herpetological community.

Introduction

Historically, large wildfires in desert communities have been uncommon because without a relatively large, continuous fuel source, wildfires have reduced size and intensity (*1*). In North American deserts, wildfires have become increasingly frequent since the 1970s. This is largely due to the introduction of exotic plant species, particularly *Erodium cicutarium* (fillaree), *Bromus sp.* (foxtail, cheatgrass), and *Schismus sp.* (Mediterranean grass). These species, native to Europe, Africa, and Asia, are adapted to fire regimes in arid ecosystems and create a blanket of dry vegetation that facilitates the spread of wildfire by creating a layer of dry, fast-burning fuel. Recurrent fire amplifies the presence of these species, which have been shown to replace long-lived natives, changing the floral composition (*2–4*). Wildfire is currently considered to be one of the main threats to native populations in the Mojave (*5*).

The Mojave Desert is subjected to frequent lightning strikes during the summer monsoons (*6*). On 22 June 2005 lightning caused multiple fires in the Mojave National Preserve (MNP), California. The fires merged to become the Hackberry Complex Fire, which burned for seven days and was contained on 28 June 2005. A total of 287 km^2 burned between elevations of 1,097-2,012 m. The fire did not consume all the vegetation and the burned landscape contained a mosaic of unburned habitat. Habitat patches may serve as refugia for reptile populations that survive wildfire, and vegetated areas produce shaded microclimates where soil temperatures are less extreme and moisture is preserved (*7–9*).

The Mojave is home to an incredible array of reptiles, and the Hackberry region supported many species. The objective of this study was to determine the effects of the wildfires on the herpetofaunal community. Because of the need for thermoregulatory, foraging, and protected sites, reptiles are highly dependent on habitat structure, and fire has been shown to reduce their abundance and limit movements (*10, 11*). A review of herpetofaunal response to fire found that many animals exhibit panic and experience high rates of mortality. Often, dramatic disturbance also results in habitats dominated by invasive plants and decreased numbers of invertebrates. This reduction in thermoregulatory and food resources results in a decrease in reptile abundance and diversity (*11, 12*).

Study

Permits were obtained from the National Park Service, California Department of Fish and Game, and California State University to allow for collecting, identifying and releasing reptiles within the National Preserve. Sampling for this study was concentrated in what was predominantly juniper woodland between the elevations of 1,370 m-1,675 m (*13*). Sites were located near Cedar Canyon and Black Canyon Roads, in the Mid-Hills area (Figure 1). All sampled sites had similar influence from cattle grazing, camping, and roads, and were more than 100 m from roads, trails, or developed areas, with the exception of one site, which was 30 m from an unmaintained dirt road. Seven unburned habitat patches, surrounded by burned landscape on all sides, and seven perimeter locations along the fire edge

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[1] San Diego Zoo's Institute for Conservation Research, Desert Tortoise Conservation Center, Las Vegas, Nevada.

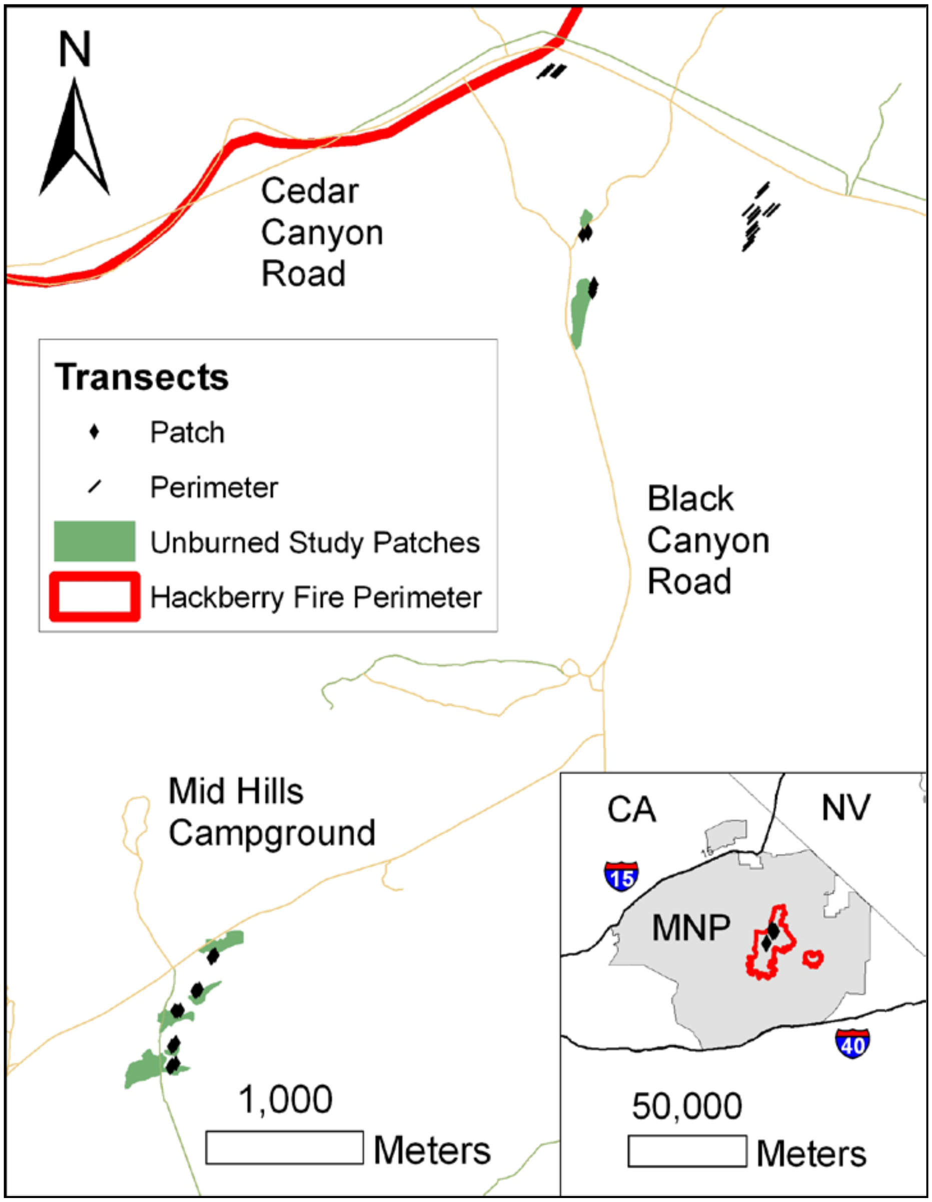


Figure 1. Habitat patch locations within the Hackberry region of the Mojave National Preserve. Habitat patches are approximate. The inset map shows the location of the Hackberry wildfire in Mojave National Preserve (MNP), Southern California.

