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Toward Integrated Research, Land Management, and Ecosystem Protection in the Malpai Borderlands: Conference Summary

January 6-8, 1999

Douglas, Arizona



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Abstract

Land management based on sound science is key to increased productivity and biological diversity along the U.S./Mexico border in southeastern Arizona and southwestern New Mexico. The USDA Forest Service's Rocky Mountain Research Station and the non-government Malpai Borderlands Group have sponsored studies and resource inventories in the region. A meeting in Douglas, Arizona, was held to inform the scientific, land management, and local communities of progress. These proceedings contain abstracts from the presentations. The reports cover a variety of topics including program overviews, resource inventories, landscape changes, fire and local ecosystems, range restoration, and species ecology and management.

Keywords: ecosystem management, ecosystem research, Southwestern Borderlands, Arizona, New Mexico, research/management partnerships

Sponsors

- * Malpai Borderlands Group
- * USDA Forest Service

Conference Coordinators

- * Dr. Gerald J. Gottfried, Research Forester, Rocky Mountain Research Station, USDA Forest Service
- * Dr. Charles G. Curtin, Malpai Borderlands Group and Department of Biology, University of New Mexico

Compilers' Note

None of the papers presented from the conference were subjected to technical review; the views expressed and the mode of expression are those of the presenters. The USDA Forest Service shall not be responsible for statements and opinions advanced in this publication. Authors are responsible for the quality of their papers.

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Foreword

The Borderlands Region of southeastern Arizona and southwestern New Mexico covers approximately one million acres in the San Bernardino and Animas Valleys east of Douglas, Arizona. The region ranges from 4,500 to 8,500 ft in elevation and contains a variety of ecosystems extending from desert shrub and tabosa grasslands to high elevation Arizona ponderosa pine and Douglas-fir stands. The mountains and valleys are home to diverse plant and wildlife populations, including some species that are rarely found within the United States. Land ownership is divided between private individuals and state and federal agencies. The Malpai Borderlands Region is home to a viable ranching community. Property and ecosystem fragmentation, which is obvious in many adjacent valleys, has not reached the area. In 1992, a group of ranchers known as the Malpai Borderlands Group organized to reduce the threat of fragmentation and to increase the productivity and biological diversity of the area's rangelands (McDonald 1995). The Group felt that their efforts should be based on good science, contain a strong conservation ethic, be economically feasible, and be initiated and led by the private sector with the agencies as partners.

Land management based on good science has been a key part of efforts in the Borderlands Region. The Malpai Borderlands Group and affiliated organizations have sponsored many research studies and inventory activities. The Rocky Mountain Research Station became involved in 1994 when it was awarded a national ecosystem management grant to conduct research within the Borderlands. The objective is to achieve ecosystem management in the southwestern Borderlands through coordinated research/management partnerships. The Rocky Mountain Station has initiated studies, but more importantly, has developed research partnerships, with scientists and managers from many universities, state agencies, private and conservation organizations, and independent investigators. These collaborations have provided expertise to address the wide variety of questions that are basic to good ecosystem management to sustain and create healthy, productive ecosystems.

A key element of science is communication. A science meeting was organized in Douglas to provide an opportunity for scientists and managers to share research progress and results with colleagues, ranchers, and members of the Borderlands community. The meeting featured 31 presentations covering a variety of topics, including program overviews, resource inventories, historical environmental changes, fire and Borderlands ecosystems, range restoration, and species ecology and Borderlands management. The meeting began with a field trip to observe research and management activities east of Douglas and concluded with a panel discussion, led by participants from private and public organizations, on linkages between species and ecosystems. Expanded or standard abstracts for the presentations and a synopsis of the panel session are included in these proceedings, as are several abstracts reporting research in the region provided by investigators who were unable to attend the meeting.

The organizers would like to thank Wendy Glenn of the Malpai Borderlands Group who handled local arrangements, Ron Bemis of the Natural Resources Conservation Service for his general assistance, and all of the people who contributed to the discussions during the meeting and the field trip.

McDonald, Bill. 1995. The formation and history of the Malpai Borderlands Group. In: DeBano, L.F.; Ffolliott, P.F.; Ortega-Rubio, A.; Gottfried, G.J.; Hamre, R.H.; Edminster, C.B., tech coords. Biodiversity and management of the Madrean Archipelago: The Sky Islands of southeastern United States and northwestern Mexico; 1994 September 19-23; Tucson, AZ. Gen. Tech. Rep. GTR-264. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station: 483-486.

Achieving Ecosystem Management in the Borderlands of the Southwestern United States Through Coordinated Research/Management Partnerships: An Overview of Research Unit RM-4651

Carleton B. Edminster, Project Leader and **Gerald J. Gottfried**,
Research Forester, Rocky Mountain Research Station, Flagstaff, AZ

The Southwestern Borderlands project is one of 19 ecosystem management research projects that were initiated by USDA Forest Service Research nationally in 1994. The project was the result of a successful proposal by Dr. Leonard DeBano (retired, Rocky Mountain Research Station) and Larry Allen (Malpai Borderlands Project Coordinator, Coronado National Forest). One of the major factors in the success of the proposal was the support of the Coronado National Forest, the University of Arizona's School of Renewable Natural Resources, the Malpai Borderlands Group, the Animas Foundation, The Nature Conservancy, the Natural Resources Conservation Service, and the Bureau Land Management.

The Borderlands project area of southeastern Arizona and southwestern New Mexico is a unique, relatively unfragmented, landscape of nearly one million acres containing exceptional biogeographic diversity in series of natural communities ranging from semi-desert grasslands and woodlands to mixed conifer forests. Maintaining the health and productivity of these natural communities is of critical importance in maintaining viable local rural economies. The geographic area of focus for the Borderlands Ecosystem Research Program is the San Bernardino Valley, San Simon Valley, southern Peloncillo Mountains, Animas Valley, and the Animas Mountains of southeastern Arizona and southwestern New Mexico. The project area is under multiple ownership and administration: 53% is in private ownership; 23% is in state ownership by Arizona and New Mexico; 17% is administered by the Coronado National Forest; and 7% is administered the Bureau of Land Management.

Much of the information gained from this project can be extended to the management of the larger Madrean Archipelago Biogeographical Region located in southern Arizona, southwestern New Mexico, and northeastern Sonora and northwestern Chihuahua, Mexico.

Results from the project contribute to the scientific basis for developing and implementing a comprehensive ecosystem management plan for the Borderlands area. The plan includes strategies for restoring natural processes, improving the productivity of grasslands and woodlands, providing wildlife habitat, and sustaining an open landscape, viable rural economy and social structure.

Problem areas for the research project are to:

1. Provide the scientific basis to establish the desired future condition for the planning region based on highest quality biological science integrated with desired future social and economic conditions within the context of private and agency partnerships.
2. Plan and implement a long-term systematic program of basic and applied research and coordinated monitoring to integrate past and future research

findings and contribute to developing guidelines for sustaining a viable rural economy and open landscapes.

In collaboration with the University of Arizona, the Borderlands Research Program conducted a conference on the biodiversity and management of the Madrean Archipelago in September 1994. The purpose of the conference was to bring together scientists and managers from government agencies, universities, and private organizations to examine the biological, cultural, and physical diversity and management challenges of the region to provide a basis for developing the research program. International and regional conferences on fire effects and management strategies in March 1996, and the future of arid grasslands in October 1996, were also held in collaboration with the University of Arizona and the University of Sonora, Mexico. Proceedings of these conferences have been published by the Rocky Mountain Research Station as General Technical Reports RM-264, RM-289, and Proceedings RMRS-P-3.

The strategy for accomplishing the research program has been to develop a comprehensive multi-disciplinary synthesis of the status of our knowledge, identify research and monitoring needs and priorities, and define critical studies and field experimentation. The results of these analyses provide the basis for future research activities and also provide managers with a comprehensive reference of our current best available knowledge.

A series of initial investigations have been completed which summarize and synthesize information on topic areas having significant management and research planning applications. These efforts include:

1. Status of knowledge on the role and importance of human and natural disturbances on plant communities in the Borderlands of U.S. and Mexico.
2. Status of wildlife information in the Borderlands ecosystem project area and proposed experimental design to address research and management needs.
3. Prehistory and early history of the Borderlands ecosystem: archeological synthesis and research recommendations.
4. Comparative research on integrated watersheds at Walnut Gulch, Arizona, the Gray Ranch, New Mexico, and other southwestern watersheds.
5. Development of an annotated bibliography for the northern Madrean biogeographic province.

A second program focus is the development of a comprehensive landscape inventory and monitoring system to serve research and management needs. Studies underway include:

1. Mapping current vegetation of the Borderlands ecosystem management area using thematic mapper satellite imagery with intensive ground validation.
2. Delineation and interpretation of geomorphic surfaces of the southwestern Borderlands area. This study along with vegetation mapping and soils mapping by Natural Resources Conservation Service will provide the basis for developing vegetation management strategies.
3. Land use history, historical landscape change, and photographic monitoring of the Borderlands region.
4. Contributing to development of a digital archive for studies at the Santa Rita Experimental Range. This project will create a geo-referenced archive of research records for the oldest range experiment station in the United States and will provide a basis for data management in the project area.

A third program focus is specific research studies identified as having high priority in filling knowledge gaps. These studies include:

1. Fire regime reconstruction in the southwestern Borderlands.
2. Effects of fire frequency on nutrient budgets of grasslands in the Borderlands area.
3. Understanding the spatial pattern of fire regimes and fire behavior at landscape scales including comprehensive fire regime reconstructions. These studies are regional in scope and in cooperation with the Coronado, Cibola, Gila, Santa Fe, and Lincoln National Forests.
4. Effects of prescribed fire on birds and vegetation and selected endangered species in the Borderlands area. These studies are being conducted in landscape scale management areas on the Baker Burn area of 1995 and the Maverick Burn area of 1997 in the Peloncillo Mountains. Additional studies include effects of prescribed burning on Palmer agave and foraging interactions with lesser long-nosed bats, survival and behavior of montane rattlesnakes, remote sensing and GIS techniques for mapping and analyzing fuels, fire behavior, and effects on plant communities in the burn mosaic.
5. Cultural and environmental history of the Borderlands. This study provides the implications of past land-use history for future management.
6. Experimental treatments to investigate various vegetation and livestock management strategies, including mechanical treatments and prescribed fire, to improve composition and productivity of perennial native grasses and reduce shrub encroachment, improve soil properties and wildlife habitat.
7. Archeological implications of revegetation treatments.
8. Techniques for fuels visualization, mapping, and fire spread modeling in selected areas of the Chiricahua and Huachuca sky island mountain ranges.
9. Developing riparian ecosystem recovery priorities for the Southwestern Region.

Future efforts will expand development of monitoring efforts and investigations of the effects of prescribed burning at the landscape scale on vegetation, wildlife, and soil properties, relating vegetation condition and response to soils and site conditions, adapting predictive models of fire behavior to prescribed burning in grasslands and woodlands, and continuing experimental treatments in restoring grassland savannas.

In addition to the Rocky Mountain Research Station, research partners include Agricultural Research Service; U.S. Geological Survey Desert Laboratory; The Nature Conservancy; New Mexico Natural Heritage Program; Arizona Nature Conservancy; Audubon Society; Desert Botanical Garden; University of Arizona School of Renewable Natural Resources; Laboratory of Tree-Ring Research; Departments of Geosciences and Geography and Regional Development; Arizona State Museum; Office of Arid Lands Studies; Arizona State University; New Mexico State University; University of New Mexico; California State University; Indiana State University; University of Oklahoma; Arizona Geological Survey; Society for Ecological Restoration; and Arid Lands Project.

Private and management agency partners also include the Malpai Borderlands Group; the Animas Foundation; Coronado National Forest; Douglas Ranger District; Natural Resources Conservation Service; U.S. Fish and Wildlife Service; San Bernardino/Leslie Canyon National Wildlife Refuge; Bureau of Land Manage-

ment; Arizona and New Mexico Land and Game and Fish Departments; Whitewater Draw (Arizona) Natural Resources Conservation District; Hidalgo (New Mexico) Natural Resources Conservation District; Fort Huachuca; and the Arizona Department of Corrections.

These partners and the many special people working with these agencies and organizations are the critical elements in making the research program successful. The project is a national example of how private citizens and organizations and public agencies can collaborate to ensure the health and future of large open landscape areas.

The Landscape and Small-Ranching Economy

Bill McDonald, Rancher, Douglas, AZ

Ranchers do have economic interest in their land. But newspapers give the view that ranchers have *only* economic interest in their land. I submit to you that anyone who gets into ranching for only economic reasons is an idiot. Yes, we have to make a living, but that's not why we get into ranching. There are many easier ways to make a buck. You can take the same amount of money, put it into almost anything else, and get a better return on your investment. Ranchers started ranching for the same reasons you scientists and managers got into research or management—not to become millionaires. If you're a scientist or work for an agency, you didn't get into it to submit to the kind of grief you get for what you're being paid. You have a feeling for the land—there's a pull there you can't resist. I love everything about the land. I don't like being compelled to defend my way of life. But I thoroughly enjoy learning, as I am this week, more about the land that I've lived in and hope to live in the rest of my life. I enjoy the insights and being able to share mine with folks who look at things differently. I think it gives us all something that we can hand down to the next generation so they can do an even better job of living with that landscape, if it's still there.

There's another side to ranching. It's a business, an unforgiving business. If you get caught up in the cattle side and are on the wrong side of it, it can be devastating. The last boom to make money in ranching was during and after World War II. There was good money to be made until the mid 1950's when there was a devastating drought. The work of Julio Betancourt showed the tremendous die-off of mesquites in the 1950's; that's how bad it was. My grandfather sold off all his cattle. My grandmother went into the hospital with what would be called severe depression now.

The '60s were not a profitable time to be in ranching. The '70s were a good time to get yourself in debt. Land prices went up, banks were willing to lend money, and in the farm sector a lot of people crashed. The '80s were a relatively good period—we had the weather patterns that Jim Brown talked about that were good for cattle weights, and the prices stayed high. The '90s have been very bad for ranching. We've had uneven weather patterns and depressed prices. In 1995 the price fell 35% from the year before, and last year it fell almost 40% from the year before.

Imagine trying to live and plan on this income. There are some factors working against small and medium-sized outfits. This is the way America is going. I believe that big government and big corporations tend to like each other, and a small entrepreneur has to figure it out on his own. The feedlots are becoming more and more consolidated. Ranchers are tenacious sons of guns, and they haven't figured out how to get rid of us yet, but they're trying.

I think we're going to have to get into niche marketing. The Malpai Group offers a good possibility to find a way to niche market beef to people who have the same concerns we do and would like to support us. But we haven't figured out how to do that yet. Attempts at niche marketing have failed miserably, so we have to be very careful. On the cost side, the weather has always been the major factor in the Southwest. Drought is the main thing we've had to worry about. It's difficult because you don't know when it starts until you're well into it, and you don't

know when it's going to end. Consequences for a cattle herd are huge. You try to hang on without destroying the resources you depend on. We spent \$30,000 on supplemental feed in 1996 in six months trying to hang on to our cattle herd. On the other hand, you'll get a year where the rains come right. This year had low average rainfall, but the rain fell at the right time, so the herd is in good shape.

There are so many things out of our control. If ranchers seem standoffish, rigid, and conservative, it's because we've had to take a lot of shots, and people have often tried to take advantage of us for one reason or another. So we're reluctant to jump into the newest idea. On the other hand, we're very flexible. We're the epitome of adaptive management, because we won't survive if we don't adapt. We have to deal with these factors that we can't control.

One thing we have some control over, but not a lot, is government regulations, which more and more are coming into play in ranching. I don't like to get hit with surprises. It bothers me worse than anything else does. Government agencies have kept ranchers in a reactive mode. We don't know what's happening until it hits us in the form of a letter or a paper and it's already a done deal. When you have to react to a crisis situation, your decision making isn't the best, your social skills don't rise to the top, and it makes for a bad scene. That's how business has been done on public lands for years and it needs to change. I think the Malpai Borderland Group offers a forum for the types of communication to allow us to avoid that sort of thing. We're not there yet, but we're getting there. When you have a large organization, you're used to running things a certain way and have laws to follow, and it's hard. But we can use this group as an example of how we can make things work.

Inheritance taxes and estate planning present big challenges. This is where many ranches bite the dust and become developments. It's tough changing from generation to generation. Grandpa doesn't want to let go of it. I know men in their sixties who haven't had a major decision to make on the ranch yet because their parents are still making the calls. Many kids leave ranches in frustration over that sort of thing. Also, many people don't do estate planning. It's complicated. You don't really know until the owner dies whether the next generation will be able to keep that ranch or not.

These things all have great significance for the things that everyone in here cares about, which are habitats and landscapes. And if we're not talking to each other, if we're pointing fingers at each other, we'll all lose. But the first thing to suffer will be the habitats and the landscape. A viable ranching economy is still an important piece of this puzzle, and if it becomes a moot point, you'll be dealing with a landscape that's very different from what it is today.

Natural Resources Conservation Service Activities in the Borderlands

Ronald J. Bemis, USDA Natural Resources Conservation Service,
Douglas, AZ

The Natural Resources Conservation Service (NRCS), formerly the Soil Conservation Service has had a presence in the Borderlands area of Arizona and New Mexico since the mid 1940's. The Malpai Borderlands Group (MBG) became a formal organization with a goal to "restore and maintain the natural processes that create and protect a healthy unfragmented landscape to support a diverse, flourishing community of human, plant and animal life in our Borderlands Region. Together, we will accomplish this by working to encourage profitable ranching and other traditional livelihoods which will sustain the open space nature of our land for generations to come."

The MBG requested the NRCS to appoint a full time person who could move freely across the state line on a local level, providing technical assistance to support the MBG's efforts in both states. The NRCS responded by creating a new position to support this locally led effort and to provide planning and application assistance on private and state lands in support of the MBG and natural resource conservation.

NRCS support includes having an active roll in the development of the MBG's conservation easements, Grass Bank, private cost sharing program, and endangered species program. It also includes working with the USDA Forest Service's Rocky Mountain Research Station on research projects on state and private lands as well as traditional range conservation planning work throughout the area. The NRCS has taken a strong interest in the MBG's program because it is a grass roots effort where local landowners are taking an active roll in leading a conservation initiative that transcends land ownership boundaries to address natural resource management on a landscape scale. This concept puts the members into a leadership position to have a more active part in determining the fate of the resources that they own and manage. The NRCS, being a technical agency, saw this as an opportunity to support a locally lead organization bringing meaningful science into commercial applications of conservation and promoting stewardship of our natural resources.

Discussion

Historically the NRCS, formerly the Soil Conservation Service (SCS), was set up to protect the nation's ability to produce food in a sustainable manner. In the early 1990's, when the SCS became the NRCS, the nation asked the agency to slightly refocus more on how agriculture is affecting natural ecosystems in the production of food and fiber. To achieve these objectives requires that the NRCS be a technical agency with expertise in doing resource assessments to develop viable alternatives to achieve landowner's objectives. This allows landowners to develop conservation plans that address all resource concerns based on technically sound information. Once decisions are made, the NRCS completes the final design for the project or projects and assists the landowner with implementation.

The NRCS follows up after implementation by monitoring the effects of the project to assist the landowner in proper management of the new system. For example, if the landowner installs a fence to improve pasture management, NRCS will monitor the plant communities to be sure the desired results are being achieved.

NRCS provides assistance to landowners through local conservation districts, which are legal subdivisions of state government. Each district board is made up of local landowners, farmers, ranchers, educators, and other concerned parties. These local boards help guide the activities of the NRCS. This partnership allows the NRCS, which is a federal agency, to work with landowners in a non-threatening manner, bringing state of the art science to local resource problem.

The MBG is quite similar to a conservation district, except it has no legal ties to any form of government. The MBG is a local self-directed board that makes decisions to support its goal statement, which is consistent with the intrinsic values of natural ecosystems and sustainable production of agricultural commodities. The MBG bases all of its decisions on the application of the best available science. Where there are voids in scientific information, the MBG works to focus dollars and politics to support research that could answer the natural resource management questions for their planning area. This is all very consistent with the manner in which NRCS does business with conservation districts. The NRCS has appointed a full-time technical support person to the project. The MBG coordinator from the NRCS also provides technical assistance to researchers as part of the job. Part of the agreement between NRCS and the Rocky Mountain Research Station (RMRS) is that the NRCS project coordinator will coordinate and facilitate research projects and activities with local landowners and provide coordination with the state land departments when necessary in the Borderlands area. This assistance was part of the agreement, because traditionally the RMRS works on Forest Service (FS) administered lands. Through the Private Forestry Stewardship Program, it is legal for the FS and RMRS to conduct, administer, and fund research activities on private and state trust lands. RMRS also provides funding to various universities that generate needed data consistent with RMRS projects. Through this linkage the NRCS becomes quite involved in a wide array of project designs for researchers and provides support functions to researchers in the Borderlands area.

The NRCS has a number of roles in relation to research in the Borderlands area. In the design phase of research to answer specific questions related to local and natural synecology, the NRCS provides detailed and historic knowledge to increase the probability of completing more meaningful long-term research. Interaction with local landowners is imperative to have access on private lands and state trust lands. NRCS helps researchers understand and comply with liability issues and laws and regulations that landowners must deal with on private property. This includes preparation of "Environmental Evaluations" on all ground disturbing research, coordination with the State Historic Preservation Office, compliance with the Endangered Species Act, and the National Environmental Policy Act. Technical designs on standard conservation practices required as part of research activities are also provided.

On several research projects in the Borderlands area, the NRCS has assisted with writing contracts to implement various phases of research projects, and has found local contractors to bid on the work. NRCS helps with quality control during the implementation phase so that the desired results are achieved.

The NRCS through its field office in the project area provides administration and training to make sensitive equipment, such as night vision goggles and GPS equipment, available to researchers. Coordination with the conservation district through the NRCS field office also makes equipment such as a range drill, a brush chopper, and hauling equipment available to researchers. Plant materials suitable

for implementation of research work are made available through coordination by the NRCS from their Plant Materials Center in Tucson.

Conclusions

The benefit of having a federal agency such as the NRCS working closely with both researchers and landowners is that a better product is more efficiently produced, to meet the needs of landowners who are trying to improve the condition of their natural resources. Working in concert with an agency, as is happening in the Borderlands region, promotes a more practical and efficient improvement in managing natural ecosystems to meet the demands modern society is placing upon these systems.

Rangeland Monitoring in the Malpai Borderlands, 1995-1998

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Rangeland monitoring is the quantitative study over time of carefully chosen plots of land, and its purpose is to provide feedback on the effects of management activities as well as natural events. Recent monitoring projects in the Malpai borderlands region have included a study of the home ranches of the grassbank ranchers, and a study of the 1997 Maverick Burn.

The home ranches of three ranchers participating in the Malpai Borderlands Group's grassbanking project were monitored in 1993, soon after cattle were removed, and in 1998, about the time cattle returned. Two of the three ranches showed significant upward trends; the third showed a slight downward trend at three of eight plots. The latter ranch is of relatively low potential, with an initial perennial grass cover of less than 10% at most plots. While individual grass plants on the ranch undoubtedly benefited from three years' rest from grazing, the effect was not detectable by the methods used.

The Maverick Burn was conducted in June 1997. Plots were established in fall 1997 to monitor the effects of the fire on cover of all plants and density of woody species, including *Agave palmeri*, an important nectar source for the lesser long-nosed bat. Results of the 1997 sampling indicated significant mortality of oneseed and alligator juniper, turpentine bush, pointleaf manzanita, pinyon pine, and cholla cactus. We observed vigorous resprouting from crowns by oaks, mesquite, catclaw, and velvetpod mimosas, mountain Yucca, sacahuista (*Nolina*), and kidneywood. Agaves suffered less than 10% mortality in the first months following the fire, but this figure was revised upwards to at least 25% by fall 1998, when the plots were re-sampled. Other species showing delayed mortality included cholla and velvetpod mimosa. The mortality of mesquite was overestimated in 1997 at 25%, and was revised downward in 1998 to 7% due to late resprouting.

Geology and Geomorphology of the San Bernardino Valley, Southeastern Arizona

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The purpose of this project is to integrate new detailed field mapping, aerial photograph interpretation, previous research, and other available data into detailed geologic and geomorphic maps (scale 1:24,000) of the San Bernardino Valley study area. Our goal is to describe the fundamental surficial and bedrock geology in a manner that can be incorporated into ecosystem and land-management research. Future work will integrate our completed maps with soil and vegetation surveys in the Borderlands Region.

The study area is in the extreme southeastern corner of Arizona in Cochise County. It is bounded on the south by the U.S.- Mexico border, on the east by the Arizona-New Mexico border, on the west by the Perilla Mountains, and on the north-northwest by U.S. Highway 80. The main geographic features in the study area include the northern half of the San Bernardino Valley, the southern portion of the San Simon Valley, and the western side of the Peloncillo Mountains. The valleys formed during the Miocene-Pliocene period of high-angle normal faulting (the Basin and Range Disturbance) that produced deep alluvial basins separated by bedrock mountains. The basins subsequently filled with volcanic and sedimentary deposits shed from the adjacent mountains and volcanic rocks erupted in the valleys.

The San Simon Valley is an alluvial valley that lies between the Peloncillo Mountains on the east and the Chiricahua Mountains on the west. A north-northwest trending drainage divide from the vicinity of Paramore Crater toward the Chiricahua Mountains separates the San Simon Valley from the San Bernardino Valley to the southwest. Topographic relief associated with this drainage divide is minimal and the geologic nature of the divide is uncertain. Streamflow in the San Simon Valley is to the north and northwest into the Gila River system. Gravity data suggests the San Simon Valley may be approximately twice as deep as the San Bernardino Valley (Oppenheimer and Sumner 1980).

The Peloncillo Mountains are composed of 24- to 30 million-year-old rhyolitic volcanics overlying a basement of Paleozoic and Mesozoic sedimentary rocks (Wrucke and Bromfield 1961). Portions of three separate calderas have been mapped within the study area. The resurgent Geronimo Trail Caldera (Deal et al. 1978; Erb 1979) occupies the southern end of the mountains just north of the international border. Although most of the caldera lies in New Mexico, the western and southwestern margins, marked by ring-fracture domes and ring-fracture system, form the boundary of the mountains and the San Bernardino Valley. Approximately 400 m of ash-flow tuff beds fill the inside of the caldera. A second caldera, informally named the Rodeo Caldera after the nearby village, erupted several ash-flow and lava sequences that comprise the Peloncillos on the east side of the southern San Simon Valley (Deal et al. 1978); indeed, the center of the caldera seems to be buried beneath the San Simon Valley. The youngest of the rhyolite eruptive centers, the Clanton Draw caldera (McIntyre 1988), truncated

the earlier Geronimo Trail Caldera and produced the thick tuff beds in Skeleton Canyon.

The San Bernardino Valley, the primary focus of our work, is an elongated, southwest-trending, gently sloping basin situated between approximately parallel mountain ranges. Gravity data suggest the alluvial basin is less than 1600 ft deep (Oppenheimer and Sumner 1980). Approximately one-half of the basin is in Arizona and the other half is in Sonora, Mexico, but only the U.S. portion of the valley is included in this study. The basin is about 30 km wide at the international border and narrows to about 20 km wide at its northeastern end. The highest elevation in the valley is 5135 ft on a cone north of Paramore Crater, and the lowest elevation is 3700 ft in Black Draw where it crosses the international border. The average topographic gradient along the valley floor is 49 ft per mile (Schwab 1992). Black Draw and its tributaries drain the San Bernardino Valley and flow southward into Mexico, where the trunk stream is known as Rio San Bernardino.

The geology of the San Bernardino Valley is comprised of three distinct elements. Paleozoic and Mesozoic sedimentary rocks and mid-Tertiary volcanics apparently form the bedrock floor of the basin. Tertiary and Quaternary alluvial deposits (plus basalt flows from vents in the adjacent mountains to the east and west that predate downdropping of the basin) filled the basin, although erosion is removing some of the earlier deposits. During the Pleistocene, the basaltic volcanic field that dominates the present landscape was active.

Prior to this project, the geology of the valley had never been mapped in detail. One of the earliest descriptions of the area (Darton 1933) reported extensive lava tubes and included a diagram of Paramore maar. Later geologists have worked in and around the San Bernardino Valley, although most have focused on the adjacent mountains and mapped the valley only on a reconnaissance basis (Cooper 1959; Drewes 1980; Drewes 1981; Drewes and Brooks 1988; Lynch 1972). Detailed bedrock mapping of limited exposures of the Paleozoic and Mesozoic bedrock on the east side of the valley just north of the international border was done by two M.S. students at the University of Arizona (Dirks 1966; Kelly 1966). Other workers contributed detailed analyses and interpretations from geochemical and petrological studies of the basalts and the interesting suite of mantle-derived xenoliths found in the valley lavas (Arculus et al. 1977; Evans and Nash 1979; Kempton et al. 1987; Kempton et al. 1982; Kempton et al. 1991; Lynch 1978). Some of the valley and flank lavas and adjacent rhyolite centers in the mountains have been dated to help ascertain the geologic history of the valley (Damon et al. 1996; Deal et al. 1978; Kempton et al. 1987; Lynch 1978; Marvin et al. 1978; Reynolds et al. 1986). Hydrologists have studied the drainage system of the valley and the quality of groundwater (Anderson 1995; Anderson et al. 1992; Robertson 1991; Schwab 1992).

The Late Cenozoic period of basaltic volcanism resulted in the eruption of more than 130 separate vents and associated lava flows and pyroclastic deposits. Limited radiometric dating indicates the San Bernardino volcanic field was active between 750,000 and 260,000 years ago (Kempton et al. 1987; Lynch 1978; Reynolds et al. 1986). Monogenetic pyroclastic cones are the most prominent features in the valley, which suggests benign Strombolian eruptions were the typical volcanic activity. Cinder cones, with varying amounts of bombs, vent lava, and agglutinate breccia, are the most common features in the valley. Several of the volcanic features have multiple eruptive vents and some cones have been partially obliterated by subsequent eruptions. The cones show a wide range of erosional morphology from well-formed, fairly "fresh" cones to rounded, subdued hills. Lava flows are typically thin and tend to follow the modern slope of the valley in

that most flow towards the south. Soils formed on the lava flows are chocolate brown, rocky, clay-rich (smectitic) vertisols that develop deep cracks when dry. Steam-blast eruptions are recognized in at least eight places in the valley and can be distinguished by distinctive craters rimmed with light-colored tuff rings that frequently contain abundant accidental sedimentary and felsic volcanic clasts.

Detailed mapping allows us to differentiate several lithologic units on the cones based on the dominant rock type. These units include cinders (Qbpc), vent lavas (Qbvl), agglomerate breccias (Qbpb), basaltic tuffs (Qbp), and poly lithic surge tuff rings (Qps). Basalt-dominated colluvium (Qcb) and alluvium (Qab) are also mapped on the flanks of and immediately adjacent to the cones. Individual cones are designated by a four digit number based on location on the township and range grid system (i.e., Vxxxx). From aerial photographs and field mapping, original extent of individual lava flows can be determined for many of the eruptions, although most are now rocky, deeply weathered, flat grasslands with few remnant flow features. When possible, the lava flows are labeled with the number of the source vent (i.e., Fxxxx). Basalt flows and pyroclastic deposits form an important portion of the basin fill in the valley.

Sediments eroded from the adjacent mountains and deposited in the main valley as alluvial fans and stream terraces are an important component of the modern basin fill. These deposits consist of moderately to poorly sorted conglomerate, with numerous lithologies represented in the clasts. Deposits representing the Plio-Pleistocene (TQo), early Pleistocene (Qo), middle Pleistocene (Qm1, Qm2), late Pleistocene (Ql, Qly), and Holocene to modern (Qy) are differentiated based on color, geomorphic position, pedogenic clay content, and soil carbonate development. Relief on these alluvial surfaces is very minimal in the northern portion of the San Bernardino Valley and the middle Pleistocene (Qm) surface is typically the oldest alluvial surface exposed. Erosional incision is more pronounced along the international border and on the western side of the basin in the Silver Creek drainage. Remnants of the older alluvial fan surfaces are exposed in these areas and the interbedded relationship of alluvial units and older basalt flows is evident. These alluvial deposits are undoubtedly important for groundwater recharge and form a complex system of aquifers interbedded with impermeable basalt flows in the San Bernardino Valley, although not much is known about the subsurface relationships.

The presence of Paleozoic outcrops located out in the basin (Cooper 1959), surrounded by Quaternary basalt and alluvial material, suggests that much of the eastern half of the present-day valley is a buried pediment where bedrock is quite shallow. Therefore, the main basin-forming graben probably occupies only the western half of the modern valley. The traces of the main faults and any subsidiary faults are difficult to recognize in the bouldery alluvium. Lynch (1972) suggested the basaltic vents followed fault zones, a conclusion that is uncertain. The most recent earthquake in the region was the Pitaycachi, Sonora, event in 1887 that produced a 75 km scarp along the east side of the San Bernardino Valley south of the international border (Bull and Pearthree 1988; Sumner 1977). Seismic hazard studies in the valley north of the border have recognized 3 to 6 Quaternary events along the eastern side of the valley (approximately along the trend of the 1887 event) (Machette et al. 1986; Pearthree 1986), all of which are east of the Paleozoic outcrops. Two possible Quaternary events have been identified on the western side of the valley (Machette et al. 1986; Pearthree 1986).

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Geomorphic Surface Mapping of the Southern Animas Creek Valley, New Mexico, for Ecological Purposes

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Geomorphic surfaces of the southern Animas Creek valley (figure 1) have been mapped by Vincent and Krider (1998) (see figure 2). The objective was to present the surficial geology (figure 3) in a way most relevant to the ecology of high desert grasslands in southwestern New Mexico, as background for establishing associations between plants and their geological substrate or environment that might ultimately provide scientific bases for land-use management (see Sundt and Vincent, this volume). The result was a set of 14 geomorphic-surface maps (7.5' quadrangles).

Substrate properties should be uniform, ostensibly, among surfaces having similar geomorphologic origin, and such surfaces should have similar position in the landscape, slope, and aspect, in addition to soil properties. Geomorphic surface map-units are therefore ideal for predicting landscape areas having similar surface and substrate properties (physical, chemical, and hydrological) important to plants, and for distinguishing among those areas with significantly differing properties.

As used here, a geomorphic surface is a piece of the landscape or area of ground that has the same geomorphologic origin within, be it erosional hillslope, depositional bottom land, or abandoned and stable alluvial fan remnant. All surfaces were grouped into one of four origin categories: alluvial deposits, hillslopes, lake deposits, and wind-blown deposits. Alluvial surfaces (floodplains, stream terraces, and fan remnants) were subdivided by age to account for time-dependent soil development that usually occurs on stable landforms. Hillslopes were distinguished by the geology of the material being weathered, eroded, and transported downhill—such as rhyolitic bedrock or unconsolidated basin-fill alluvium. Other map-unit subdivisions were made including notation of local soil properties and subsurface material that vary from the typical.

The maps and report by Vincent and Krider can be obtained from the Geotechnical Information Center (505 835-5145) of the New Mexico Bureau of Mines and Mineral Resources. Other papers resulting from this project include Vincent (in review) and Krider (1998).