were surveyed. Patch sites were mapped using a handheld Global Positioning System (GPS) unit and ranged in size from 1,527 to 36,580 m^2.

Ambient, ground, and subterranean temperatures were collected from May through October 2006 and March through August 2007 using a handheld Ashcroft dial thermometer. All temperatures were recorded after the thermometer was placed in a temporarily shaded area for 2 minutes and collected at the start of each transect on both the burned and unburned sides. Air temperature was recorded after holding the thermometer several feet above the ground, ground temperature was recorded after placing the thermometer on the soil surface, and subterranean temperature was recorded after placing the tip of the thermometer 3-5 cm into the soil.

Transects were used to assess species diversity and abundance across distinct habitat types with clearly defined borders (*14*). At each sampling site three parallel transects that crossed the transition zone from burned into unburned habitat were monitored. Each transect was 50 m in length and bisected the habitat, with 25 m in each habitat type. Transects were separated from replicates by 20 m (Figure 2). Transects were measured using a 25 m Lufkin tape measure, and GPS waypoints marked the start and end locations.

Vegetation point-intercept transects were conducted by walking the transect lines and recording vegetation height every five meters. At each point a 7-cm diameter pole was placed directly on the point, and the height of each plant that touched the pole was recorded (*15*). Plant height was classified as <10 cm, 10-30 cm, 30-50 cm, 50 cm-1 m, and >1 m. Data from dead or severely burned vegetation was not included. Vegetation transects were conducted once a month from May through October 2006 and March through August 2007. A total of 504 vegetation transects were conducted (14 sites x 3 replicates x 12 times).

During the fall and spring, transect surveys were conducted throughout the day; however, in the summer, when temperatures were high, transect surveys were conducted in the morning and late afternoon. In order to find lizards by direct observation in both burned and unburned areas, each transect line was walked two times and a snake stick used to flush lizards from grasses and shrubs. Sighting effort was concentrated to 5 m on either side of the transect line. During the course of this study a total of 1,542 transects (14 sites x 3 replicates x 36 times) were conducted.

Analyses involving herpetological community structure were conducted using PRIMER. All other analyses were completed with PRISM statistical software. The mean, standard deviation, and minimum/maximum temperatures were calculated. Air and ground surface temperatures in warm (May through August 2006 and 2007) and cold seasons (September through October 2006 and March through April 2007) were analyzed

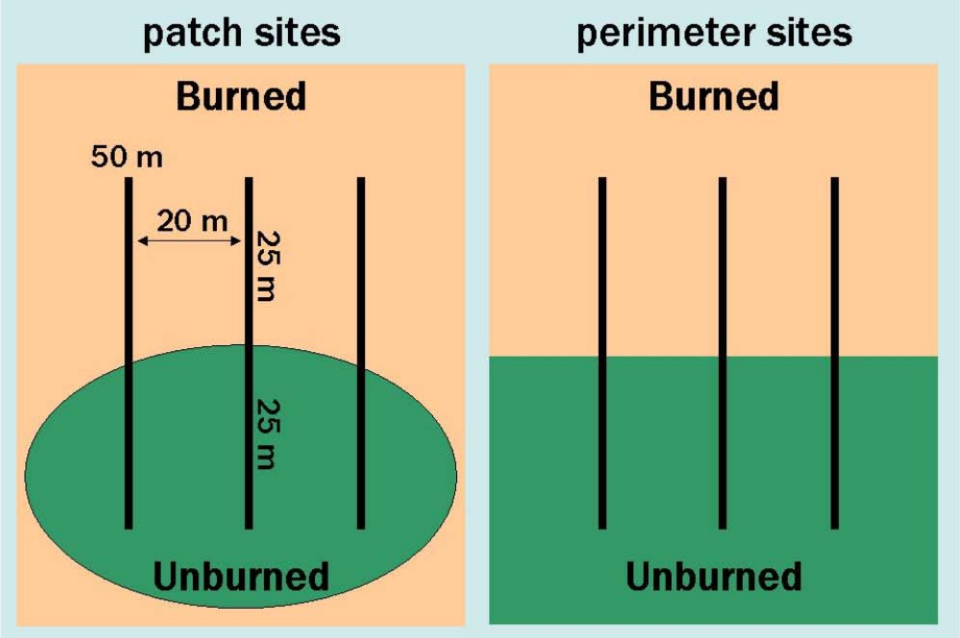
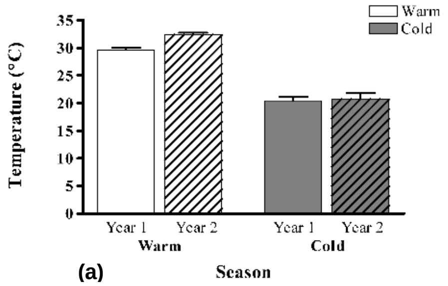


Figure 2. Transect design. Each site had three 50 m transects separated by 20 m. Half (25 m) of each transect was located in burned habitat and 25 m in unburned habitat.

using paired t-tests. Vegetation data were analyzed using χ^2, with the mean and standard deviation of each plant height class calculated to compare heights in burned and unburned areas. The reptile species observation rate during transect surveys was calculated. ANOSIM (analysis of similarity) of species diversity between years and in burned and vegetated habitats and SIMPER (similarity percentages) analyses were conducted. *U. stansburiana* data were analyzed using χ^2 and Fisher's Exact test.