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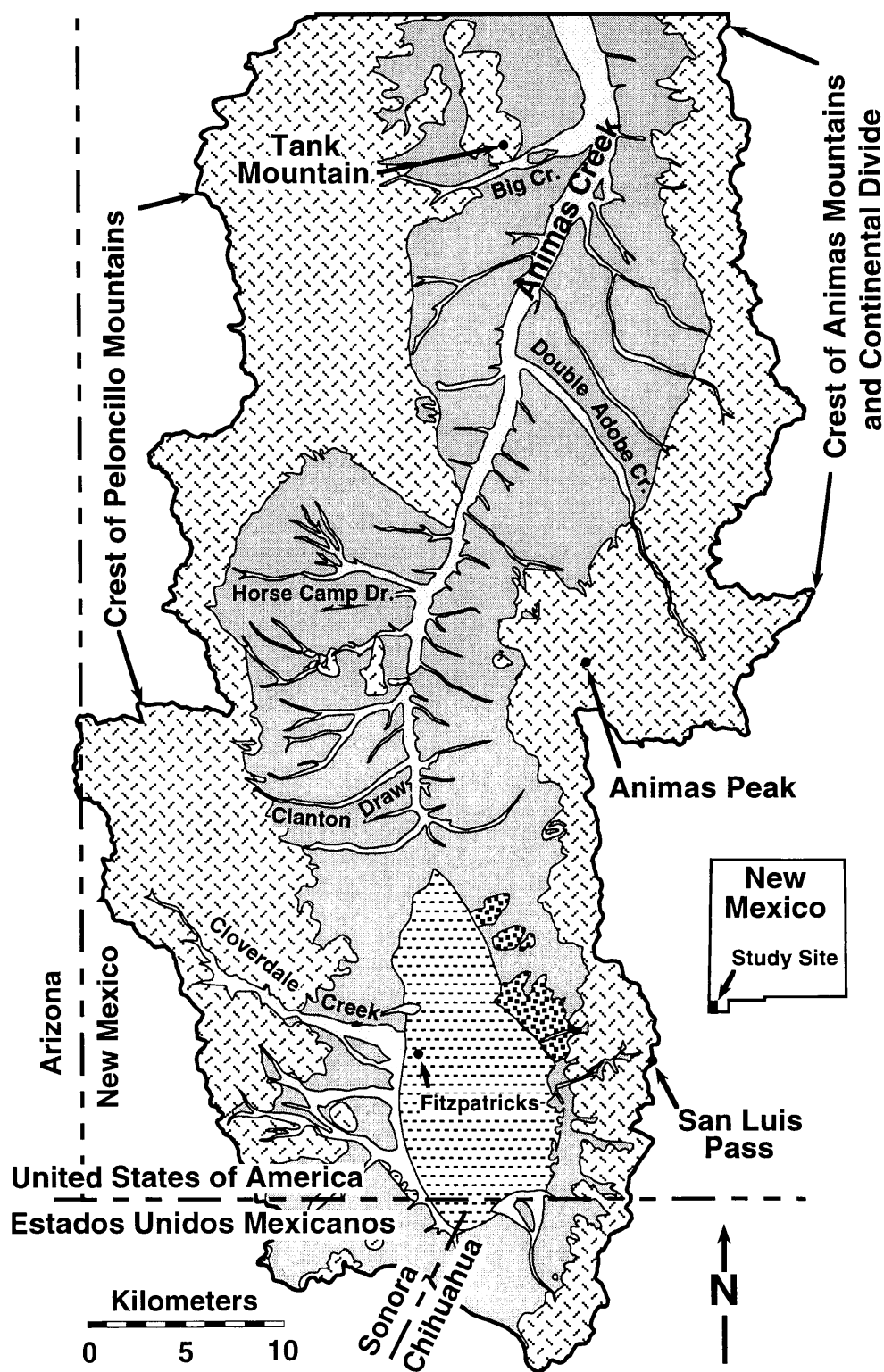
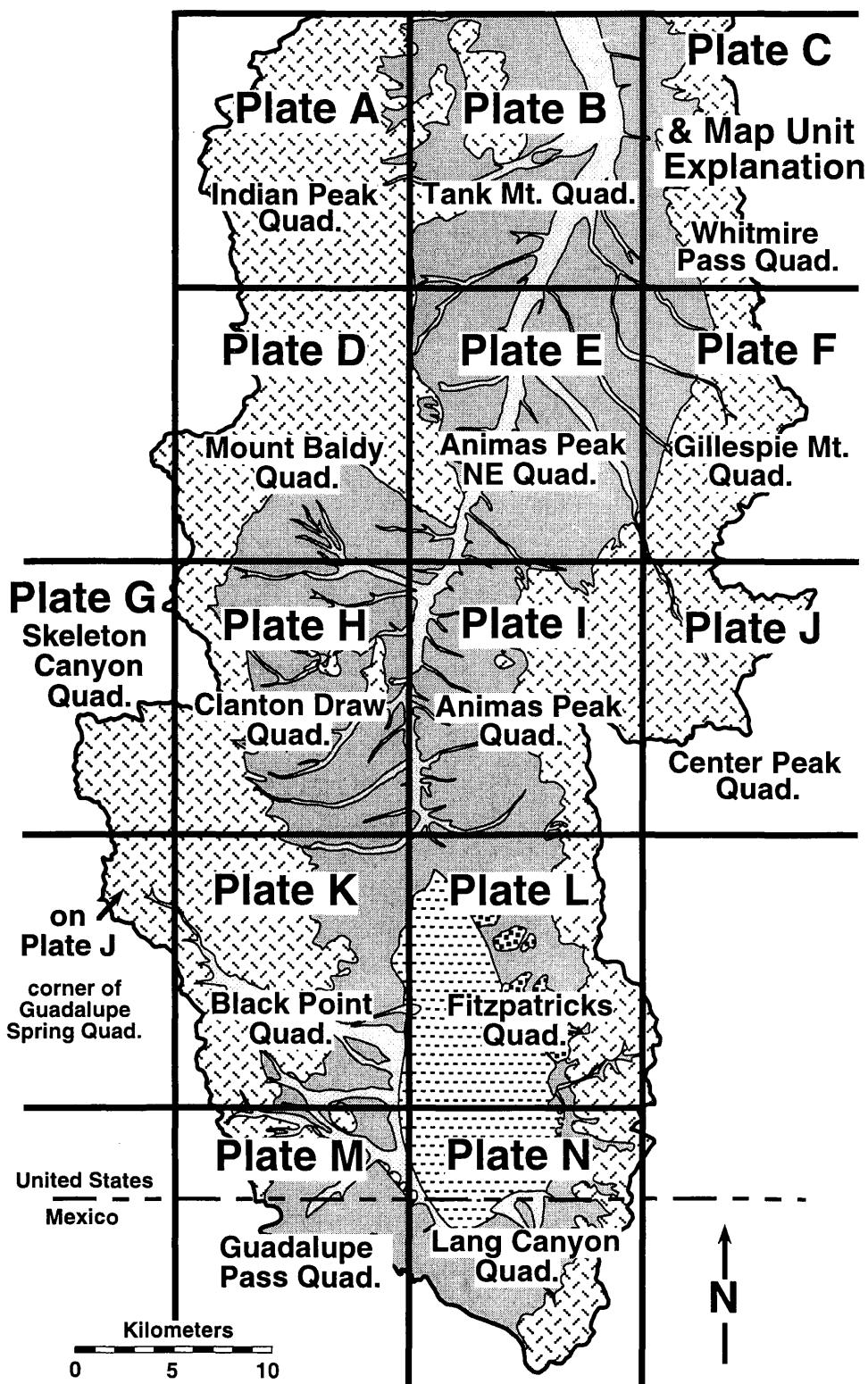


Figure 1. Location of geomorphic mapping study in the Animas Creek valley of southwestern New Mexico.

Figure 2. Location of geomorphic surface maps (Plates) by Vincent and Krider (1998).



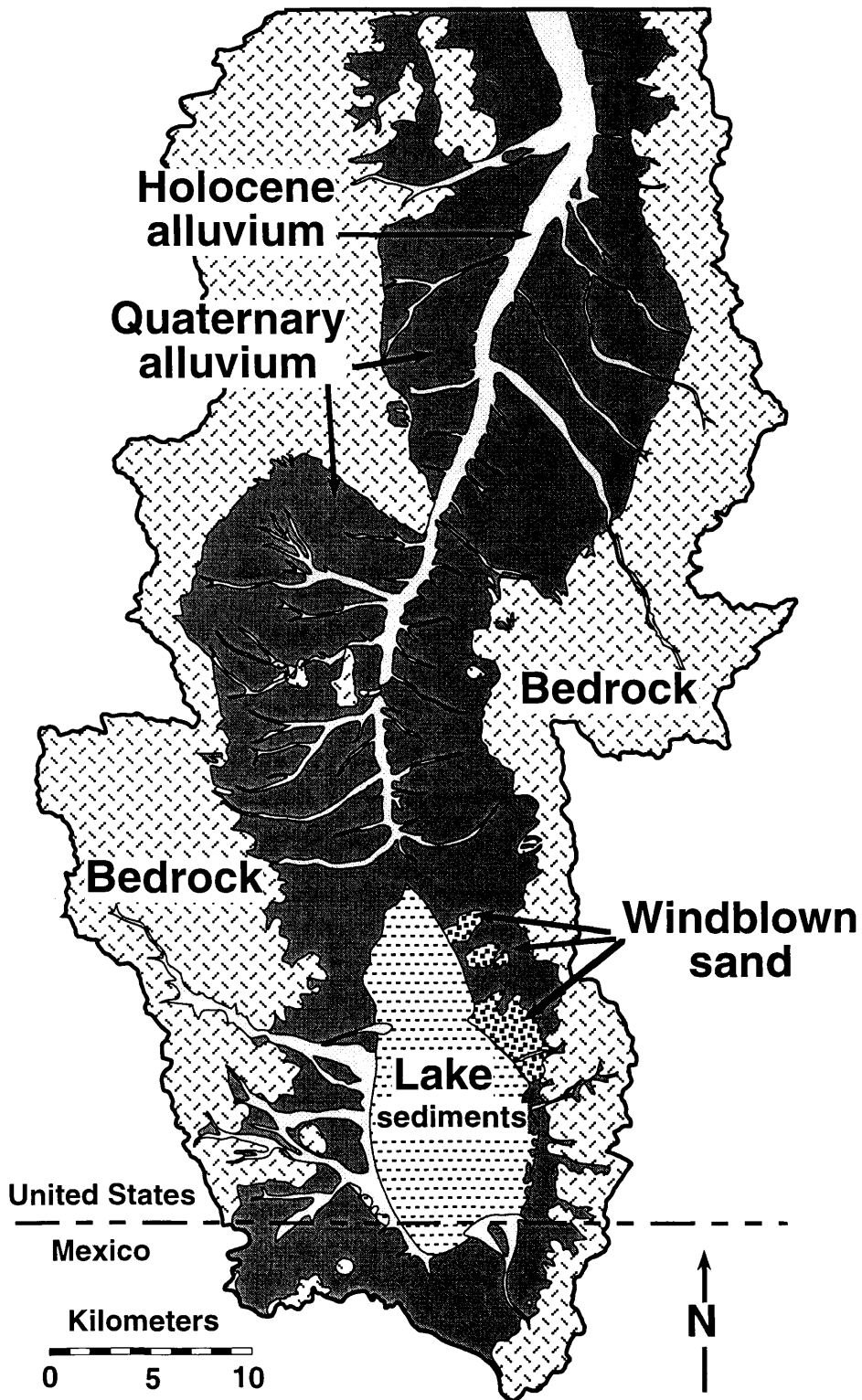


Figure 3. Generalized geologic map of the study area.

The Soil Survey of the San Bernardino Valley

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Field mapping by: Cathy E. McGuire, William A. Svetlik, Charles R. Peacock, and Donald J. Breckenfeld, Natural Resources Conservation Service

Natural Resources Conservation Service, formerly the Soil Conservation Service, has been producing soil surveys for almost 100 years. The Tucson Soil Survey started mapping southern Cochise County in 1994, with two special reports: Soils Inventory of Fort Huachuca and Soils Inventory of Walnut Gulch. These two special reports were the beginning of the Soil Survey of Cochise County, Douglas-Tombstone Part. The Soil Survey of the San Pedro Valley is an interim report and covers the area just south of St. David, Arizona, to the U.S.-Mexico border. This report was completed in 1996. The Whitewater Draw NRCD requested that the San Bernardino Valley be mapped next to assist with the ongoing research and ranching occurring in the Malpai Borderlands area. The Soil Survey of the San Bernardino Valley is an interim report and about a third of the Soil Survey of Cochise County, Douglas-Tombstone Part. The interim report was produced to expedite information to users. The interim report was completed in August 1998 and extends south from Portal, Arizona, to the U.S.-Mexico border and from the Chiricahua, the Perilla, and the Pedregosa Mountains on the west to the Arizona-New Mexico state line on the east. The survey area makes up about 302,000 acres and covers the Arizona part of the Malpai Borderlands area.

The survey area is part of the Chihuahuan Desert section of the Basin and Range Physiographic Province, which is characterized by north-south trending ranges of mountains with broad basins or valleys between the mountains. The survey area is complex in the variety of both the terrain and soils. Vegetation ranges from desert shrub lands to pine woodland. Elevation ranges from 3,719 feet (1133.6 meters) in the San Bernardino Wildlife Refuge west of Douglas to 5,929 feet (1807.2 meters) in the Pedregosa Mountains. Precipitation ranges from 12 to 20 inches (304.8 to 508.0 mm). Mean annual air temperature ranges from 57 to 67 degrees Fahrenheit (13.9 to 19.4 degrees Celsius). The major drainages in the valley are Mulberry Draw, Silver Creek, Cottonwood Wash, and Black Draw. These drainageways all flow southward into Mexico. The upper part of the valley, from just south of Apache, drains toward the north into the San Simon Valley.

The soil survey identifies the different soil types that occur in the survey area, their position on the landscape, and their potential uses. Soil scientists identify these different soil types by observing and analyzing the soils' physical and chemical characteristics, topography and drainage patterns, native plant communities, and parent materials that contribute to soil formation. Many sites are investigated by boring holes to study the soil profiles. A soil profile is the sequence of natural layers or horizons in a soil. Detailed soil descriptions are recorded to differentiate these soil profiles. Soil scientists observe all the soil characteristics and then taxonomically classify and name the soil accordingly. The common name of a soil is the series. The soil series is the most common reference term used to designate soil map unit components. Once the soils are classified and named, soil scientists traverse

the landscape and delineate the soils on aerial photographs. The delineations are called map units. Map units consists of one or more different soil series per delineation. Range conservationists then identify present and potential plant communities and assign a range site to each series in the map unit.

The dominant features of the valley are the volcanic flows and cinder cones. There were several soil series that had been historically mapped in the late 1950s. We researched the old series, kept the original concepts, and updated them to current soil taxonomic levels. These series include the Boss series (Clayey, mixed, superactive, thermic Lithic Ustic Haplargids), the Paramore series (Fine, smectitic, thermic Leptic Haplotorrerts), and the Krentz series (Loamy skeletal over cinder, mixed, superactive, thermic Vitrandic Haplocambids). Several new series were also established in the valley on the volcanic flows, including Outlaw (Fine, smectitic, thermic Typic Calcitorrerts) and Borderland (Clayey over loamy, smectitic over mixed, thermic Aridic Calcicusterts). Soils formed from the volcanic flows have very high clay content. The clays are smectitic, which makes them have very high to high shrink-swell potential. Some soil cracks measured more than four inches (10.16 cm) wide and 30 inches (76.20 cm) deep. Map units were designed to separate soils formed from volcanic flows and soils formed from fan alluvium. Examples would be map unit 1190 Outlaw-Epigraph-Paramore complex, 0 to 15 percent slopes, which is formed from flows; and map unit 1290 Eloma sandy loam, 1 to 10 percent slopes, which is formed from fan alluvium. This distinction will aid in land management decisions.

The valley is also influenced by limestone. Some of the map units affected by calcium carbonate would be map unit 23 Stronghold-Bernardino complex 10 to 30 percent slopes, map unit 1265 Kahn-Zapolote complex, 1 to 15 percent slopes, and map unit 1110 Blankeney-Luckyhills complex, 3 to 15 percent slope. The high percentage of calcium carbonate will affect native plant communities and how fast these areas will respond to land treatments.

New soil series and a map unit were also established in the Peloncillo Mountains; map unit 1270 Cherrycow-Magoffin-Rock outcrop complex, 15 to 65 percent slopes. Cherrycow is a moderately deep soil that forms dominantly on noncalcareous breccia. Cherrycow is a fine, smectitic, thermic Aridic Argustolls and Magoffin is a loamy, mixed, superactive, thermic, Lithic Ustic Haplustolls.

The interim report contains an index map, detailed soil maps, map unit descriptions, taxonomic descriptions, tables that rate each soil's potential use, and brief sections on landforms, range, wildlife habitats, and geology. Map units describe the setting, composition, typical profiles, properties, and qualities of each series, inclusions, use and management statements, special management concerns, range site names and numbers, and land capabilities. Taxonomic descriptions give detailed information about the series and a range of characteristics. All of this information is useful in determining the potential of a soil in the planning process and for correlating ongoing research.

The Soil Survey of the San Bernardino Valley was produced in very small quantities, but is available through the NRCS Douglas Field Office and can be purchased through Tucson Blueprint, 520-624-8881.

Runoff and Sediment Yield Derived from Proxy Records, Upper Animas Creek Basin, New Mexico

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Effective rangeland management in the upper Animas Creek Basin of southwestern New Mexico depends on knowledge of basin characteristics, including runoff and sediment-discharge rates. Data describing these rates are unavailable for the Animas Creek Valley, and therefore records from other watersheds are employed as proxies. Conditions of climate, soils, vegetation, and topography in the Walnut Gulch/San Pedro River Basin, AZ, the San Simon Wash Basin, NM and AZ, and at the Jornada Experimental Range, NM, are generally comparable to those of the Animas Creek Basin. Records of runoff and streamflow and of sediment yield from these areas permit comparison of hydrologic and sediment-discharge conditions with those in the upper Animas Creek Basin.

The Walnut Gulch Experimental Watershed, in the area of Tombstone, AZ, is the source of perhaps the most extensive data base for climate, hydrology, sediment discharge, soil characteristics, vegetation, and land-use practices ever collected in semiarid drainage basins of comparable size. The Walnut Gulch Basin was carefully selected for research activities as representative of erosional conditions in large portions of the grazing lands of the southwestern United States; research and data collection began in 1954. The climate of the Walnut Gulch Basin, as indicated by weather records collected at Tombstone beginning in 1941, is gradational between semiarid and arid. Weather-record summaries show that Tombstone has hot summers and mild, relatively dry winters; about 60% of precipitation typically occurs in the monsoon season of July, August, and September. Annual precipitation is highly variable, having ranged from 170 mm in 1956 to 437 mm in 1994.

Discharge records from 22 flumes in the Walnut Gulch Basin vary in length from 13 to 37 years and records of inflow to 11 ponds are 5 to 21 years in length; areas represented by these data range from 0.00182 to 149 km². Sediment-yield records are available also for eight of the flumes and deposition data for 10 of the ponds. Periods represented by these data vary from 3 to 21 years.

The upper Animas Creek Valley, including the 1300-km² Gray Ranch, occupies much of the bootheel of extreme southwestern New Mexico; headwaters of the basin are in the States of Sonora and Chihuahua, northern Mexico. Runoff and sediment-discharge data are generally unavailable for Animas Creek, but data were collected in the San Simon Wash Valley, west of the Peloncillo Mountains, and provide proxies for conditions in the Animas Creek Basin.

Annual maximum discharges recorded at a crest-stage gage are available for Animas Creek near Cloverdale, New Mexico. Peak discharges from the 76.4-km² contributing drainage basin, for water years 1959 through 1994, ranged from 1.0 to 96 m³/s. Of the 32 water years for which dates of the annual maximum discharge are known, 24 occurred in the monsoon months of July (9), August (7), and September (8). The other eight peaks occurred in January (1), March (2), October (3), and December (2).

Annual runoff data for 1936 through 1970, and sediment-yield data, 1936 through 1958, are available for San Simon River near Solomon, AZ. Data on inflows of water and sediment to two reservoirs in the San Simon Wash Basin were compiled for years 1956, 1957, and 1958. In contrast to the Gila River in the Safford Valley, where about 70% of streamflow results from winter frontal storms, most of the ephemeral streamflow in San Simon Wash occurs in summer following monsoonal precipitation.

Although the drainage basins of Animas Creek, Walnut Gulch, and San Simon Wash are similar in many respects, an exception is surface-water hydrology. The Walnut Gulch and San Simon Wash Basins generally have well developed drainage networks, whereas runoff from headwater areas of the Animas Creek Basin collects in the Cloverdale Playas. Animas Creek streamflow in the northern part of the basin enters an area of low slope where the creek loses channel definition. Further north runoff continues to the Animas Playa west of Lordsburg, NM. These ephemeral-lake basins, or playas, are topographic relics of late-Pleistocene time, when cooler, possibly wetter conditions caused higher runoff rates and sediment accumulations in bottomland areas than occur now.

Unit runoff, in $\text{m}^3/\text{s}/\text{km}^2$, varies through time and with watershed area, but averages about 1×10^{-4} from Walnut Gulch, 6×10^{-5} from San Simon Wash, and, based on very limited data, 5×10^{-4} from small upland plots in the Jornada Experimental Range. These rates of mean runoff compare to estimates of roughly 2×10^{-3} for the Walnut Gulch and San Simon Wash areas, and 1×10^{-3} for the Jornada area, that were generalized for the conterminous United States.

Runoff characteristics in the Animas Creek Basin appear to be similar to those of the Walnut Gulch Basin, ranging from roughly $1 \times 10^{-4} \text{ m}^3/\text{sec}/\text{km}^2$ from a basin area of 100 km^2 to about $3 \times 10^{-4} \text{ m}^3/\text{sec}/\text{km}^2$ from subwatersheds of 1 to 5 km^2 . These rates may be largely unchanged from pre-development conditions. Owing to relatively high runoff rates from areas of bedrock exposures in mountains bounding the Animas Valley, unit runoff from watersheds smaller than 1 km^2 may be generally greater than for otherwise comparable alluvial uplands of the Walnut Gulch Basin.

Sediment yield from the Animas Valley is inferred to be lower than from the Walnut Gulch Basin. This interpretation assumes that runoff characteristics from the two basins are similar, but the vegetation cover in the Animas Valley, dominated by grasses, provides better protection against erosion than is available to shrublands of greater topographic relief that are typical of the Walnut Gulch Basin. If, as a result of causes such as excessive grazing, fire, or climate change, grassland of the Animas Creek Basin converts to shrubland, gully erosion in various parts of the drainage network is likely to increase and sediment yields could increase as much as three orders of magnitude.

If (owing to future changes in factors such as land use, vegetation, fire frequency, or climate) tributary and upland erosion in the upper Animas Creek Basin increases, a likely result will be aggradation in the Animas Creek channel. Animas Creek has not been and presently is not subject to the same base-level conditions that probably led to erosion in drainage networks of other Southwestern watersheds. If upland rill and interrill erosion results in significantly increased sediment yield in the upper Animas Valley, it is inferred that much of the sediment will be deposited along Animas Creek, and that most will not leave the Gray Ranch area.

Sediment yields from the Walnut Gulch, San Pedro River, and San Simon Creek Basins vary widely with sub-basin and period of record, but, for drainage basin areas exceeding 100 km^2 , currently average between 150 and $200 \text{ t}/\text{km}^2/\text{yr}$. Owing to similar watershed conditions but a significantly lower channel gradient

relative to runoff, it is anticipated that the present sediment yield for most sites along Animas Creek may fall within or below that range.

Although current watershed conditions in the Walnut Gulch Basin do not generally exhibit significant disturbance, partial conversion from grassland to shrubland in the basin during the last 100 years suggests that present sediment yields may be higher than those prior to the influx of cattle. A sediment-yield curve for the San Simon Wash Basin is based on only three data sets of questionable reliability, has been drawn to conform partially with more credible accelerated-erosion data of the Walnut Gulch drainage network, and probably denotes sediment-yield rates lower than those that prevailed during the 1930s and 1940s.

Influences of Geomorphology on Vegetation in the Animas Creek Valley, New Mexico

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Explaining the distribution and abundance of plant species in the landscape is one of the principal objectives of plant ecology. This study proceeds from the theoretical premise that some patterns of plant distribution and abundance are determined by landforms, because of the soil and other physical properties associated with individual landforms. The study site is the Upper Animas Creek Valley of southwestern New Mexico, and can be located on Figure 1 of Vincent (this volume). We acknowledge that non-physical factors, such as interplant competition, can be of great importance to plant distributions, but seek here to establish relationships among geomorphic surfaces and the occurrence and abundance of important plant species. These correlations may suggest physical limitations to plant ranges and aid in understanding the potential natural vegetation of the region.

Landforms integrate a number of physical characteristics which are relevant to plants. These include geological parent material, age, position in the landscape, slope, aspect (and resulting soil properties), and subsurface stratigraphy. Landform characteristics influence plant growth and reproduction through hydrology (surface and subsurface water supply, infiltration capacity, permeability, total porosity, water holding capacity), the supply of essential nutrients and inhibiting chemicals, soil and air temperature (resulting from altitude, aspect, or cold air drainage), and mechanical factors (like shrinking and swelling of soil, and soil-surface crusts or cemented horizons difficult for roots to penetrate).

Plant species vary in their adaptations to these physical factors. Each species has a "tolerance range" (Good 1931) of conditions within which it can potentially grow and reproduce. For some species these tolerance ranges are quite broad and overlap those of many other species; for other species these tolerance ranges are narrow. For each species, there is a suite of physical/chemical characteristics suitable for growth, but there may also be numerous other species adapted to those conditions. Whether a plant population persists, dominates, or locally cannot become established or persist depends on its intrinsic ability to compete with its neighbors, as well as on regimes of fire, herbivory, pollination and seed dispersal. In the absence of biological competition, for example, a species might thrive within its "physiological optimum" suite of physical conditions, but faced with competition (or regime of fire, herbivory, etc.) a species may have an "ecological optimum," or survive and reproduce best, under a different suite of physical conditions (Smith and Huston 1989).

A broad distribution (presence on most geomorphic surfaces in an area) should indicate that a plant species has a large range of tolerance for variation in soil and other physical characteristics. For a widely distributed species, a peak of relative abundance on a single geomorphic surface should indicate that the characteristics of that surface most nearly approximate the species' ecological optimum. Conclusions must be drawn cautiously however. The absence of a broadly distributed species from a widely occurring surface may suggest an intolerance for the physical characteristics of that surface. Similarly, the restriction of a species to a few

surface types may suggest a narrow tolerance range, but these observations may also result from low sample sizes. Also, a highly palatable grass may find its optimum soil characteristics on a certain surface and yet be of low relative abundance there because it is heavily grazed. Some variation in grazing history among plots discussed here is likely, although an attempt was made to account for that by locating plots at the same distance from water.

We cautiously cast our conclusions as hypotheses because we have a limited sample size. We use data from 53 vegetation plots and general observations made over more than 8 years of field work in the area. The vegetation plots are located on numerous geomorphic surfaces mapped independently by Vincent and Krider (1998), see Figure 2 of Vincent (this volume). We also compare and contrast our observations with those of previous workers.

Previous studies have explored the influence of geomorphic and/or soil characteristics on plant species distributions and abundance (e.g. Clark et al. 1995, McAuliffe 1994, El-Demerdash et al. 1994, Esler and Cowling 1993, Abbas et al. 1991, Jensen 1990, Cox 1988, Leonard et al. 1988, Stein and Ludwig 1979, Kleiner and Harper 1977). The Natural Resources Conservation Service (NRCS) of the U.S. Department of Agriculture has used the correlations among soils, topography, climate, and plant distributions to classify rangelands of the western United States into "ecological sites" (formerly "range sites"; USDA 1976, Shiflet 1973). The NRCS classification scheme subdivides broad climatic regions on the bases of physiography and soils to generate site designations such as "Loamy Uplands, 16-20 inch precipitation zone." The classification does not depend upon extant or potential vegetation, but rather upon the physical factors that influence vegetation. Included with each site designation is a list of species comprising the "potential natural vegetation," based on extensive experience by field workers with numerous examples of each land type. Their units may contain more than one geomorphic surface when a factor such as soil pH, a shallow water table or periodic run-on water has critical effects on vegetation. For example, the description of the Sandy Bottom site says: "The site occurs on flood plains, low stream terraces and alluvial fans. It benefits from extra moisture received as runoff from adjacent uplands." Thus, although geomorphic surface and ecological site mapping units are not always identical, the NRCS ecological site guides are valuable compendia of the effects of physical factors on vegetation and will be referred to in interpreting the results of this study. (Ecological site guides referred to in this paper can be obtained on the Internet at <http://ag.arizona.edu/oals/agnic/siteguides/>).

Methods

The study area is the upper watershed of Animas Creek and the adjacent topographically closed dry-lake bed in the bootheel of southwest New Mexico, from 25 to about 50 miles south of the town of Animas (see Figure 1 of Vincent, this volume). Thirty-eight vegetation plots were established in the study area in 1993 to monitor the effects of cattle grazing. The plots were located non-randomly, with the objective of typifying the vegetation of large areas around the plots that would provide significant forage for cattle. Although the geomorphic surface maps were not available at the time of plot establishment, an attempt was made to locate plots on geomorphically uniform areas, usually of low slope. Since this study makes opportunistic use of data collected for other purposes, sampling of vegetation was not applied equally to all geomorphic surfaces. The geomorphic surfaces were mapped by Vincent and Krider (1998) without regard to vegetation and without

knowledge of vegetation plot locations. Ultimately, all plot locations were superimposed on the geomorphic surface maps of Vincent and Krider (1998).

In addition to the 38 plots established in 1993, the vegetation was sampled adjacent to 15 soil pits excavated by Vincent and Krider (1998) to characterize various geomorphic surfaces. These plots are identified with the prefix "S," e.g., plot S15. Canopy cover was estimated by inspecting single points along lines, generally every 0.5 m or 1.0 m. Sample sizes were from 200 to 600 points.

Most of the plots are 80 m by 30 m rectangles. Sampling consisted of the systematic placement, 225 times per plot, of a 40cm by 40cm frame made of PVC pipe. The identity of the plants, litter or bare ground directly under the point at each of the four corners of the frame was recorded at each frame placement, for a total of 900 points per plot, providing an estimate of the percent of the ground covered by the canopy of each species, by litter and by bare ground within the plots. For the analysis of species distribution and abundance with respect to geomorphic surface, the relative cover of each species is a better parameter than absolute cover because it allows direct comparison among plots. Relative cover is the contribution of a particular species to the total plant cover of the plot. For example, in plot 20 blue grama has an absolute cover of 10%, while bare ground and litter account for 23% and 26% of the total area respectively. Subtracting the areas of bare ground and litter leaves a live plant cover of 51%. The relative cover of blue grama is then $10/51 = 20\%$.

Annual forbs and grasses were not identified to species, but rather were grouped together. Similarly, several species of *Aristida* and of *Sphaeralcea* were grouped together because of the difficulty in distinguishing them.

Results

Tables 1 through 6 tabulate the vegetation cover data (relative cover) by geomorphic surface type. The geomorphic surface symbols, and detailed descriptions, are given in Vincent and Krider (1998). A key to plant codes, common names, and scientific names is given in Appendix 1. Included in Tables 1 through 6 are the relative cover of each species, the total plant cover of each plot, the total number of species in the plot encountered during sampling, and the altitude of the plot in feet. Only those plant species that had at least 1% relative cover are listed in the tables. A symbol is also listed for the sub-basin in which the plot occurs. The upper basin (U) drains into the now-dry lake bed of Pluvial Lake Cloverdale, the middle basin (M) is the headwaters of Animas Creek from Foster Draw to the confluence of Animas and Indian Creek, and the relatively dry lower basin (L) extends Indian Creek to Tank Mountain (see Vincent and Krider (1998).

Blue Grama (*Bouteloua gracilis*)

Blue grama is one of the most common and widespread grass species in the study area and throughout the North American grasslands from Alberta to central Mexico, and Wisconsin to California. It is a high quality forage grass and is well-adapted to grazing, fire, and drought (Gould 1973). Of the 53 plots analyzed in this study, blue grama occurs in 39 (74%). In 2/3 of these, it is dominant or co-dominant (one of the top three species in relative cover). With few exceptions, it occurs on all types of geomorphic surfaces in the study area, from dune sands and young draw bottoms with silty soils to very old alluvial fan remnants with dense argillic horizons. However, blue grama is absent from all but one of the six plots which occur on surfaces with calcium carbonate in the surface soil and stage III

carbonate horizons in the subsoil (Vk and Ok surfaces). This observation suggests that blue grama is disfavored by the alkalinity found on old surfaces with exposed carbonate. However, most of the plots from which blue grama is absent are at low altitudes, at or below 5000 ft, including the five plots affected by carbonate. Blue grama may be disfavored by the lower rainfall in the lower altitude sites, rather than by, or in addition to, the correlated alkalinity. The NRCS range site guide for Limy Uplands, 16- to 20-inch precipitation zone, includes blue grama (10-25% by weight in the potential natural vegetation), while it is absent from the Limy Uplands, 16- to 20-inch precipitation zone guide.

Blue grama is also absent from the two plots located in the bed of now-dry Lake Cloverdale on the Lb surface, as well as from plot 88 on the shore of low-level lake stands (Ld/M). The deep silty clay loam soil with almost no gravel (see soil descriptions 8a and 8b in Vincent and Krider [1998]) has very low permeability and water ponds on the surface, sometimes for weeks. These sites are inhospitable to all but a few perennial species, notably squirreltail grass, aparejo grass, vine mesquite grass, and *Helianthus ciliaris*.

Blue grama is absent from 3 of 6 plots on Y surfaces, i.e. plots 13, 30 and 6. Plots 30 and 6 are at or below 5000 ft altitude, where rainfall may be insufficient for blue grama, as discussed above. Its absence from plots 13 and 6, both located in abandoned silty flood plains of draw bottoms, may be due to overgrazing. Both plots are dominated by species of threeawn grass (*Aristida*), which are believed to

Table 1. Vegetation on bedrock hillslopes in the Animas valley, New Mexico. See text and Appendix 2 for explanations of geomorphic surface symbols and basin designations and Appendix 1 for plant species codes.

Geomorphic Surface	Hr	Hb	HI	HI	Hr	Hr	Hb	Hr	Hr
Plot #	S21	S20	20	82	101	S23	S22	23	80
Live cover	36%	50%	51%	40%	52%	37%	69%	65%	72%
Total #spp	16	17	28	27	41	12	12	25	27
Basin	U	U	M	M	U	U	U	U	L
Elevation (ft)	5680	5650	5600	5520	5440	5420	5420	5380	5300
Species	Relative cover								
ARIS			8%	10%	6%			18%	18%
BOCO									4%
BOCU	22%	22%	12%	5%	10%				
BOER			6%	3%					
BOGR	8%	20%	20%	13%		41%	3%	28%	17%
BOHI	17%	10%	14%	15%	4%	5%		23%	
BRDE									3%
ERIN			10%	15%	6%	5%			
ERWR	8%	2%	6%	5%			1%	6%	
FORB	25%	16%	12%	15%	2%	11%	3%	17%	26%
GRAS	6%	18%				5%	75%		4%
GUSA									3%
HIBE	14%	6%				8%			
HIMU							13%		
MIBI		2%				11%			
MUEM					6%				
NOMI								5%	
OENOTH		2%							
OPSPI							9%		
QUAR					23%				
QUEM					15%				
SCCI					15%				
SIDA									1%

increase with heavy grazing (Gould 1973). By contrast, blue grama is dominant or codominant on similar Y geomorphic surfaces at plots 8, 105 and S26.

Blue grama is part of the potential natural vegetation of all 17 NRCS ecological sites in the 16- to 20-inch precipitation zone found in the study area. It is represented most abundantly in the Loamy Swale, Clay Bottom, and Shallow Upland sites.

On the basis of these data, blue grama is broadly tolerant of variation in soil characteristics but may require more rainfall than is available in the lower elevations of the study area. It is perhaps disfavored by alkalinity, an hypothesis worthy of further study.

Three-awn Grasses (*Aristida* spp.)

Because of the difficulty in consistently distinguishing the several species of *Aristida* in the study area they were grouped into one category during sampling. Their distribution thus reflects the adaptedness of several species, no single one of which is probably as widespread. Perennial species found in the study area include *A. ternipes* Cav., *A. hamulosa* Henr., *A. divaricata* Humb. and Bonpl., *A. harvardii* Vasey, *A. orcuttiana* Vasey, *A. arizonica* Vasey, *A. longiseta* Steud., *A. purpurea* Nutt., *A. fendleriana* Steud., and *A. wrightii* Nash.

Aristida is present in 43 of the 53 study plots (81%), is dominant or codominant in 18 plots, and occurs on all but 2 of the geomorphic surfaces. Although *Aristida* is absent from both plots located on basalt hillslopes (Hb, plots S20 and S22), it is present in both latite hillslope plots (Hl) and in 2 of 4 rhyolitic hillslope (Hr) plots. There is inadequate evidence of a parent-material influence on its dis-

Geomorphic Surface	V/I	Vk	V or O	V	V	V	Vk	Vk
Plot #	83	27	106	S7	107	S13A	31	S16
Live cover	52%	27%	54%	48%	56%	19%	38%	16%
Total #spp	44	25	29	5	12	18	31	14
Basin	M	M	U	U	U	M	L	L
Elevation (ft)	5640	5340	5230	5215	5200	5160	4780	4845
Species	Relative cover							
ARIS	4%		9%		2%	37%	45%	13%
ASTER								25%
BOCU	8%							
BOER		4%					29%	
BOGR	4%	41%	2%	31%	43%	16%		
BOHI	23%	15%	6%					
DAFO								25%
DAPU								13%
ERIN	10%	37%	37%					
ERWR	2%	7%	6%		4%			
FORB	10%	11%	17%	6%	39%		5%	
GRAS				8%				
GUSA	2%	4%	13%				5%	6%
HIMU				52%	16%		8%	
HODE								6%
LYPH		7%	2%					
NOMI	2%							
PRGL	4%					26%	5%	19%
SCCI	2%							

Table 2. Vegetation on middle Pleistocene alluvial fan remnants in the Animas valley, New Mexico. See text and Appendix 2 for explanations of geomorphic surface symbols and basin designations and Appendix 1 for plant species codes.

tribution since it is absent from each of the Hr plots (i.e., plots S21 and S23), which are near the basalt plots.

The grouped *Aristida* species are thus very widespread and abundant, but no other clear signal is present in this data. All of the *Aristida* species are of low palatability to livestock and tend to increase with heavy grazing (Gould 1973). They are also relatively vulnerable to fire (Sundt, unpubl. data, in which *Aristida* declined in relative cover in 10 of 15 monitoring plots burned in a summer wild-fire). Their present distribution in the Animas valley, therefore, may largely represent a complex interaction of fire and grazing histories.

Black Grama (*Bouteloua eriopoda*)

Black grama is a widespread and valuable forage grass in the southwestern U.S. and Mexico. It occurs on 30% of the plots in the study area and on a wide variety of geomorphic surfaces, from old soils with argillic horizons (O surface, e.g., plot S15), old calcareous soils (Vk surface, plots 31 and 27), medium-aged deep sandy loams (M surface, plot S12), and young silt loams in draw bottoms (Y surface, plot 6) to sandy lakeshore deposits (Ls surface, plots 1 and 11). It is

Table 3. Vegetation on late Pleistocene alluvial fan remnants in the Animas valley, New Mexico. See text and Appendix 2 for explanations of geomorphic surface symbols and basin designations and Appendix 1 for plant species codes.