Average air temperature in the warm season of 2007 was significantly higher than 2006 (t = 5.420, df = 195, $p < 0.0001$, $\bar{x}$ 2006 = 29.6 ± 5.1, $\bar{x}$ 2007 = 32.4 ± 4.5). The mean temperature of the cold season was not significantly different (t = 0.3196, df = 55, p = 0.7505, $\bar{x}$ = 20.6 ± 7.2) when comparing 2006 and 2007 (Figure 3a). Ground surface temperature data for 2006 and 2007 were divided by habitat type, season, and year. Burned habitats in the warm season had significantly higher ground surface temperatures (t = 11.61, df = 415, $p < 0.0001$, $\bar{x}$ unburned = 31.5 ± 5.9, $\bar{x}$ burned = 32.5 ± 6.0) than unburned habitat (Figure 3b). In the warm season subterranean temperatures in the burned areas were significantly higher (t = 50.08, df = 417, p < 0.0001, $\bar{x}$ unburned = 30.9 ± 6.9, $\bar{x}$ burned = 32.6 ± 6.9) than in the unburned area (Figure 3c).

The total number of plants in the unburned areas (1,440; 68.58% total cover) was higher than in burned areas (846; 40.28% total cover). There were differences in the distribution of vegetation heights in each habitat (χ^2 = 389.9, df = 1, p < 0.0001). In the burned areas plants under 10 cm in height significantly outnumbered plants in all other height classes (Table 1). In addition, the number of plants in the under-10 cm height class increased from the 2006 to 2007 growing season (264 to 345 total plants). For all heights, except <10 cm, unburned habitats had more plants per site than burned. All plants seen were not recorded to species. Of the plants identified in the unburned areas 2% were *Erodium cicutarium* and 21% were grasses of several species. In burned areas this trend was reversed with *E. cicutarium* accounting for 31% and grasses making up only 7%.

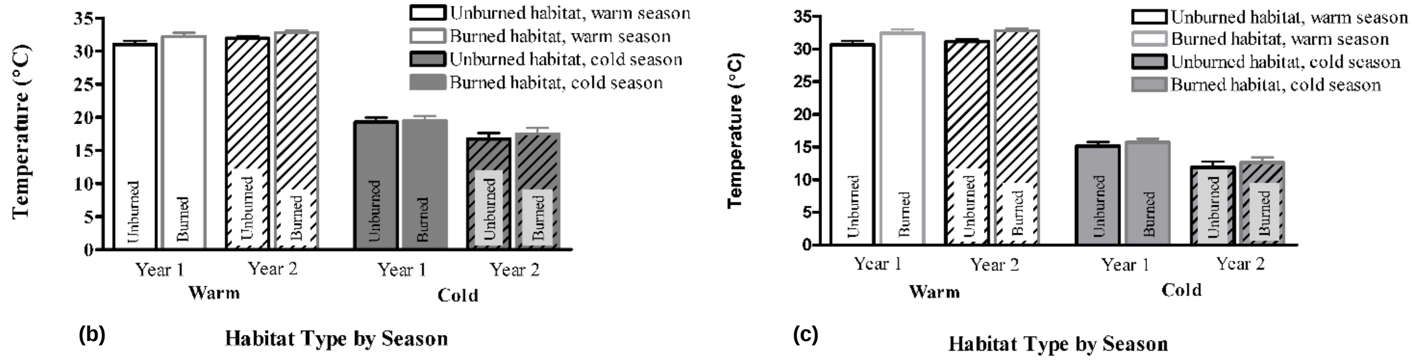


Figure 3. Ambient, ground, and subterranean temperatures ($\bar{x}$ ± SD). (a) Average ambient temperatures by year in the warm and cold seasons. (b) Average ground temperatures for unburned and burned habitats by year in each season. (c) Average subterranean temperatures for both habitats by year in each season.

Table 1. Percent Vegetation Cover in Unburned and Burned habitats by Height Class

Height Class (cm)	Unburned		Burned	
	Number	Percent Cover	Number	Percent Cover
<10	220	10.48	631	30.05
10-30	295	14.05	133	6.33
30-50	248	11.81	63	3.00
50-100	345	16.43	16	0.76
>100	332	15.81	3	0.14
Total	1440	68.58	846	40.28

During transect surveys five lizard and one snake species were observed (Table 2). Species found at perimeter and patch sites did not differ significantly (R = 0.038, p = 0.272); however, differences were found (R = 0.220, p = 0.022) between unburned and burned locations. A SIMPER analysis showed that in the unburned areas, *U. stansburiana* accounted for 88.0% of individuals, with *A. tigris* and *S. occidentalis* making up 14.7% and 13.5% of individuals, respectively. In the burned areas *U. stansburiana* comprised 98.6% of individuals. Differences were found between habitat types (χ^2 = 9.952, df = 3, p = 0.0190) and most *U. stansburiana* were recorded in burned areas along perimeter sites in 2006, followed by unburned patch sites in 2007 (Figure 4). Combining perimeter and patch sites in order to compare burned to unburned areas yielded more individuals in unburned habitat (n = 77 compared to n = 62); however, there were no significant differences (Fisher's Exact test; p = 0.0624). Combining burned and unburned areas in order to compare perimeter to patch sites found perimeter sites to have significantly more *U. stansburiana* (Fisher's Exact test; p = 0.0258).