Geomorphic Surface	O	O	O	O	O	O5	O6	O	Ok	Ok	Ok	O6	O
Plot #	4	92	14	16	94	S10	S6	26	78	75	77	S15	S17
Live cover	68%	70%	68%	73%	62%	65%	42%	43%	66%	50%	64%	40%	50%
Total #spp	22	28	30	31	23	17	17	26	30	22	25	18	15
Basin	M	M	M	U	M	M	U	M	L	L	L	L	L
Elev. (ft)	5550	5400	5370	5360	5330	5300	5215	5080	5015	4900	4810	4725	4710
Species	Relative cover												
ARIS	26%	7%	10%	5%	2%	12%		35%	36%	8%	13%	15%	50%
ASTRAG						2%							
BOBA						5%							
BOCU	10%	6%	3%	3%						2%			
BOER								2%			70%	70%	
BOGR	4%	11%	18%	15%	8%	28%	14%	16%					
BOHI	44%	39%	21%	49%		6%	7%	14%					
BUDA					58%	14%							
CRCO												8%	
DICA													6%
ERIN	7%	4%	18%	1%		15%	12%						
ERLE							33%						
ERWR		6%	1%	4%							3%		
EVOL			1%					2%					
FORB	4%	20%	13%	21%	21%			7%	18%	24%	2%		
GRAS									6%				2%
GUSA		4%	3%	4%			14%						
HIBE				3%									
HIMU							2%		23%	60%			10%
HODE									3%	2%			
LYPH			3%	1%		6%	7%						
MIBI	3%			1%									
MUAR							2%				3%		
MUPO													4%
PAOB					2%				3%			3%	10%
PRGL		7%	4%	4%	10%				2%		2%		2%
SCBR													6%
SPSP											2%		
ZIGR								2%					

absent from the Cloverdale Lake bottom, as are all but a few species—probably because of periodic ponding. While present on both plots in latite hillslopes (H1, plots 20 and 82), it is absent from all 5 plots on rhyolite hillslopes and both plots on basalt hillslopes; this pattern, however, probably does not reflect an intolerance to the chemistry of rhyolitic or basaltic soils because the chemistries of rhyolite and latite are very similar. Black grama is a dominant species in the potential vegetation of the NRCS Basalt Hills ecological site.

Black grama attains its greatest relative covers (70%) at plots S15, an O surface with a shallow argillic horizon, and 77, an Ok surface, both of them at elevations less than 5000 ft, where it may outcompete other grama grasses because its suffrutescent growth form gives it an advantage in the more arid climate of the lower valley basin (Burgess 1995). It is also abundant at plots 31 (Vk surface: 29%), 30 (Y surface: 17%), 3 (M surface: 16%), and 6 (Y surface: 14%). Of the numerous NRCS ecological sites in the study region of which it is part of the potential vegetation, black grama is in the highest cover class (45-55%) in the Shallow Uplands 16- to 20-inch precipitation zone site, described as occurring on “gently sloping to moderately steep pediments” with soil less than 20 inches deep at elevations from 3300 ft to 5200 ft.

Geomorphic Surface	M/O	M	M	M	M	M?	M3	M
Plot #	15	12	3	19	91	S8A	S12	S18
Live cover	69%	58%	77%	65%	73%	66%	61%	33%
Total #spp	27	24	20	24	25	8	5	18
Basin	M	M	U	M	U	U	M	L
Elevation (ft)	5500	5430	5230	5220	5200	5165	5110	4810
Species	Relative cover							
ARIS	7%	10%	22%	32%	15%	8%	16%	55%
BOBA			1%					
BOCU	6%	2%						
BOER		2%	16%	8%			13%	
BOGR	3%	14%	29%	5%	26%		59%	
BOHI	22%	7%			1%			
BUDA					14%	3%		
DECO					4%			
DICA				2%				
ERIN	28%	17%	1%	8%	23%			
ERWR		5%	6%	17%	5%	8%		9%
EVOL	1%							
FORB	4%	10%	38%	12%	12%			27%
GRAS						55%		6%
GUSA	10%	2%						
LYPH	6%	14%	1%		8%		11%	
MUAR					1%			
MUH SP					1%			
MURE						6%		
NOMI		5%						
PAOB						9%		
PRGL	3%							
SPFL						14%		
SPSP					1%			

Table 4. Vegetation on latest Pleistocene alluvial fan remnants in the Animas valley, New Mexico. See text and Appendix 2 for explanations of geomorphic surface symbols and basin designations and Appendix 1 for plant species codes.

Black grama reproduces only rarely by seed (Nelson 1934, Neilson 1986) and is suffrutescent; that is, its growing points are above ground and it stores carbohydrates in aboveground culms (Burgess 1995). These characteristics make black grama individuals and populations relatively intolerant of defoliation by grazing and fire (Briske and Richards 1995; Canfield 1939; Cable 1965). Because of its sensitivity to defoliation its abundance pattern is probably influenced by historical variations in grazing pressure and fire.

Hairy Grama (*Bouteloua hirsuta*)

Hairy grama occurs in 21 (40%) of the 53 study plots, and is dominant or codominant in 11 of 21 plots in which it occurs. Its greatest relative cover is in plots on O surfaces (plot 16: 49%, plot 4: 44%, plot 92: 39%). These plots are all located on the proximal portions of old alluvial fan remnants, within 1 km of the mountain front, and have high gravel content in the surface soils. It is absent from almost all plots at elevations less than 5200 ft (the exception being an O surface at 5080 ft), and hairy grama, like blue grama, may be intolerant of the drier climate of the lower valley. However, there is also evidence in its pattern of occurrence of an affinity for rocky upland surfaces with intact argillic horizons. It is found on most hillslope plots, irrespective of lithology, all but one of the 6 plots on O

Table 5. Vegetation on inset Holocene stream terraces, and flood plains in the Animas valley, New Mexico. See text and Appendix 2 for explanations of geomorphic surface symbols and basin designations and Appendix 1 for plant species codes.

Geomorphic Surface	As	Am	Y2	Y	Y2	Y2f	Y	Y
Plot #	85	28	8	105	13	S26	6	30
Live cover	50%	64%	71%	41%	72%	62%	49%	52%
Total #spp	29	26	15	11	17	12	29	37
Basin	M	U	M	M	M	M	M	L
Elevation (ft)	5270	5240	5220	5170	5100	5100	5000	4815
Species	Relative cover							
ARIS	12%	22%	31%		39%	37%	41%	33%
BOBA						5%	2%	2%
BOCU								4%
BOER	6%						14%	17%
BOGR	32%		37%	22%		10%		
BOHI	8%							
CRCO	4%							6%
DAPU		2%						4%
ERIN		2%					2%	
ERWR		2%	1%					
EULA								2%
FORB	22%	11%	34%	29%	38%	3%	14%	15%
GAURA		3%						
GRAS		8%				34%		
HIMU		8%						
LYPH	8%		7%			2%		
MELE								2%
MUAR		2%					2%	13%
MURE		23%		22%	15%			
PAOB		13%			1%	3%		
PRGL	2%				1%			2%
SCBR								2%
SILE		2%						
SOEL		6%		2%	1%			
SPFL		8%				6%		4%

surfaces, and in 3 of 8 plots on M surfaces, but it is completely absent from plots on Y surfaces, from wind-deposited sandy surfaces (Wd and Ws), and from the lake bottom (Lb), all of which lack argillic horizons. Of the two plots on M surfaces where hairy grama is absent and for which there is soil data, one (S12) lacks an argillic horizon, and the second (S18) has a 30 cm deep loamy A horizon, and is at a low altitude (4810 ft). It is also absent from the 3 plots on Ok surfaces (all <5200 ft altitude), and from the low altitude Vk surface plot (plot 31, altitude 4780 ft).

Among the NRCS ecological sites hairy grama has its highest relative percentage in the potential vegetation of Shallow Uplands 12- to 16-inch precipitation zone, described as "gently sloping to moderately steep pediments" with shallow non-calcareous soil over bedrock. In the ecological sites of the 16- to 20-inch

Geomorphic Surface	Ld/M	Lb	Lb	Ls	Ls	Wd	Ws/O or As
Plot #	88	89	90	1	11	22	21
Live cover	59%	52%	69%	59%	68%	59%	81%
Total #spp	14	10	13	14	23	33	25
Basin	U	U	U	U	U	U	U
Elevation (ft)	5140	5130	5135	5165	5160	5200	5160
Species	Relative cover						
ARIS	3%			5%	13%	3%	35%
BOBA							1%
BOER				2%	9%		
BOGR				2%	21%	8%	11%
BOHI					21%		
BUDA							19%
CODI						2%	
ERIN							1%
ERWR					3%		
EVOL					1%		
FORB	3%	4%	52%	53%	37%	5%	12%
GRAS	61%	69%	14%				
GUSA							1%
HECI	3%	6%	7%				2%
LYPH					1%	2%	
MUAR			1%				1%
MUH SP				7%		3%	
MURE	14%		23%				16%
NOMI						12%	
PAOB	2%	2%	1%				11%
PASE				14%		14%	
PEFL						8%	
QUERCUS						42%	
RHTR						7%	
SIHY	14%	31%	13%				
SILE	2%	2%	1%				
SOEL							1%
SPFL				14%		3%	
SPSP					1%		1%

Table 6. Vegetation on lacustrine and eolian landforms in the Animas valley, New Mexico. See text and Appendix 2 for explanations of geomorphic surface symbols and basin designations and Appendix 1 for plant species codes.

precipitation zone, hairy grama is in the highest cover class in Clayloam Uplands where "dense clay horizons occur near the surface."

Plains Lovegrass (*Eragrostis intermedia*)

Plains lovegrass is found in 21 of the 53 study plots (40%), and is dominant or codominant in 10 of them. It is absent from the following surfaces: Hb, Ok, most Y, Ls, and Lb. Plains lovegrass attains its greatest relative cover in plots 27 (Vk surface: 37%), 106 (V or O: 37%), and 15 (M/O: 28%). Its absence from 5 of 6 plots on Y surfaces, as well as from plots on Ls and Wd surfaces, suggests that plains lovegrass, like hairy grama, may be disfavored by deep well-drained soils. Among the NRCS ecological sites plains lovegrass has its highest relative percentages (40-50% and 30-40% classes respectively) in the potential vegetations of Loamy and Clayloam Uplands, both of which have soils with well-developed argillic horizons near the surface.

Plains lovegrass is apparently favored by disturbances such as fire and brush-clearing. Sundt (unpubl. data) found that plains lovegrass increased from 11% to 39% frequency in one year in a 50 m x 50 m plot on an O surface in the Upper Animas Valley from which mesquites were mechanically uprooted. Plains lovegrass commonly occupies graded roadsides and the middle vegetated strip in dirt roads in the upper Animas valley. Bock et al. (1995) found that survival of plains lovegrass during the late 1980s drought in southeastern Arizona was enhanced by burning and by grazing relative to undisturbed plots. Because plains lovegrass maintains some green leaves and stems year-round, it probably receives greater grazing pressure than its winter-dormant competitors.

Tobosa Grass (*Hilaria mutica*)

Tobosa is a tough, rhizomatous grass of low palatability except for its young foliage. It occurs in 9 (17%) of 53 study plots, and on Hb, Vk, V, O, Ok and Am surfaces. Its highest cover is attained at plots 75 (Ok: 60%), S7 (V: 52%), and 78 (Ok: 23%). A common denominator among the surfaces on which tobosa occurs is a high clay content in the plant rooting zone (0-50 cm). It is absent from all plots on M, Y, W and L surfaces, none of which have soils of high clay content. Neuenschwander et al. (1975, p.257) describe its distribution as follows: "Tobosa is found primarily on clay soils...almost pure stands of tobosa occupy hard-land flats...maximum cover is in swales on heavy clay soils where intermittent flooding occurs...in addition to bottomland clay sites, it is present on dry mesas, sandyloam hills, and rocky substrates... Buffington and Herbel (1965) found tobosa as the dominant grass growing in lesser drained areas with slopes less than 3% on calcareous and gypsum soil, silt loam, and clayey soils." Tobosa dominates the potential vegetation listed in the NRCS ecological site guides for Clay Bottoms and Clay Uplands and is abundant (10-20% relative composition by weight) on Clay Hills. Tobosa has been found to be a reliable indicator of clay soil throughout the study area (pers. obs.)

Vine Mesquite Grass (*Panicum obtusum*)

Vine mesquite grass is most abundant on plot 28 (surface Am, 13% relative cover), plot 21 (surface Ws/O or As, 11% relative cover), plot S17 (O surface, 10% relative cover), and plot S8a (M surface, 9% relative cover). Each of the plots in which vine mesquite grass has its greatest cover has a potential for periodic flooding, or at least a high clay content in the soil. However, it is not restricted to such sites and also occurs in 2 plots on Y surfaces, both of them silty abandoned floodplains that probably do not receive regular channel overflow, and in plot 78

on an Ok surface. In these less favorable sites it attains very low relative cover (1-3%). The habitat of vine mesquite grass is described by Gould (1973, p. 287) as "swales, mud flats, heavy-soiled lowlands, and marshy pasturelands that periodically dry out." Among the NRCS ecological sites, vine mesquite grass has its highest relative percentages (40-50% classes) in the potential vegetations of Loamy Swales and Clayey Bottoms.

Aparejo Grass (*Muhlenbergia repens*)

Aparejo grass is found in 7 study plots, most of them in or near the topographically closed bed of Pleistocene Lake Cloverdale. Its highest relative cover (23%) is found at plot 90 in the center of the lake, where it co-occurs with vine mesquite grass, squirreltail grass, *Helianthus ciliaris*, and annuals on a soil of deep silty loam. It is also found on fine-textured, deep soils at plot 21, a Ws/O surface north of the ancient lakeshore berm, where water stands for long periods, and plots 88 and S8A, both on the eastern margin of the lake, where a silty clay loam overlies a silty clay. It has 23% relative cover at plot 28, an alluvium-mantled slope about 1 km northeast of the lakeshore. At each of these near-lake plots, it co-occurs with vine mesquite grass and may be favored by the same conditions of occasional supplemental moisture from flooding. At plots 105 and 13 it occurs on Y surfaces in the deep silt of floodplains.

Sideoats Grama (*Bouteloua curtipendula*)

Sideoats grama may be the most valuable forage grass in the study area, and its distribution and abundance have undoubtedly been restricted by long-term grazing. It is found in 14 of the 53 study plots (26%), and its greatest abundance is attained on hillslopes. It occurs on hillslopes of all 3 rock types at comparable relative covers. Although we have no vegetation plots on incised piedmont alluvium-hillslopes (Ha), field observations indicate that sideoats grama is quite abundant in such sites. Judging from its representation in the NRCS ecological site guides, it is a widely adapted species that should be in dominant classes of the potential natural vegetation in Clayloam Uplands, Loamy Uplands, Sandyloam Uplands, Deep Sandyloams, Clay Hills, Loamy Hills and Limy Slopes. Its peak of abundance on slopes in the upper Animas valley most likely reflects grazing pressure. Cattle are less likely to graze on slopes than on level ground and over decades have reduced the abundance of sideoats on level sites throughout the valley.

Wolftail Grass (*Lycurus phleoides*)

Wolftail grass, a valuable forage grass, is found in 16 of 53 study plots (30%). In none of these is it dominant, and it only attains a relative cover greater than 10% in two plots: 12 (M surface: 14% relative cover) and S12 (M3 surface: 11%). The soil at S12 is a deep sandy loam. Wolftail grass is absent from all hillslope plots, despite the fact that it is in a dominant class (45-55% by weight) of the potential natural vegetation of the NRCS ecological site Shallow Uplands, which is found on pediments with exposed bedrock.

Mesa Dropseed Grass (*Sporobolus flexuosus*)

Mesa dropseed occurs in 6 study plots, all of them characterized by young, deep soils. Geomorphic surfaces include M, Am, Y, Y2f, Ls, and Wd. Mesa dropseed is most abundant at plots 1 (Ls surface: 14% relative cover) and S8a (Am surface: 14% relative cover). Plot 1 is a unique site, located on the northern lakeshore in the lower part of the upper basin (see discussion in Vincent and Krider, 1998), where deep sandy soil severely restricts the number of species present. Mesa

dropseed is codominant there with *Paspalum setaceum*, which occurs at only one other plot in the study area: plot 22, a site of deep, wind-deposited sand dominated by oak trees. It is included as part of the potential natural vegetation of only one NRCS ecological site: Deep Sandyloam, described as occurring on fan and stream terraces, with sandyloam soil to at least a 30-inch depth.

Shrubby Buckwheat (*Eriogonum wrightii*)

Shrubby buckwheat is a perennial forb with a deep taproot. A broadly-distributed, fire-tolerant species (Sundt, unpubl. data), it occurs in 43% of the study plots, most consistently and abundantly on M surfaces (6 of 7). It is absent from the lake bottom and from the wind-deposited Wd and Ws plots. Its broad distribution and peak of abundance in plots on M surfaces suggests that it finds its optimum soil conditions on that surface, possibly because its taproot is able to grow to considerable depth in loose soils. Shrubby buckwheat roots were observed at a depth of 130cm at soil pit 18 on an M surface. Among the NRCS ecological sites shrubby buckwheat has its highest relative percentages (10-20% class) in the potential vegetation of Loamy Hills, which corresponds to geomorphic surface Ha. However, it is also included in the 10-15% class of the potential vegetation of Shallow Uplands, which is a shallow soil over bedrock. Although described by Kearney and Peebles (1951) as "fair browse for cattle," it is rarely if ever used by cattle in the study area (pers. obs.).

Discussion

Evidence of affinity (or disaffinity) for particular geomorphic surfaces or topographic positions were displayed in these data by hairy grama, tobosa, mesa dropseed, shrubby buckwheat, aparejo grass, *Paspalum* and vine mesquite grass. The common and almost ubiquitous species blue grama may avoid calcareous soils such as those on Ok surfaces. Plains lovegrass and hairy grama may be disfavored by undeveloped soils such as occur on Y floodplains, the sandy lakeshore, and dunes. Mesa dropseed is most common on young, deep soils such as on stream terraces and lakeshores. Shrubby buckwheat finds its greatest abundance on loose soils of M surfaces. The grouping of several species of *Aristida*, however, are ubiquitous and no correlation with geomorphic surface is apparent in their distribution.

Field observations offer several other examples of important geomorphic or topographic influences on plant distributions. One is the apparent restriction of the shrubs winterfat (*Eurotia lanata*) and woody dalea (*Dalea formosa*) to calcareous soil. Winterfat has proven to be a reliable indicator of limy surface soil wherever encountered in the study area (pers. obs.), including its only appearance in these data at plot 30, where proximity to an incised Ok surface has enriched the adjacent Y surface with calcium carbonate. Woody dalea dominates the vegetation at soil pit S16, a Vk surface with strong HCl effervescence at the surface from which the A horizon has probably been stripped by erosion. Aster, a perennial herb, is also anomalously abundant (25% relative cover) at the site. Texas bluestem (*Schizachrium cirratum*) is found fairly commonly on rocky pediments, but in the alluvial piedmonts of the upper Animas basin it occurs exclusively on north-facing hillslopes incised into fans (Ha), where it can be locally dominant. *Hilaria berlandieri*, a stoloniferous forage grass, is found almost exclusively in bedrock hillslopes (the one exception in these data, plot 16, is at the foot of a hill at the upper edge of an O surface). The grass *Paspalum setaceum* is locally abundant in

deep sands (e.g. plots 1 and 22) but occurs nowhere else. The distribution of mesquite (*Prosopis glandulosa*) in the upper Animas valley appears to be controlled by temperature through the agency of topography. Minimum overnight winter temperatures are much lower in valley and canyon bottoms than in the uplands, apparently due to cold air drainage and pooling; mesquite is absent from low-lying locations. The distributions of other species are probably also responding to these thermoclines.

Tobosa grass (*Hilaria mutica*) tends to dominate the vegetation on heavy clay soils. Clay, due to its electrically-charged lattice structure, can store much more water than a comparable volume of sand or silt, but holds it much more tightly. Tobosa may be physiologically able to extract water from clays better than most other species (perhaps by osmotic adjustment, Brown 1995) and therefore outcompetes those species on heavy clays. Soils with very high clay content subject to deep cracking (vertisols) occur patchily throughout the study area, often associated with basalt parent materials. The extreme shrinking and swelling of these soils severely limits the number of species that can occupy them. Prominent among the species present on vertisols are tobosa and cholla (*Opuntia spinosior*). Both of these species may be able to persist in the mechanically unstable soils by bridging the deep cracks with their tough roots, and by their abilities to regenerate from fragments.

Beargrass or sacahuiste (*Nolina microcarpa*) is a widespread species that is very abundant, almost a monoculture, in a large area of wind-blown sand overlying an old alluvial fan surface at 1 m or more depth (Ws/O) on the western piedmont of the Animas Mountains. Beargrass is also abundant (12% relative cover) at plot 22, on a Wd surface. It is apparently well-adapted to grow and reproduce in conditions of a deep (>1 m) sandy topsoil perched on a dense clay. Deep infiltration is prevented by the clay horizon, so that much of the water that enters the soil remains in the upper 1 m of sandy topsoil. Beargrass has a large fleshy storage organ below ground and fibrous roots penetrating at least 1 m; it is thus capable of harvesting and storing water that periodically saturates the sandy topsoil, using the stored moisture to endure drought. Other succulent species in the study area have similar strategies, for example cholla, but these apparently are outcompeted by beargrass, which is also more tolerant than cholla of the fire that frequently sweeps the area (Sundt, unpubl. data) and probably of cold air drainage as well.

Correlation of geomorphic surface map units and plant abundance data has suggested habitat preferences of several important species in the study area. Making the step from correlation to cause-and-effect is dangerous, however, and further study is necessary to avoid spurious conclusions. For example, McAuliffe (1994) showed that the widespread correlation of creosote bush (*Larrea tridentata*) with calcareous soil in the Chihuahuan and Sonoran Deserts is not due to a physiological requirement of *Larrea* for alkaline soil, as many have assumed, but rather to the avoidance by *Larrea* of soils with well-developed argillic horizons, which prevent deep infiltration of rainwater. Inhibition by carbonate of the formation of an argillic horizon (Gile 1981) reinforces the correlation. Similarly, in this study the negative correlation of blue grama with calcareous soils may be an artifact of the correlation of calcareous soils with low elevations.

A geomorphic surface map is a very valuable resource in the mapping of ecological sites. In many cases, geomorphic surface and ecological site boundaries are the same. For example, in the upper Animas valley, V and O age geomorphic surfaces are almost always identical with Clayloam Upland ecological sites; M age surfaces with Loamy Uplands; Ha surfaces with Loamy Hills; and Y surfaces with Loamy Bottoms. The ongoing refinement of the ecological site classification sys-

tem will greatly benefit from a more explicit and technical consideration of geomorphology.

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Appendix 1. Species codes, scientific and common names of plant species included in this study. Authorities various, principally Kearney & Peebles, Arizona Flora, Gould, Grasses of southwestern United States, Benson & Darrow, Trees and Shrubs of the Southwestern Deserts, Benson, Cacti of Arizona, Martin et al, Fall Wildflowers of New Mexico, and Allred, Field Guide to the Grasses of New Mexico.

Field Code	Common name	Scientific name
ARIS	Three awn grasses (grouped)	<i>Aristida spp</i>
ASTER		<i>Aster sp</i>
ASTRAG		<i>Astragalus spp</i>
BOBA	Cane beardgrass	<i>Bothriochloa barbinodis</i>
BOCO		<i>Boerhaavia coccinea</i>
BOCU	Sideoats grama	<i>Bouteloua curtipendula</i>
BOER	Black grama	<i>Bouteloua eriopoda</i>
BOGR	Blue grama	<i>Bouteloua gracilis</i>
BOHI	Hairy grama	<i>Bouteloua hirsuta</i>
BRDE		<i>Brayulinea densa</i>
BUDA	Buffalograss	<i>Buchloe dactyloides</i>
CRCO	Croton	<i>Croton corymbulosus</i>
DAFO	Woody or feather dalea	<i>Dalea formosa</i>
DAPU	Fluffgrass	<i>Dasyochloa pulchella</i>
DECO		<i>Desmanthus cooleyi</i>
DICA	Arizona cottontop	<i>Digitaria (=Trichachne) californica</i>
ERIN	Plains lovegrass	<i>Eragrostis intermedia</i>
ERLE	Lehmann's lovegrass	<i>Eragrostis lehmanniana</i>
ERWR	Shrubby buckwheat	<i>Eriogonum wrightii</i>
EULA	Winterfat	<i>Eurotia lanata</i>
EVOL		<i>Evolvulus sp</i>
FORB	Annual forbs (grouped)	
GAURA	Gaura	<i>Gaura sp</i>
GRAS	Annual grasses (grouped)	
GUSA	Broom snakeweed	<i>Gutierrezia sarothrae</i>
HECI		<i>Helianthus ciliaris</i>
HIBE	Curly mesquite grass	<i>Hilaria berlandieri</i>
HIMU	Tobosa	<i>Hilaria mutica</i>
HODE	Hog potato	<i>Hoffmansegia densa</i>
LYPH	Wolftail grass	<i>Lycurus phleoides</i>
MELE		<i>Melampodium leucanthum</i>
MIBI	Catclaw mimosa	<i>Mimosa biuncifera</i>
MUAR	Sand muhly	<i>Muhlenbergia arenicola</i>

Appendix 1. Cont'd.

Field Code	Common name	Scientific name
MUEM	Bullgrass	<i>Muhlenbergia emersleyi</i>
MUH SP		<i>Muhlenbergia</i> sp
MUPO	Bush muhly grass	<i>Muhlenbergia porteri</i>
MURE	Aparejo grass	<i>Muhlenbergia repens</i>
NOMI	Sacahuiste, beargrass	<i>Nolina microcarpa</i>
OENOTH	Evening primrose	<i>Oenothera</i> sp
OPSPI	Cholla	<i>Opuntia spinosior</i>
PAOB	Vine mesquite grass	<i>Panicum obtusum</i>
PASE		<i>Paspalum setaceum</i>
PEFL		<i>Petalostemum flavescens</i>
PRGL	Mesquite	<i>Prosopis glandulosa</i>
QUAR	Arizona white oak	<i>Quercus arizonica</i>
QUEM	Emory oak	<i>Quercus emoryi</i>
QUERCUS	unknown oak	<i>Quercus</i> sp
RHTR	Skunkbush	<i>Rhus trilobata</i>
SCBR	Burrograss	<i>Scleropogon brevifolius</i>
SCCI	Texas bluestem	<i>Schizachrium cirratum</i>
SIDA		<i>Sida</i> sp
SIHY	Squirreltail grass	<i>Sitanion hystrix</i>
SILE		<i>Sida lepidota</i>
SOEL	Horsenettle	<i>Solanum eleagnifolium</i>
SPFL	Mesa dropseed	<i>Sporobolus flexuosus</i>
SPSP	Mallow	<i>Sphaeralcea</i> sp
ZIGR	Desert zinnia	<i>Zinnia grandiflora</i>

Appendix 2. Geomorphic Surface Symbols and Basin Designations

Alluvial depositional landforms

Y	=	Surface of active floodplain in bottomland with sandy loam soil.
As	=	Like Y but inset into fan remnants as shallow swales without streams.
Y2 & Y2f	=	Surface of late Holocene stream terrace (or small fan remnant denoted by subscript f) in bottomland with sandy loam or loamy sand surface horizon and locally sandy clay subsoil with or without stage I carbonate.
M	=	Surface of latest Pleistocene inset terrace, 2-6 m above bottomland, with ?20 cm thick loam, sandy loam or gravelly loam surface horizon and highly variable subsoil ranging from gravelly clay without carbonate to gravelly sandy clay loam with stage II carbonate. Sub-units M3 and M4 differ slightly in age but have similar soils and position in the landscape.
M/O	=	Unit M surface and soil burying a unit O soil.
O, O5, O6	=	Surface of late Pleistocene fan remnant composing the low gradient uplands, 2-40 m above bottomland, with 10-30 cm thick loam surface horizon, 35-45 cm thick clay Bt-horizon, and sandy loam or clay loam subsoil with 20-70% gravel. Stage II carbonate is generally present below the Bt-horizon. Sub-units O5 and O6 differ slightly in age but have similar soils and position in the landscape.
Ok	=	Like unit O but calcium carbonate is present in the surface horizon and stage III carbonate is present in the subsoil.
V	=	Surface of middle Pleistocene fan remnant composing part of the low gradient uplands, 2-40 m above bottomlands, with 10 cm thick silt loam to clay loam surface horizon, 20-70 cm thick clay or gravelly clay Bt -horizon, and gravelly clay or gravelly clay loam subsoil. Stringers and pockets of calcium carbonate may be present at depths > 90 cm.
Vk	=	Like unit V but calcium carbonate is present in the surface horizon and stage III+ carbonate is present in the subsoil.
V/l	=	Unit V surface and soil that buries latite bedrock at shallow depth.

Lacustrine surfaces

Am	=	Probably a unit O or V fan but at the foot of range front and may be partially reworked and may also contain colluvium.
Ls	=	Lake spit with loam to gravelly loam surface soils over more sandy deposits.
Lb	=	Dry-lake bottom with 10 cm silt loam A-horizon over deep silty clay loam.
Ld/M	=	Lake-shore delta with silt loam soils overlying unit M soil.

Windblown landforms

Appendix 2. Cont'd.

- Wd = Sand dunes of sand or loamy sand and locally cemented with silica.
- Ws/O = Sand sheet, > 20 cm thick, consisting of loamy sand or sandy loam covering a unit O soil at shallow (< 1 m) depth.

Hillslopes

- Hr = Surface of erosional hillslope composed of thin colluvium on rhyolite bedrock
- Hl = Surface of erosional hillslope composed of thin colluvium on latite bedrock
- Hb = urface of erosional hillslope composed of thin colluvium on basalt bedrock

A Vegetation Map of the Borderlands Ecosystem Management Area

Esteban Muldavin, Department of Biology, New Mexico Natural Heritage Program, University of New Mexico, Albuquerque, NM

A map of current vegetation of the Borderlands Ecosystem Management Area in southwest New Mexico and southeast Arizona was developed from LANDSAT Thematic Mapper satellite imagery to serve regional, ecosystem-based planning. A preliminary vegetation classification was developed based on over 500 ground samples and served as the basis for defining 34 map units. Vegetation ranged from montane coniferous forests, woodlands, and shrublands, to chaparral, grasslands, desert scrub, and riparian areas. Overall map accuracy was 79.3% with most errors associated with closely related vegetation or at ecotones between types. Brief descriptions are provided for each map unit with respect to plant community composition, environment, and distribution along with representative photographs and a species list.

For more information on how to obtain the map write to:
Southwestern Borderlands Ecosystem Research Program
Rocky Mountain Research Station
2500 South Pine Knoll
Flagstaff, AZ 86001-6381

Review of New Mexico's Wildlife Conservation Act and of Department of Game and Fish Studies of Special Status Species in the Borderlands of Southwest New Mexico

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The listing of species by the state of New Mexico as endangered or threatened is the function of the New Mexico Department of Game and Fish (Department), as approved by the State Game Commission. This authority is granted under the Wildlife Conservation Act (WCA), which became effective on 1 July 1974. Presently, the WCA (Sections 17-2-37 through 17-2-46 NMSA 1978 compilation, as amended in 1995) gives listing jurisdiction to the Department over all indigenous mollusks, crustaceans, fishes, amphibians, reptiles, birds, and mammals.

Under the WCA, "endangered species" are those species whose prospects of survival or recruitment within the state are in jeopardy due to any of the following factors: 1) present or threatened destruction, modification, or curtailment of habitat; 2) overutilization for scientific, commercial, or sporting purposes; 3) effects of disease or predation; 4) other natural or human-made factors affecting prospects for survival or recruitment within the state; or 5) any combination of the foregoing factors. "Threatened species" are those that are likely to become endangered within the foreseeable future within all or a significant portion of their ranges within New Mexico. The focus on status within the state means that the Department must base its determination of endangerment solely on the basis of a taxon's status in New Mexico, regardless of its status beyond the boundaries of the state.

Listing criteria are based on biological and ecological evidence only, and include population and habitat information, threats to species or habitats, and assessments of the quality of biological information. Economic and social issues are received via written testimony; such issues are considered in recovery planning. The Department, through its Director, makes listing recommendations; and State Game Commission makes listing decisions.

Among the provisions of the WCA are the following: 1) the Department shall conduct a biennial review of all species currently listed as endangered or threatened, to include recommendation for uplisting or downlisting; 2) separate processes, including investigations requiring peer review by university scientists plus public hearings, are necessary for new listings as well as for delistings; 3) to the extent practicable, recovery plans shall be developed for listed species; 4) it is unlawful to take (harass, hunt, capture, kill, or attempt to do so), possess, transport, export, process, sell or offer for sale, or ship listed species, and penalties are stipulated; 5) the Department shall establish programs for the management of listed species, including programs for research, management, habitat acquisition, propagation, law enforcement, and education; 6) funds from the sale of hunting and fishing licenses may not be used for endangered species programs; 7) specific land use activities are neither required nor prohibited; 8) persons adversely af-

affected by actions of the State Game Commission may seek judicial review through the court of appeals.

The WCA allowed for the establishment of an Endangered Species Program (ESP) within the Department. The activities of the ESP range from surveys and research to habitat acquisition, dissemination of information, and law enforcement. The ESP is supported by a small General Fund appropriation, with the majority of that appropriation being matched with U. S. Fish and Wildlife Service federal aid funds. The chief source of federal aid is from the Pittman-Robertson Act, which provides for the study and management of nongame birds and mammals. A lesser funding component for the program is that from the Dingell-Johnson Act, which allows for the general study and management of nongame fishes in association with game species. Finally, some program funds are obtained under Section 6 of the federal Endangered Species Act as well as from grants directed at specific studies, including grants from Bureau of Land Management, Bureau of Reclamation, and U.S. Forest Service.

Five biologists plus a full-time program manager currently staff the ESP, with the biologists being specialists in the following disciplines: invertebrate biology, ichthyology, herpetology, ornithology, and mammalogy. Owing to the biological diversity of the Borderlands region plus the concentration of endangered, threatened, and special concern species there, all biologists (with the exception of the ichthyologist), maintain active research programs in the region. These activities are briefly discussed below.

Mollusk Studies

Some 13 species of land snails are known or believed to be endemic to the montane sky islands of Hidalgo County, New Mexico. These include seven species in five genera in the Big Hatchet, Little Hatchet, and Alamo Hueco mountains (including three species restricted entirely to the Big Hatchet Mountains); four species in four genera in the Animas Mountains, including an undescribed species of *Holospira*; an undescribed species of *Sonorella* in the San Luis Mountains, and one species in the Peloncillo Mountains.

A systematic inventory of land snails distribution and abundance is currently underway in the Animas and San Luis mountains on the Gray Ranch and, in collaboration with university specialists, two new species are being described. A similar inventory of land snail distribution and abundance is underway in the Big Hatchet, Little Hatchet, and Alamo Hueco ranges. Additionally, surveys for aquatic mollusks and crustaceans found in wetland areas associated with the land snails are being carried out.

Amphibian and Reptile Studies

Of the 123 species of amphibians and reptiles known from New Mexico, at least 60% occur in Hidalgo County. With the permission and support of various landowners and federal agencies, an active herpetological research program has been underway there since 1987. Antelope Pass, about 6-8 miles west of Animas, was found to support the highest lizard diversity of any area in North America, with at least 20 species occupying the area. Currently in preparation is an in-depth manuscript on the distribution, habitat needs, and status of the amphibians and reptiles of the Gray Ranch and Guadalupe Canyon. Department studies, con-

ducted in cooperation with university contractors, of the federally threatened New Mexico ridgenose rattlesnake (*Crotalus willardi obscurus*) are discussed elsewhere.

Recent and/or on-going activities have included: Antelope Pass pit fall study (April 1987-October 1992), targeting *Cnemidophorus dixonii*, with over 12,000 captures; Guadalupe Canyon pit fall study (April 1992-August 1997), targeting state listed species including *Bufo alvarius*, *Rana yavapaiensis*, *Eumeces callicephalus*, *Cnemidophorus burti*, *Heloderma suspectum*, and *Elaphe triaspis*; Gray Ranch pit fall study (March 1994-October 1997), targeting *Sceloporus scalaris*, with over 3000 captures/recaptures and including pre/post fire data; and leopard frog (*Rana spp.*) studies (on-going), especially as regards distribution, status, and habitat usage of *R. chiricahuensis*.

Bird Studies

With 82% (26 of 32) of New Mexico's state-listed birds occurring in the Borderlands region, much of the Department's endangered bird program activities are focused there. Surveys, monitoring, and/or research are conducted annually in Guadalupe Canyon, the Peloncillo Mountains, the middle and southern Animas Valley, the Animas Mountains, and the west Playas Valley. Work focuses primarily on breeding birds, including raptors, and secondarily on wintering birds.

In Guadalupe Canyon, a transect was established and consistently monitored for breeding birds during the 12-year period 1987-1998, providing the only long-term status and trend information for several state-listed birds, 12 of which breed (or bred) in the New Mexico portion of the canyon. In the Peloncillo Mountains, Department surveys discovered what has proven to be New Mexico's only breeding population of Elegant Trogons (*Trogon elegans*); annual monitoring through 1998 has documented one-two pairs yearly of this cavity-nesting, riparian species. The Whiskered Screech-Owl (*Otus trichopsis*) is another listed species known to breed in New Mexico only in the Peloncillo Mountains; reported there only twice prior to 1990, Department survey and monitoring efforts since then documented this cavity-nester in five canyons, but fires in 1997 destroyed habitat and eliminated the species from at least one canyon.