Conclusion

Due to air temperature variation, 2007 was warmer than 2006, but both surface and subterranean temperatures were higher in burned areas than in unburned areas in both years. The plant community in unburned areas had almost 30% more cover than burned areas and remained relatively stable through time. However, the burned areas had more than twice the number of plants in the <10 cm height class, and very few grew to over 10 cm during the course of this study. This is consistent with long term studies of plant communities in the Southwest that have found areas affected by wildfire are rapidly colonized by low growing ground cover species that are predominantly alien (*3, 5*).

Uta stansburiana was the dominant reptile species in all surveys; however, the absence of other species may have been due to the fact that they were not present or visible along the transect lines conducted. In 2006 the highest number of *U. stansburiana* were found along the fire perimeter on the burned side, which is similar to a study conducted after a wildfire in Arizona that found reptiles exhibited a preference for disturbed sites (*16*). However, in 2007 the number of individuals found in this area decreased by more than half. It may be that individuals utilized the burned area more heavily initially because the higher ground temperatures allowed for optimal basking sites. In 2007 temperatures may have become too high, creating a habitat

Table 1. Reptile Species Observed During Transect Surveys

Species	2006		2007		Unburned		Burned	
	Number	Rate	Number	Rate	Number	Rate	Number	Rate
Aspidocelus tigris Western whiptail	7	0.3684	4	0.2105	11	0.2895	0	0
Gambelia wislizenii Long-nosed leopard lizard	2	0.1053	0	0	1	0.0263	1	0.0263
Masticophis taeniatus Striped whipsnake	1	0.0526	0	0	0	0	1	0.0263
Phrynosoma platyrhinos Desert horned lizard	0	0	1	0.0526	0	0	1	0.0263
Sceloporus occidentalis Western fence lizard	8	0.4211	7	0.3684	5	0.1316	10	0.2632
Uta stansburiana Side-blotched lizard	80	4.2105	56	2.9474	75	1.9737	61	1.6053
Total	98	5.1579	68	3.5789	92	2.4211	74	1.7105

Note: Observation rates were calculated using number of observations/number of transects conducted.

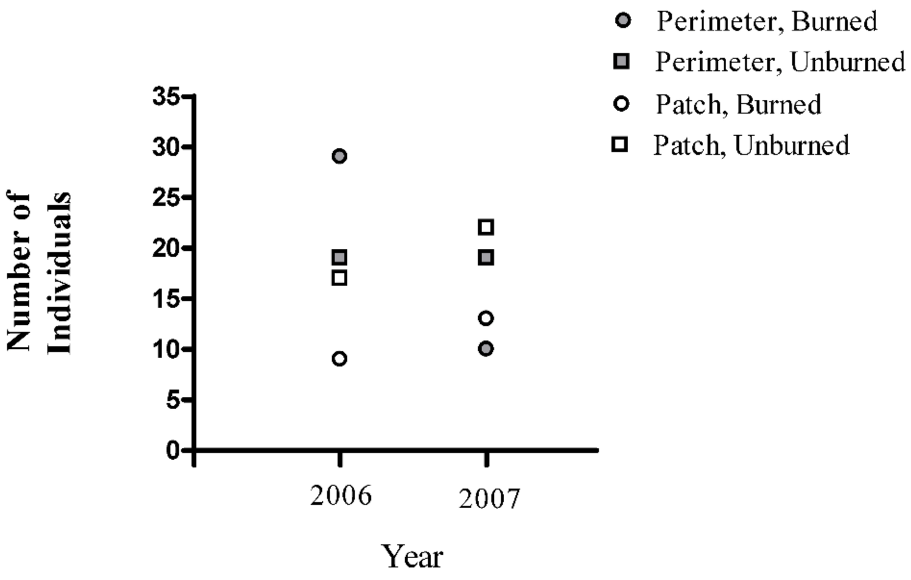


Figure 4. Total number of *Uta stansburiana* observed during transect surveys in each habitat type by year.

type that did not provide a thermoregulatory gradient or enough cover. The number of individuals in unburned perimeter locations was relatively constant through time, indicating that this population was the most stable. The numbers found at patches increased from 2006 to 2007 in burned and unburned areas, with unburned sites having more individuals.

Although the results of a study conducted in a single location and affected by a single event may not be fully extrapolated to other locations and events, it is clear that wildfire is a serious threat to biodiversity in the Mojave. Information on floral community succession and faunal survival is useful to help understand the long-term consequences of altering landscapes and could lead to a better understanding of how to control invasive species. Invasive species have created an unnatural grass-fire cycle in the Mojave, resulting in habitats that are increasingly homogeneous and provide few resources for native species (*4, 6, 11*).

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Physiological Responses of Mojave Desert
Shrubs to Simulated Summer Wash Flow: Preliminary Results

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Research into the nature of vegetation response to soil moisture and geomorphology has been ongoing in Mojave National Preserve for about ten years through the U.S. Geological Survey Priority Ecosystems Science program. This summer a directed infiltration experiment was conducted using isotope-labeled water to see how Mojave perennial vegetation would respond to a simulated summer thunderstorm. These preliminary results will help managers understand how predicted increasing temperatures, increasing summer precipitation, and increasing precipitation variability may affect desert ecosystems.

Over the past century the climate of the United States has experienced a 0.6°C warming and by 2100 it is projected to increase an additional 4-6°C, depending on region (*1*). Average annual precipitation has also increased 5-10% in the past 100 years, which has been attributed to increased frequency and intensity of rainfall events (*1–3*). Some climate models for the 21st century predict that the largest increases in extreme weather events will occur in the arid Southwest region, altering both winter and summer precipitation patterns (*1*). Biogeographic models predict that changes resulting in increased precipitation would have a dramatic effect on desert ecosystems, potentially leading to habitat conversion and a complete loss of desert vegetation (*1*).


A water truck and perforated hose were used to simulate runoff in a small alluvial channel.

Desert ecosystems have been defined as "water-controlled ecosystems with infrequent, discrete, and largely unpredictable water inputs" (*4*). Water inputs into desert ecosystems are what drive plant productivity and are strongly linked to soil water availability and its distribution in the soil profile (*5*). Therefore, the frequency and magnitude of precipitation events strongly affect soil moisture availability and, in turn, plant water availability.

Soil moisture models simulating increased intensity of precipitation events revealed altered soil moisture patterns in the upper (10-20 cm) and lower (80-90 cm) soil layers, thus affecting plant water availability and overall vegetation composition in arid lands (*6*). Model results (*6*) indicate a greater amount of plant-available water in lower layers due to increased runoff and lateral redistribution of runoff water. Soil substrate and age further influence plant-water availability as runoff is enhanced in older soil substrates, increasing infiltration into younger substrates with excess runoff water made available to plants bordering washes (*7*). Water infiltration is highest in washes, and provides the greatest availability of water for plants across a typical Mojave bajada, underscoring the importance of washes in the hydrogeology of desert landscapes.

The Mojave Desert is the driest desert in North America, and precipitation patterns are known to be highly variable (*8*). Rainfall during the winter months (Oct-April) is longer in duration, of lower intensity, and occurs broadly across the Mojave region; whereas summer rainfall (July-Sept) is localized, more intense, and less frequent (*9, 10*). As a result, summer rainfall events more commonly lead to wash flow. As a winter-rainfall dominated ecosystem, climate changes in the Mojave that increase summer precipitation may play an important role in altering vegetation processes influenced by washes. An increase in the frequency and intensity of summer rainfall events could increase the amount of water available to plants, especially those adjacent to washes.

To investigate how plants in the Mojave Desert might respond to increases in summer precipitation, we simulated wash flow that would occur following an early summer rain event. Specifically, we replicated wash flow that would occur down-slope on an alluvial fan when an isolated summer rain storm occurs higher-up. Several previous studies have quantified summer precipitation use by applying watering treatments to the plants at the surface (*11–15*) or by measuring plant responses to natural summer rain events (*8, 16, 17*); however, there is limited information on how plants utilize water derived specifically from water pulses in washes.

Collaborators from the USGS and the Plant Physiological Ecology Laboratory at California State University, Fullerton are collectively working as part of the Recoverability and Vulnerability of Desert Ecosystems (RVDE) project, funded by USGS, to understand how changes in precipitation patterns might affect the physiological functioning of perennial plants and the hydrogeology of desert landscapes. The objectives of the present

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study are to: 1, quantify the responses of the native perennial species *Larrea tridentata* (creosotebush) and *Ambrosia dumosa* (white bursage) to simulated wash flow that would occur during a summer precipitation event; and 2, assess how these responses vary based on plant proximity to the wash. These measures will allow us to quantify the influence of washes on plant-water availability in desert landscapes and, specifically, how runoff events in these washes affect plant activity.

The study site is located at the foot of the Providence Mountains within the Mojave National Preserve. It is approximately 50 km SE of Baker, CA and 5 km NE of the Kelso train depot. The site is on an alluvial fan that is dominated by the perennial shrubs *Larrea tridentata* and *Ambrosia dumosa*. The *Larrea-Ambrosia* desert scrub vegetation type occupies approximately 70% of the total area of the Mojave Desert (*18*).

To simulate water runoff into a wash during a summer storm event, 2,000 gallons of water were distributed along a 30-m stretch of a 1-m wide wash using a fire hose that was perforated with two 6-mm holes (on opposite sides of the hose) every 25 cm, thus allowing uniform water distribution to the soil along the 30-m stretch. On each side of the wash, equal numbers of *Larrea* (n=28; 14 per side) and *Ambrosia* (n=36; 18 per side) plants were selected at three distances from the wash: bordering (0-1 m), intermediate (1-3 m), and distant (3-5 m).

Before and after the pulse of wash water was administered, a suite of physiological measurements were taken. They included, pre-dawn and mid-day xylem water potential (Ψ), measures of minimum and maximum daily plant-water stress respectively; and leaf stomatal conductance (g_s), a measure of active water release from the plant. (Stomatal conductance is also related to leaf uptake of carbon dioxide for photosynthesis.) Values of xylem water potential were measured in the field with a Scholander-type pressure chamber (*19*). One to two Ψ measurements per plant were taken at pre-dawn (Ψ_{pd}) and at mid-day (Ψ_{md}). (In this report we discuss only the former, as patterns for both were very similar.) Due to the time-consuming nature of these measurements and to minimize damage to plants, only 24 *Larrea* and 18 *Ambrosia* plants were sampled per day. Stomatal conductance measurements were taken on all *Larrea* and *Ambrosia* plants using a hand-held leaf porometer (*20*). All measurements were taken 1 day before the pulse to serve as baseline data, and then again on days 1, 3, 6, 13, 21, and 35 following the event. Additional sampling was done in August and September 2009.

For each species, data for Ψ_{pd} and g_s were analyzed using a repeated measures analysis of variance (ANOVAR). The independent variable used was the distance category (bordering, intermediate, distant), and day was the repeated measure variable. Results from day -1 were excluded from the ANOVAR analysis; they were analyzed with a one-way ANOVA to test the null hypothesis that plants in the three distance categories were not significantly different from each other before the simulated rain event. Mean values for each distance category of the above parameters on individual days were compared with Tukey's post-hoc analysis. All data was analyzed using JMP 8 statistical software (SAS) and reported as statistically significant if $p < 0.05$.