Among the longest running studies of any grassland bird in the southwestern U.S. has been the Department's annual breeding season survey of the state-listed Arizona grasshopper sparrow (*Ammodramus savannarum ammolegus*) in the southern Animas Valley. This locally-distributed desert grassland species was first documented in New Mexico in 1987; a transect was established and annual monitoring initiated in the Animas Valley that year (and expanded to the west Playas Valley in 1992), with 1998 marking the 12th consecutive year of consistent data gathering. A species of special concern is Botteri's sparrow (*Aimophila botterii*), a tall-grass specialist first documented in New Mexico along Animas Creek in 1991. Intensive survey and monitoring efforts by the Department 1995-1998 documented two-three dozen territories annually, primarily along Animas Creek but also in the Deer and Whitewater drainages east of the Animas Mountains.

In the Animas Mountains, recent efforts by Department personnel and contractors have focused on New Mexico's only breeding population of the state-listed Yellow-eyed Junco (*Junco phaeonotus*) plus other local breeders including the Mexican Chickadee (*Parus sclateri*), a species which breeds nowhere else in the state.

A significant portion of the Department's work in the region involves raptors, including (but not limited to) breeding Apache northern goshawks (*Accipiter*

gentilis apache), zone-tailed hawks (*Buteo albonotatus*), peregrine falcons (*Falco peregrinus anatum*), and Mexican spotted owls (*Strix occidentalis lucida*) plus grassland surveys for aplomado falcons (*Falco femoralis septentrionalis*). Work with non-breeding birds in the region has focused mainly on wintering grassland species in the Animas Valley, with Baird's sparrow and Sprague's pipit being of particular concern.

Mammal Studies

The Department's ESP personnel conducted general faunal surveys in the Animas Mountains 1976-1979; those surveys included all vertebrates (as well as butterflies and plants), but the major focus was on mammals and birds. During those surveys, presence of the Arizona shrew (*Sorex arizonae*) in upper Indian Creek Canyon was documented, establishing the first record of the species in New Mexico. Fifty-three percent (8 of 15) of New Mexico's state-listed mammals occur in the Borderlands region.

The white-sided jackrabbit (*Lepus callotis*) occurs in the U.S. only in a small area of southern Hidalgo County, where ESP surveys for the species were initiated in 1975. In 1976, seven surveys conducted on the Gray Ranch revealed a survey mean of 15 (range 5-25) white-sided jackrabbits, but eight surveys conducted in the same area in 1981 yielded only about half that number. Surveys conducted in 1990 resulted in 3.2 white-sided jackrabbits per survey, while seven surveys conducted 1995-96 revealed only 1.1 animals per survey. More recently, monthly surveys were initiated in April 1997, and these have continued into 1999. Preliminary analysis of data suggests recent numbers are similar to those recorded in 1976. The largest number of white-sided jackrabbits observed during recent efforts was 25 individuals in November 1998.

Information on Borderlands Resources: A Bibliography for Planners, Managers, and Research Workers

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Scientific literature on resources of the Malpai Borderlands had been largely uncollected and, therefore, unknown to many planners, managers, and research workers until a comprehensive bibliography of about 5,000 references was compiled. The geographical scope of the bibliography is the Madrean Biogeographic Province north of 27 degrees latitude, including the Malpai Borderlands. Literature from similar ecosystems on adjacent areas was also included in the bibliography because of the significant ecological overlap.

The bibliography contains citations of historical and contemporary relevance to the Malpai Borderlands region. More general citations have also been included when specific mention has been made of this region in the reference. References relating to technologies, methodologies, and procedures have been largely omitted from the bibliography.

Computerized and hardcopy data bases were searched for appropriate literature in compiling this bibliography. The computerized data bases interrogated were FS INFO; CAB Abstracts; AGRICOLA; BIO SIF Previews; Life Science Collections; Southwestern Center for Biological Diversity: Grazing Abstracts; and *Riparian Bibliography for New Mexico and the Southwest: Selected Annotations*. Published hardcopy data bases searched included *Selected References: The Encinal Woodlands*; *Livestock Management Effects on Wildlife, Fisheries, and Riparian Areas: A Selected Literature Review*; *Annotated Bibliography: Ecological Impacts of Livestock Grazing in Western North America*; *Southwestern Research Station Bibliography (1955-1994)*; *A Bibliography for the Northern Madrean Biogeographic Province*; *Southwest Watershed Research Center: A History of Research for Today and Tomorrow*; *Land Use History of the San Rafael Valley, Arizona (1540-1960)*; and *An Annotated Bibliography of Reports, Publication, and Theses on the Appleton-Whittell Research Ranch Sanctuary*.

Papers presented at the conference on the Biodiversity and Management of the Madrean Archipelago: The Sky Islands of Southwestern United States and Northwestern Mexico, held in Tucson, Arizona, on September 19-23, 1994, are also included in the bibliography, along with relevant literature cited in these papers. Additional references were obtained from an *Annotated Bibliography of Publications from the Southwest Watershed Research Center*; *A Selected Bibliography: Effects of Fire on the Madrean Province Ecosystems*; *The Santa Rita Range: History and Annotated Bibliography*; and *Literature of Wildlife Research in the Madrean Archipelago: 1800s-1994*. Theses and dissertations on the resources of the Malpai Borderlands are listed in the bibliography. Fugitive literature, i.e., office reports, field trip summaries, map references, and other unpublished but relevant materials on the resources of the Malpai Borderlands region are also included where appropriate; this literature is most commonly found in special collections of large libraries.

Citations contained in the bibliography are listed alphabetically by senior author's last name in categories determined to be most appropriate to the subject matter of the reference by the bibliography's compilers. In cases where a citation could have been placed into two or more categories, it was placed in the one category judged most appropriate based on the main emphasis of the reference. Categories in the bibliography are Climate and Weather Patterns; Conservation and Management; Economics, Policies, Sociology; Fire and Fire Effects; History of Land Use; Human Impacts; Hydrology and Watershed Management; Invertebrate Ecology; Plant Ecology; Range Management and Livestock Grazing; Recreation and Tourism; Riparian Ecosystems; Soils, Minerals, Geological Features; and Vertebrate Ecology.

It is often necessary to search more than one category to complete a listing of references on a particular topic when interrogating the bibliography. For example, references on a topic in RANGE MANAGEMENT and LIVESTOCK GRAZING might be found in this category and also in the categories on CONSERVATION AND MANAGEMENT and PLANT ECOLOGY. References on RIPARIAN ECOSYSTEMS are found in both this category and the categories on HYDROLOGY AND WATERSHED MANAGEMENT and VERTEBRATE ECOLOGY. References on FIRE AND FIRE EFFECTS can be found in this category and also in the categories on CONSERVATION AND MANAGEMENT and PLANT ECOLOGY.

The large number of references in the bibliography precludes its publication. However, the bibliography, and individual categories therein, are available on a World Wide Web site. The address

www.rms.nau.edu/publications/madrean/

provides a connection to the bibliography's main menu. Background information and topical categories can then be downloaded from the Web site onto computer disks for further analysis.

Financial support from the Cooperative Park Studies Unit, Geological Survey, U.S. Department of the Interior enabled the effort to compile this bibliography to begin. Subsequent funding was provided by the Rocky Mountain Research Station, USDA Forest Service, through the Borderlands Ecosystem Management Program, and the School of Renewable Natural Resources, University of Arizona, to complete the collation of the bibliography.

Human Occupation and Ecological Change in the Borderland Region of Arizona/New Mexico/Sonora/Chihuahua: An Analysis of Causes and Consequences

Diana Hadley, Senior Editor, Documentary Relations of the Southwest; **Thomas E. Sheridan**, Ph. D., Curator of Ethnohistory, Arizona State Museum; **Peter Warshall**, Editor, Ph. D., Whole Earth Magazine

This study examines the human impacts that have shaped the nature and rate of ecological change in the Borderlands region. The study area includes the San Simon, San Bernardino, and Animas valleys, the western portion of the Playas Valley, and the Peloncillo and Animas mountain ranges in Cochise County, Arizona, and Hidalgo County, New Mexico, extending several miles across the international boundary into contiguous portions of Sonora and Chihuahua. The study covers the period of recorded human occupation, with a strong emphasis on the late nineteenth and early twentieth centuries, the period when human occupation and ecological change were most intense. To assemble data for this study, researchers have examined public records on the federal, state, and county level, private record collections, and published and unpublished sources, including historical diaries and travel accounts. In addition, researchers have conducted oral histories, made on-site visits accompanied by informants, and have used repeat photography to assess change. The full report contains nine chapters, eight maps, over twenty photographs, and eight appendices.

Archaeological remains indicate that the San Bernardino, Animas, Playas and San Simon valleys were inhabited during the late Pre-Columbian period, the valleys forming migration routes from Sonora and Chihuahua to the Mogollon Rim and the Rio Grande. The remains of multi-structure settlements indicate that the Animas and San Simon valleys were northern extensions of the Casas Grandes culture. The Janos, Jacomes, Sumas, Mansos, Cholomes, and Jumanos appear in seventeenth century Spanish records as distinct groups that migrated in and out of different portions of the Borderlands area, engaging in periodic struggles for control of the mountain ranges and valleys of the Borderlands area. Linguistic specialists agree that the majority of these groups were probably Uto-Aztecan speakers, although the Janos and Jacomes may have been Athapaskan.

By the early eighteenth century, Athapaskan-speaking Apache bands had moved into the Borderlands, the Chokonon group occupying the Chiricahua and Peloncillo mountain ranges, and the Nednhi group occupying the Sierra Madre ranges of Sonora and Chihuahua. Although Apache occupation did not have significant ecological impact on the Borderlands region, with the possible exception of intentionally initiated fire drives for hunting and/or warfare, the Apache economy of raiding and warfare had severe social impacts, driving out other native peoples and preventing permanent Spanish occupation of the area. The confluence of distinct culture groups in the Borderlands region established it as frontier zone of shifting populations and frequently warring peoples.

The Spanish military established *presidios* (garrisons) at Janos, Chihuahua in 1684 and at Fronteras, Sonora in 1690. A *camino real* (a royal highway) connected the two forts through Guadalupe Canyon. Although the viceroyalty of New Spain initially pursued a coordinated, centralized Indian policy, cooperation between the Spanish provinces and the local presidios gradually disintegrated. Apaches traded regularly and sought protection at the presidio of Janos, but were vigorously pursued by troops from Sonora. From 1775 to 1780, the garrison from Fronteras was stationed at the former ranch at the San Bernardino springs, where the army constructed extensive fortress style buildings. After 1786, the Spanish military supported a successful peace program for Apaches, settling them at *establecimientos de paz* near presidios, where they received rations, liquor, and obsolete weapons, in a system not unlike the reservation program later adopted by the United States. During the struggle for Mexican independence, the peace program ended. Apaches from Janos, where up to 800 of them had often camped, moved back to the Animas and Alamo Hueco mountain ranges where the Apaches by then were familiar with Spanish military practices and more sophisticated in warfare from their years of exposure to the Spanish army at the presidios. An undetermined number of domestic livestock were present at the *rancho* San Bernardino, both before and after its brief use as a presidio. This was the only location occupied by Euro-Americans and the only land grant (1821) issued by either the Spanish or Mexican governments within the study area.

Spanish and Mexican landscape descriptions contain considerable detail about the study area's major valleys and the *camino real*, including locations of springs, specific vegetation types, and wildlife. When Anglo-American explorers and travelers first penetrated the Borderlands area during the Mexican period (1821-1854), they wrote descriptions similar to those of their Spanish and Mexican predecessors and retained many Spanish place names. The collective picture provided by the early descriptions indicates a landscape with more abundant and robust grasses, more numerous springs, several extensive cienegas, and much higher concentrations of a wider variety of wildlife than found today. Although the reliability of the descriptions is not uniform, locations can be identified and site specific information is useful. For example, beaver and jaguar were observed in Guadalupe Canyon; prairie dog towns were extensive along the Janos road, the Playas Valley, and near the Dog Mountains; and "water lizards" (salamanders) in the thousands were found in the Playas and Animas dry lakes and at Cloverdale. Antelope were seen in numbers exceeding 100 and grizzlies were seen in the Animas, San Luis, and Peloncillo ranges. Between 1849 and 1854, Forty-niners created one of the first major human impacts in the immediate vicinity of the Southern Overland Route, which followed the former *camino real*, where their livestock depleted forage and damaged water sources.

Although the United States acquired the Borderlands region in 1854 through the Gadsden Purchase, Apache hostilities and the Civil War delayed settlement until the 1870s. Ironically, the Apache Wars introduced U. S. military personnel to the attractive, unoccupied lands of the Borderlands area, and many former soldiers were among the earliest settlers. The short-lived Chiricahua Apache Reservation (December 12, 1872 to May 9, 1876) included the entire Arizona portion of the study area. Even before its termination, settlers began to preempt homestead sites on its more fertile sections. Among the first locations settled by Americans were the San Simon cienega, the cienega near Michael Gray's ranch in the Animas Valley, and Cloverdale. In some of these areas, impacts from land use were soon apparent. The San Simon Cienega, for example, was promptly chan-

neled into a series of irrigation canals, prompting one of Cochise County's earliest lawsuits.

The Borderlands area has always had a low population density. In-migration peaked during the 1890s and again between 1905 and the onset of World War I. The second peak occurred as a direct response to promotion of dry farming by the USDA and agricultural research stations. Homesteaders farmed, raised limited numbers of livestock (cattle, sheep, swine, and Angora goats), and succeeded in establishing several small dispersed rural settlements: Cloverdale, Middle Animas, Guadalupe Canyon, "Taylorville," and Walnut Wells in New Mexico, and Apache, Cottonwood, and San Bernardino in Arizona. Homestead entries, school and post office records, and oral histories document these settlements, some of which endured until the rural out-migration of the late 1940s and 1950s, by which time all of the dispersed rural settlements were abandoned. Other small towns developed along the Southern Pacific Railroad (1881) and the El Paso and Southwestern Railroad (1902) and at the short-lived mining sites of Old Hachita, Steins, Granite Gap, and Guthrie. The towns of San Simon, Rodeo, Animas, and Hachita owed their existence to a combination of farming and the railroads.

Although the earliest settlers were small-holding homesteaders, the greatest impacts were created by large, incorporated cattle companies. In 1881, the Southern Pacific Railroad completed its track across the northern boundary of the Borderlands area, facilitating large scale importation of livestock. Within months, James Parramore and Clayborne Merchant, Abilene ranchers, began acquiring natural water sources throughout the San Simon valley. They set up a headquarters for the San Simon Canal and Cattle Company on the cienega, imported thousands of head of Texas cattle (estimates run as high as 20,000 to 30,000), and distributed them to camps on their water sources throughout the valley. In 1882, a group of San Francisco based capitalists, including James Ben Ali Haggin, Lloyd Tevis, George Hearst, and Addison Head, formed the Victorio Land and Cattle Company and began acquiring large tracts of land throughout southwestern New Mexico. Haggin, principal owner of the Kern County Land and Cattle Company that held more than 450,000 acres in California's Central Valley and owner of mines in Montana and Peru, spearheaded the acquisitions in New Mexico. In California his land and water speculation had resulted in lawsuits and negative publicity. In New Mexico, Haggin made his acquisitions quietly, using land agents. By the 1890s, the Victorio controlled the Animas, Playas, and Hachita valleys, the eastern slope of the Peloncillos, the Animas, Alamo Hueco, Dog Mountains, and Big and Little Hatchet mountain ranges. The company had more than 20,000 head of cattle, with cowboys stationed at camps throughout the area. South of the two large companies, John H. Slaughter, former sheriff of Cochise County, ran a similar number of cattle on the former San Bernardino land grant, in both Arizona and Sonora. Slaughter began leasing the grant during the late 1880s and in 1891 the Court of Private Land Claims approved it. In a policy similar to that of Parramore and Merchant, Slaughter attempted to establish control of all the major water sources along the international boundary from the area of Douglas to Cloverdale.

During the cattle boom of the 1880s and 1890s, stock raisers attempted to control the open range of the public domain by controlling water sources. By 1885, all of the available natural waters in the San Simon, San Bernardino, and Animas valleys were claimed. Ranchers practiced competitive stocking, in order to prevent "outside" livestock owners from importing cattle into areas under their control. In the Borderlands area, the majority of homesteads were acquired through the Homestead Act of 1862 and the Stock Raising Homestead Act of 1916. Although the federal land laws were intended to provide small, inexpensive land-

holdings for citizens without economic resources, astute businessmen employed nefarious methods to amass large holdings, creating land tenure situations unintended by the framers of federal land programs. The use of "dummy entrymen" to acquire homesteads, well documented in California, becomes clear in the patterns of homesteads and subsequent sales, particularly in the New Mexico portions of the Borderlands region. Sale of scrip, railroad lieu lands, and state lands provided additional means for large landholdings. The pattern of land tenure in the Animas Valley contrasts with that in the San Simon. In the Animas, the Victorio persisted in its dedication to purchase of large contiguous parcels of land, while the San Simon Canal and Cattle Company was content to control large units of land through purchase of small parcels surrounding key water sources. Differing ownership patterns and management regimes may be partially responsible for the contrast in ecological condition in the two valleys.

In 1885, the first of a series of droughts began, with extreme drought years reoccurring in 1892-93 and 1902-03. During the droughts up to fifty percent of the cattle on the ranges starved to death, and range resources depleted rapidly, resulting in the acceleration of erosion, downcutting, and desertification. Social and economic factors also contributed to the drought-related ecological deterioration. These included the inefficient livestock marketing system by animal unit rather than by weight, the absence of herd reduction strategies, the failure to implement a leasing system on the public domain, and the persistent optimistic belief that droughts would not last. During the 1890s, stocking rates in both Cochise and Hidalgo counties were double present stocking rates. Prior to 1900, both livestock owners and range management specialists observed drought-induced ecological deterioration in large areas of the Borderlands.

The Peloncillo portion of the Douglas Ranger District of the Coronado National Forest is at the center of the Borderlands area. Its administration has been remarkable for the continuity of permittees leasing grazing rights on its allotments and for its comparative lack of conflict. Initially known as the Animas-Peloncillo Forest Reserve, the two mountain ranges were set aside in 1906 by President Roosevelt under the 1891 General Land Law Revision Act, which gave the president authority to create timber reserves on the public domain for the purpose of forest and watershed protection. The reserve contained approximately 320 sections in two non-contiguous divisions: the Peloncillo (approximately 88,000 acres) and the Animas (approximately 55,700 acres). After initially excluding livestock from reserves, the National Forests under the USDA developed a system of leasing grazing rights to permittees on specific allotments. The Animas-Peloncillo Reserve underwent several adjustments of administration and size. It was incorporated into the Chiricahua National Forest in 1908 and in 1916 that forest in turn became part of the Coronado National Forest. The Animas Division was removed from national forest designation, with the elimination the southern portion near the international boundary in 1910, and the privatization of the remaining 50,000 acres in 1948, in an exchange for degraded private forestland in New Mexico deemed more important for watershed protection than the Animas Division.