Preliminary Results

ANOVA results revealed that on day -1 all distance groups were not significantly different for both Ψ_{pd} (*Larrea*, $p = 0.14$; *Ambrosia*, $p = 0.88$) and g_s (*Larrea*, $p = 0.10$; *Ambrosia*, $p = 0.59$). Water status, based on Ψ_{pd}, significantly differed among distance groups one day after the pulse for both *Larrea* ($p = 0.004$) and *Ambrosia* ($p < 0.001$). Following the water application, we found that plants both bordering and near the wash exhibited decreased water stress (increased Ψ_{pd}), while those farther away did not. Plants farthest from the wash (3-5 m) had less than a 2% increase in water potential for both species, whereas plants bordering the wash (0-1 m) increased by 39% and 37% for *Larrea* and *Ambrosia*, respectively. Plants in the intermediate area (1-3 m) also increased by 23% and 16%, respectively (Figures 1 and 2). One month (day 35) following the pulse, *Larrea* plants at bordering and intermediate distances from the wash still had significantly higher Ψ_{pd} values than those farthest from the wash ($p < 0.001$), whereas, *Ambrosia* plants were significantly different across all distances ($p < 0.001$) (Figures 1 and 2).

In all, we detected reduced water stress for all plants within 3 m of the wash, and this persisted for up to a month. Post-pulse water potentials of plants more than 3 m from the wash were indistinguishable from pre-pulse values, indicating no benefit from watering.

Stomatal conductance for *Larrea* significantly increased after just one day following the water application ($p = 0.0075$) and rose rapidly through day 3, after which it steadily declined. Plants bordering and intermediate to the wash experienced > 2x and > 3x higher values, respectively, on day 1 than on day -1 (Figure 3). The rate of increase for *Ambrosia* plants was much slower, however, not peaking until 21 days following the water pulse. The proportional response for *Ambrosia* was greater than for *Larrea*, with plants bordering the wash increasing nearly 6x, and plants intermediate to the wash increasing more than 2x relative to values measured before the event (Figure 4).

By day 35, g_s values for *Larrea* had declined considerably, but bordering and intermediate plants were still significantly higher than those farthest from the wash

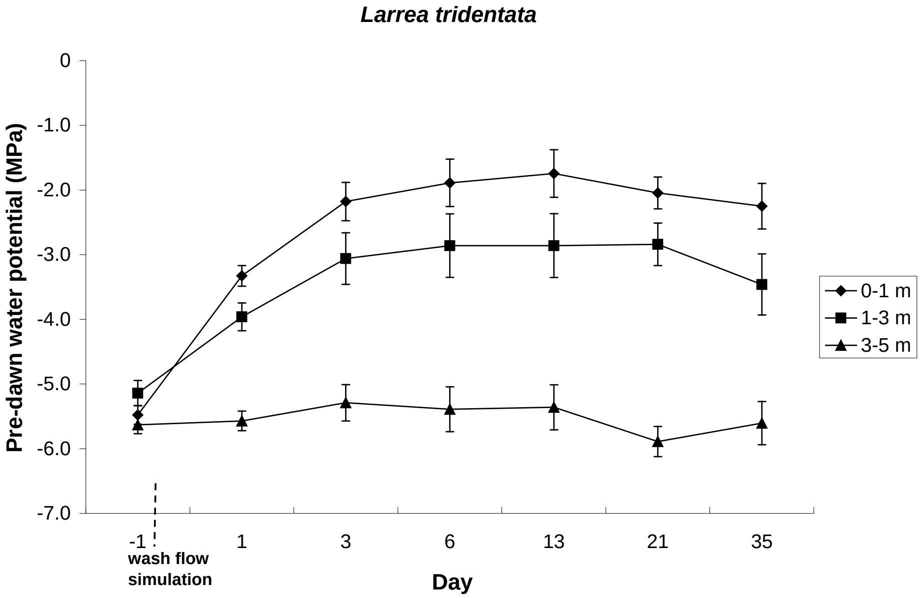

Figure 1. Pre-dawn water potential values after a simulated water pulse for *Larrea tridentata* plants at different distances from the pulsed wash. Each point is the mean +SE. n=9, 5, and 10 at distances 0-1, 1-3, and 3-5 m, respectively. Values were not significantly different on day -1 (ANOVA, f =2.09, p = 0.14). Following the simulated rain pulse plants were significantly different from each other based on distance from wash (ANOVAR; f = 42.35; p < 0.0001). The interaction of day*distance was also statistically significant (ANOVAR; f = 3.33; p = 0.0083).

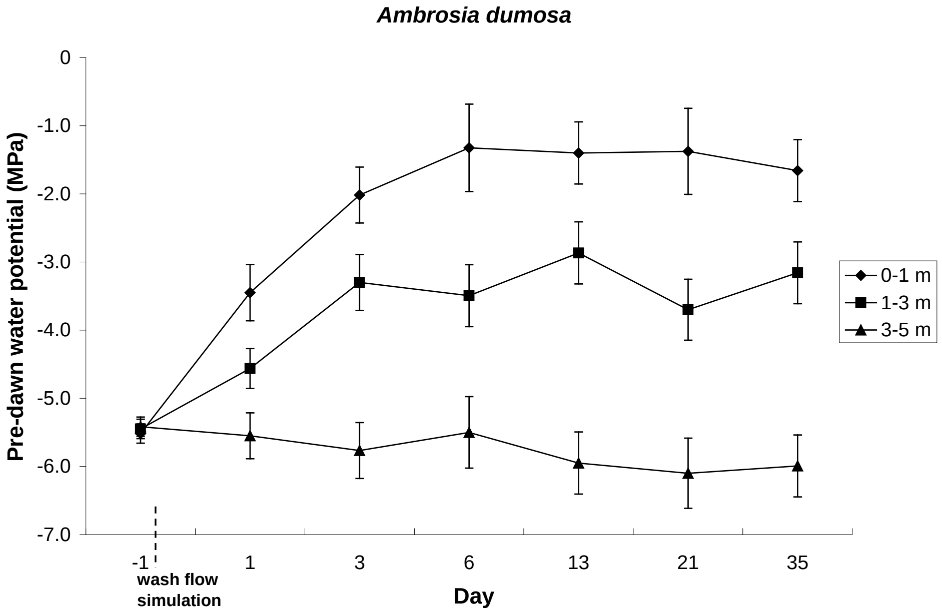

Figure 2. Pre-dawn water potential values after a simulated water pulse for *Ambrosia dumosa* plants at different distances from the pulsed wash. Each point is the mean +SE. n=10, 14, and 12 at distances 0-1, 1-3, and 3-5 m, respectively. Values were not significantly different on day -1 (ANOVA, f =0.12, p = 0.88). Following the simulated rain pulse, plants in each distance category were significantly different from each other on days 1, 6, and 21 (ANOVAR; f = 14.01; p = 0.0004) and on days 3, 13, and 35 (ANOVAR; f = 25.95; p < 0.0001). The interaction of day*distance was statistically significant on days 1, 6, and 21 (ANOVAR; f = 3.92; p = 0.0083) but was not significant on days 3, 13, and 35 (ANOVAR; f = 1.52; p > 0.05).

(p = 0.003) (Figure 3). In contrast, on day 35, values for bordering and intermediate *Ambrosia* plants were still 4x and 3x greater, respectively, than g_s values on day -1. They were also significantly greater than those farthest from the wash (p < 0.0001).

Discussion

Following the simulated wash flow event, plants bordering and at intermediate distances from the pulsed wash became significantly less water-stressed and more physiologically active. By day 6 there was a large amount of new growth on both species, and greenness of plants adjacent to wash was noticeably greater than for those farther from the wash. *Ambrosia* had new leaves in large numbers on plants near the wash. *Larrea* had broader, greener leaves, and by day 13 some plants even had flower buds (*21*). These results show that a summer precipitation event causing wash flow for ~2 hr duration results in responses for perennial plants within ~3 m of the wash and that these plants take up water through root biomass that is close to, or beneath, the wash.

Stomatal conductance response of *Ambrosia* initially lagged behind that of *Larrea*, but eventually exceeded *Larrea*, on days 13, 21 and 35. This could be attributed to the differences in leaf phonologies whereby the response of *Ambrosia*, like other drought-deciduous shrubs, is constrained early-on by the lack of leaf area. After new leaves are produced, however, these species typically exhibit greater activity leading to higher growth rates and more rapid water use than evergreen shrubs, such as *Larrea* (*22*). These results indicate some degree of resource-use partitioning, in that these two species make use of wash water by different mechanisms, at least temporally.

Little is known about how increased summer rains will affect the balance between *Larrea* and *Ambrosia* in the

Mojave Desert. *Ambrosia* is a drought avoider, a growth strategy that allows the plant to drop its leaves and go dormant when there is not sufficient water for new growth. *Larrea*, on the other hand, is a drought tolerator, staying active year-round. Thus, it must utilize water efficiently and exhibit good stomatal control. Understanding the physiological responses of these two species to increased summer rain pulses will help identify how plant distributions may change in response to changes in the precipitation regime of the Mojave Desert. Our studies will also reveal how plant functions are related to wash proximity in desert landscapes—an important consideration given the importance of washes to plant production, distribution, and success.

Repeated photography and field observations have shown that plant populations and communities have changed over the past 100 years in the Mojave Desert in response to climate variability, such as prolonged drought or wet periods (*9*). These changes could result from fine-scale changes, such as ephemeral pulses of summer water as shown in this study, yet the majority of climate models are created at large temporal scales (e.g. annual or seasonal). Such models do not make predictions about the magnitude or variation of precipitation changes at smaller scales, the scale that is shown to strongly influence plant and ecosystem responses to climate change (*24*). Therefore, research on smaller spatial (regional and local) and temporal (days or months) scales is crucial to improving long-term predictions about vegetation changes in response to altered precipitation patterns.

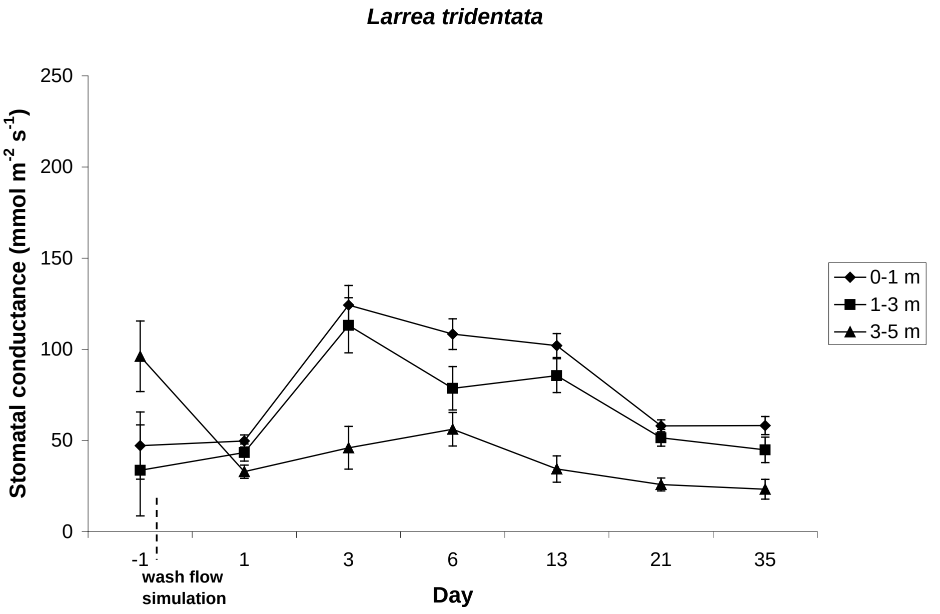

Figure 3. Stomatal conductance values (mmol m^{-2} s^{-1}) following a simulated water pulse for *Larrea tridentata* plants at three distances from the pulsed wash. Each point is the mean +SE. n=12, 6, and 10 for the 0-1, 1-3, and 3-5 m distances, respectively. Values were not significantly different on day -1 (ANOVA, f = 2.52, p = 0.10). Following the simulated rain pulse, plants in each distance category were significantly different from each other (ANOVAR; f = 43.65; p < 0.0001). The interaction of day*distance was also statistically significant (ANOVAR; f = 3.59; p = 0.0016).

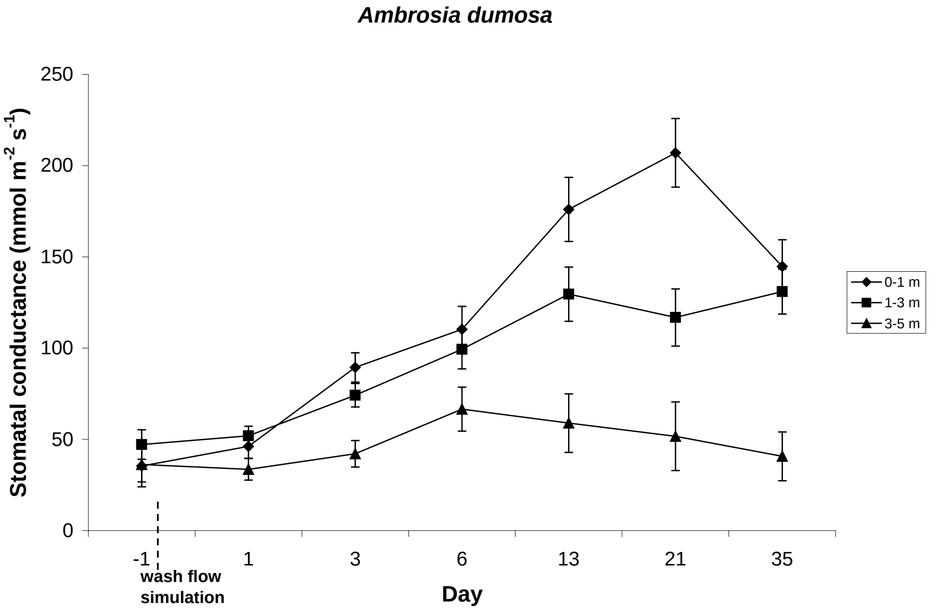

Figure 4. Stomatal conductance values (mmol m^{-2} s^{-1}) following a simulated water pulse for *Ambrosia dumosa* plants at three distances from the pulsed wash. Each point is the mean +SE. n=10, 14, and 12 for distances 0-1, 1-3, and 3-5 m, respectively. Values were not significantly different on day -1 (ANOVA, f =0.53, p = 0.59). Following the simulated rain pulse plants in each distance category were significantly different from each other on days 1, 6, and 21 (ANOVAR; f = 11.22; p = 0.0003) and on days 3, 13, and 35 (ANOVAR; f = 17.12; p < 0.0001). The interaction of day*distance was statistically significant on days 1, 6, and 21 (ANOVAR; f = 6.23; p = 0.0003) and on days 3, 13, and 35 (ANOVAR; f = 3.93; p = 0.006).

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Information for Authors

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Larrea tridentata **leaves have unfolded, and some new growth has appeared on Day 6 following the simulated rain pulse.**

Resource Management Issue: Managing the Effects of Climate Change

Global climate models (GCMs) generally agree that a drying trend is already under way in the desert southwest and will continue through the century. Seager and others (*1*) analyzed time series of precipitation from 19 GCMs used in the Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report to show a general drying trend through mid 21st century in Southwestern North America. There was broad consensus among the climate models that this region will dry in the 21st century and that the transition to a more arid climate may already be underway.

Although much uncertainty remains, especially at resolutions smaller than single grid cells of a model, variability in precipitation is expected to increase. The proportion of precipitation that comes from extreme events is expected to increase as well as the duration and intensity of droughts. Diffenbaugh and others (*2*) used the results of 15 GCMs from the IPCC Fourth Assessment Report to show that areas of the southwestern United States and northern Mexico are the most persistent hotspots for climate change. Much of the responsiveness of the southwestern hotspot comes, not from progressive warming or a long-term rise or fall in precipitation, but from increased variability in precipitation from one year to the next.

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The two driest years on record (2002 and 2007) and the wettest year on record (2005) in the Mojave Desert have already caused significant impacts in Mojave National Preserve. Record winter precipitation in the winter of 2004-2005 followed by two dry summer months resulted in abundant fuel. Lightning strikes then ignited the Hackberry Complex Fire, the largest wildfire in the park's history.

Surveys conducted over the past five years of sparse, groundwater-dependent wetlands that sustain wildlife and often endemic biota indicate that most of these water sources are sensitive to precipitation variability. Springs in Mojave National Preserve appear to respond rapidly to annual rainfall and, on average, may have aquifer storage capacity to persist through only a few years of extreme drought. Understanding and preserving natural resources in the face of climate change is one of the great challenges facing resource managers.

A trend towards drier conditions, increasing temperatures, and precipitation variability is likely to exacerbate wildfires. A consequence may be vegetation type conversion from perennials to annual and more weedy species.

The National Park Service has created a new natural resource funding category called Climate Change Response (*3*) "to assist parks with natural and cultural resource-management issues related to detrimental consequences of climate variability and change. Projects must promote or plan for on-the-ground conservation actions or communication activities that promote resource stewardship and protect park resources. Priority for funding will be directed towards projects that demonstrate tangible benefits to resources and ecosystems that are experiencing measurable impacts from climate variability and change and are expected to receive serious consequences of climate change in the near future. Priority resources and ecosystems include coastal, marine, and riverine systems, high elevations, high latitudes, and arid lands. Projects must identify known or expected threats from climate change to specific resources and address how proposed actions will ameliorate those threats."

Mojave National Preserve is interested in working with scientists to understand and mitigate the effects of climate change on park resources. Projects can range from $30,000 to $900,000 and must be completed in three years. We would like to work with interested researchers to develop proposal ideas for fiscal year 2011 and 2012 competition. Proposal ideas would be vetted at the 2010 fall meeting of the Mojave Network, and full proposals for regional competition are due October 1, 2010.

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