During its 93-year existence, management of the Peloncillo District has reflected the changing concepts of range management adopted by Forest Service personnel. Each year, the forest ranger estimated grazing capacity and set maximum and minimum stocking limits (for cattle, horses, sheep, hogs or goats) for individual permittees and for the district as a whole. In 1913, for example, the limit for the Peloncillo was set at 1900 cattle and horses, and the Animas at 1400 cattle and 150 swine. Initially, most of the land in both the Animas and Peloncillo

divisions was leased in communal allotments, with livestock belonging to several owners grazing on the same allotment. From the 1920s to the 1940s, the Peloncillo division contained approximately 13 allotments. After World War II, these allotments were sub-divided into 20 separate fenced units, and communal allotments were discontinued. Seven of the 10 allotments in the Animas Division were leased by the Victorio Land and Cattle Company, which purchased them after the privatization of the Animas Division in 1948. From 1906 through the 1970s, management history of the Animas-Peloncillo District is characterized by a pattern of reduction in stocking rates, initiation of scientific management, and implementation of range improvements, particularly the construction of new livestock waters in order to spread livestock into "underutilized" portions of the forest.

After 1906, the Forest Homestead Act provided for the removal of arable land from forest reserves, in homesteads of up to 40 acres. In 1921 provisions of the Enlarged Homestead Act were extended to the Forest Homestead Act, increasing the amount of acreage that could be homesteaded. The majority of the 16 homesteads approved in the Peloncillo Division were filed during the 1920s. All of the homesteads established were on riparian areas. Although the object of the law was to encourage farming, homesteaders under the Forest Homestead Act were entitled to Class A grazing permits, and the majority of the forest homesteaders in the Peloncillos became stockraisers and abandoned farming. Throughout the Peloncillos, forest homesteads were used as base land for National Forest grazing permits.

A secondary impact of the livestock industry was the deliberate extirpation of target wildlife populations. Beginning in the 1890s, individual ranchers and livestock associations paid bounties for wolf, lion, and coyote scalps. In 1893, territorial bounty acts were passed. During the early 1900s, the Biological Survey began its predator control programs. In 1914, the Biological Survey began stationing trappers along predator migration routes in the Animas and San Simon valleys. After the 1916 creation of Predator and Rodent Control (PARC) in the Biological Survey, trappers killed several dozen wolves annually. By 1926, wolf populations had declined and trappers redirected their efforts to coyotes.

PARC also conducted rodent control programs, designed to eliminate competition for forage. Agents extirpated entire colonies of pocket gophers and black-tailed prairie dogs, and organized community jackrabbit drives in which local "co-operators" herded rabbits into wire mesh pens where they were clubbed. During the 1930s, Depression era work programs expanded the manpower for predator and rodent control. In the Animas Valley alone, 377,000 acres of land was treated with 33,085 pounds of poisoned grain to eliminate rodents. From the 1940s until 1972, PARC (as a division of Fish and Wildlife) controlled coyotes with the predicide Compound 1080, an indiscriminate method that caused secondary deaths of many other species. As early as the 1890s, observers in New Mexico noted a distinct decrease in predators and other types of wildlife. By the 1940s, private trappers and hunters began to express opposition to federal and state predator control programs and during the 1950s, the New Mexico Game Protective Association began reporting incidental kills and the Varmint Callers Association stated formal opposition to government control programs. During the past three decades, wildlife management in the area has focused on maintenance and preservation, with reintroductions of Bighorn sheep and Pronghorn antelope.

Human population in Borderlands area peaked during the three decades between 1890 and 1920. It was during this period that the most significant ecological impacts occurred. From the 1920s through the 1990s, settlement has declined, with the exception of the new smelter town at Playas, New Mexico. In recent

years, ecological tourism and retirement have increased in economic importance, resulting in a slight reversal of the population decline. Throughout the Borderlands area, livestock raising has remained the most significant extractive economic activity, with farming second in importance, while mining was attempted in several locations without lasting success.

During the late 1960s and early 1970s, a number of scientific studies focused on the Peloncillo District of the Coronado National Forest, with the result that knowledge of the exceptional biodiversity and endemism of the Borderlands region was widely dispersed. Since that time, Forest Service management of the district has increasingly focused on protection of biodiversity. After the 1990 formation of the Malpai Borderlands Group, a non-profit organization dedicated to preserving rangeland health and preventing landscape fragmentation, ranchers and non-ranching residents of the Borderlands region have cooperated on creative management programs that have made them leaders in conservation ranching.

Fire History in Canyon Pine-Oak Forests, Intervening Desert Grasslands, and Higher-Elevation Mixed-Conifer Forests of the Southwest Borderlands

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Tree-ring, historical, and anthropological evidence provide an interdisciplinary understanding of past fires in the Southwestern Borderlands (Kaib 1988). Crossdated fire-scarred pine samples were used to reconstruct fire history in canyon pine-oak forests, adjacent desert grasslands, and higher-elevation mixed-conifer forests (Fig. 1; See Baisan and Swetnam 1995; Danzer et al. 1996; Dieterich 1983; Kaib et al. 1996; Seklecki et al. 1996; Swetnam et al. 1989, 1992; Swetnam and Baisan 1996a, 1996b). Six canyon-forest sites were selected for evidence of low-elevation fire-scarred pines and intercanyon connectivity via lower grassland communities (Kaib 1998). Grassland fire regimes were inferred from synchronous fire events recorded between canyons by multiple trees. These were fires that in all likelihood spread between the lower canyons through the intervening grasslands. Pine-oak forest and desert grassland fire reconstructions were analyzed statistically and compared with those of nearby mixed-conifer forests. During 230 years (1650 to 1880), mean fire intervals (MFIs) recorded by at least 10-25% of the sampled trees ranged between 4-8, 3-7, and 4-9 years respectively for the desert grasslands, canyon pine-oak forests, and the mixed-conifer forests.

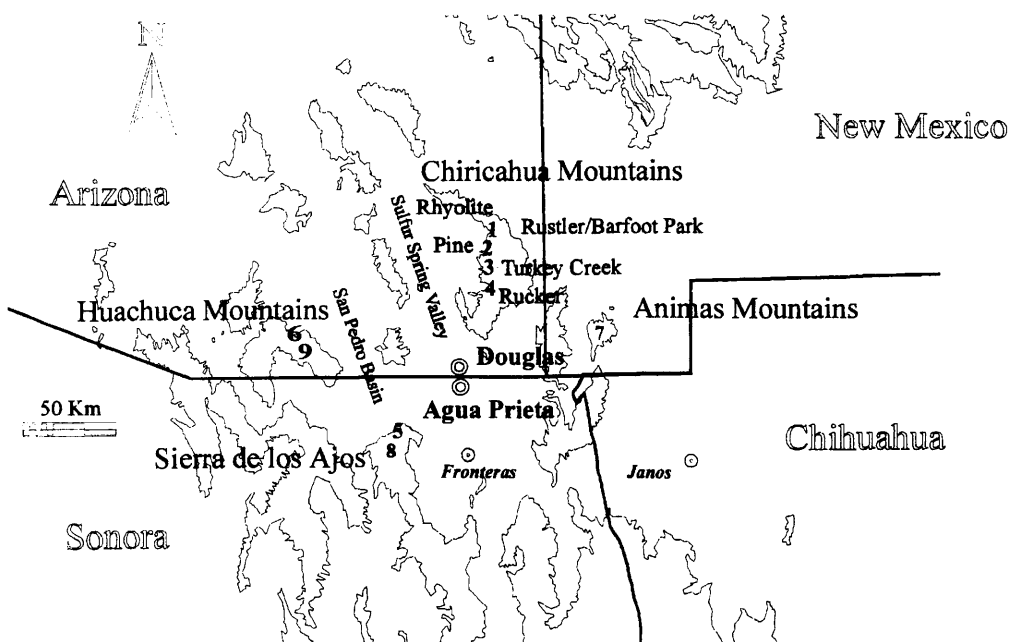


Figure 1. Fire reconstruction sites in the Southwest Borderlands. Canyon pine-oak forest sites include Rhyolite (1), Pine (2), Turkey Creek (3), Rucker (4), Canon del Oso (5), and McClure Canyons (6). Mountain ranges that have fire history collections in mixed-conifer forests include the Animas (7), Sierra Ajos (8), and Huachuca mountains (9).

Fire history analyses were cut at 1880, due to the dramatic shift in the fire ecology following this time period (Fig. 2). American colonization of the Southwestern United States began with the settlement of the Apache on reservations (1870s), and the completion of the transcontinental railroads (1880s). Livestock ranches, sawmills, mines, and fuelwood cutting operations spread across this new U.S. territory, leaving in places profound environmental changes (Bahre 1991, 1995; Bahre and Shelton 1993, 1996; Wagoner 1952). Arroyo and stream systems were incised, extensive sheet erosion occurred, and associated vegetation changes were later documented (Bahre and Bradbury 1978; Humphrey 1987; Leopold 1951; Meinzer et al. 1913). More than 50 fire history studies throughout the Southwestern United States show the end of widespread fires occurred in close association with this period of settlement (Swetnam and Baisan 1996a; 1996b). The scarcity of fire scars after the 1870s or 1880s resulted from the influence of intensive land-uses, typically livestock production, that fragmented the landscape and reduced the ability of surface fires to spread over large areas (See Fig. 2; Baisan and Swetnam 1990; Leopold 1924; Savage and Swetnam 1990; Swetnam and Baisan 1996a). Improved fire suppression further maintained this ecological pattern beginning in the early decades of the 1900s (Fig. 2; Cooper 1960; Swetnam and Baisan 1996a; Pyne 1982; Weaver 1951). Remarkably, this characteristic pattern was not encountered in fire reconstructions from northern Mexico (Fig. 3; Kaib 1998; Swetnam and Baisan 1996b; Minnich 1983), where widespread fires have continued uninterrupted into the 20th century (Fule 1996, 1998; Marshall 1962; Swetnam et al. In Press).

Oral and written records suggest that Mexican forests evolved under very different land-use histories than related forests in the Southwestern United States (Gingrich 1993; Marshall 1957; Sheridan 1988). Tree-ring reconstructions also show that some fire-regime changes in Mexico coincided with land tenure and agricultural reforms in the 1940s and 50s (Fule 1997; Kaib 1998). National and

Sites, n = tree-ring samples

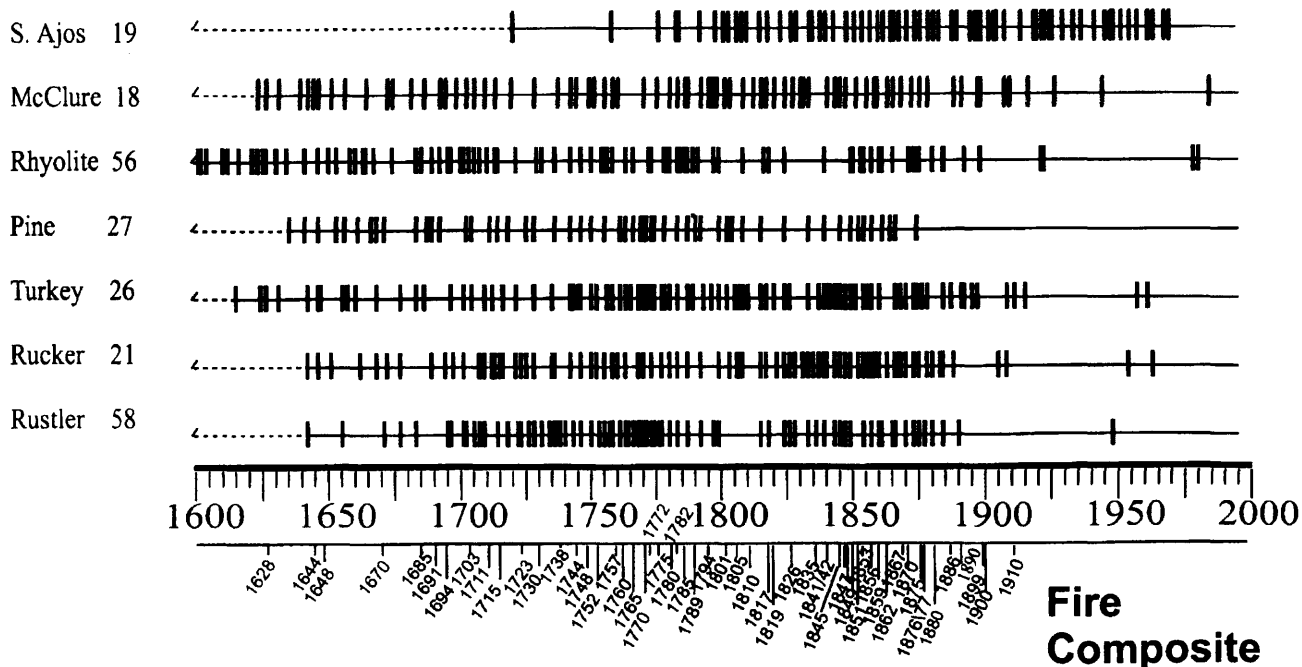


Figure 2. Master fire chronologies for 7 fire history sites in the Southwest Borderlands. The fire composite lists fires recorded by 3 or more sites.

private logging ventures in northern Mexico have in recent decades entered the last remaining stands of uncut pine-oak forests (Gingrich 1993; Lammertink et al. 1996). In these areas fires have continued to be a landscape and ecosystem structuring process recorded frequently by the pines (See Fig. 3). Furthermore, fire regimes in these areas have continued unchanged for more than a century after fires had been suppressed in Southwestern U.S. forests, and following Apache settlement on U.S. reservations. Interviews with nearby ranchers and at *ejidos*, with communal land owners, indicate that fires have continued in these Mexican forests primarily from lightning ignitions and due to limited fire suppression (Kaib 1998). Although human ignitions did occur, these interviews suggest that human-caused fires have been generally discouraged due to the perceived detrimental effects to pasture and grasslands.

Comparative analysis of fire histories show that some forests in Mexico are structurally and biologically less-disturbed than related forests in the Southwestern United States (Escobedo-Montoya 1998; Marshal 1957; 1962). In the 1930s, Aldo Leopold wrote of the unaltered nature of Mexican forests and the visible differences between Mexican and American forests (Leopold 1937). It was these differences that inspired Leopold's land ethics and which later provided a foundation for U.S. wilderness management. Unfortunately, most of the forests Leopold visited have now been cut over, and the few that remain are now severely threatened (Lammertink et al. 1996). Mexican forests have contributed to a better understanding of land-use history and forest ecology throughout the Borderlands, and they still may provide unique research and conservation opportunities.

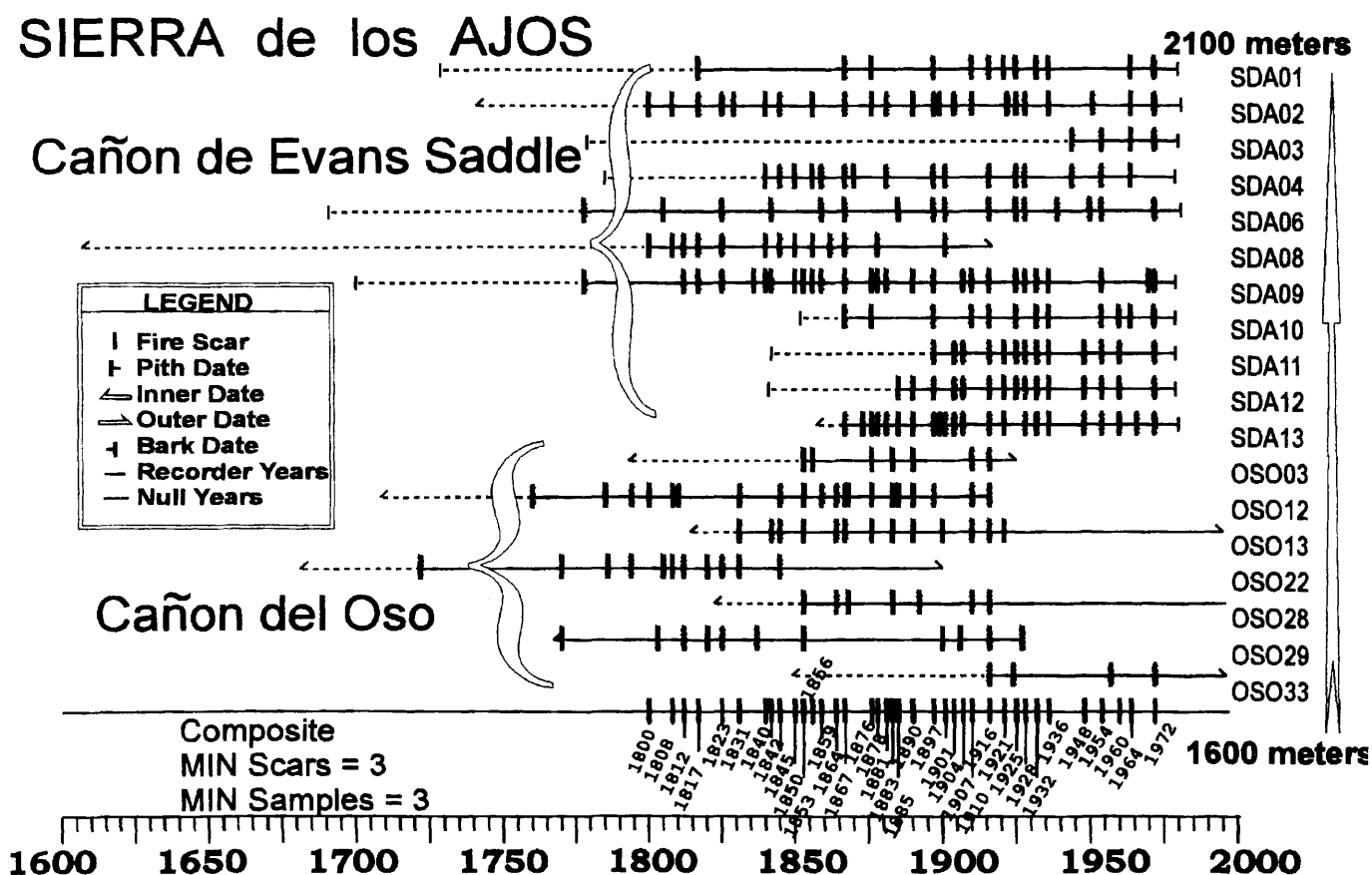


Figure 3. Fire history reconstruction for the Canon del Oso and Saddle Sites, in the northern Sierra de los Ajos. Horizontal lines represent individual fire-scarred pine specimens and vertical hatch marks are dated fire events. The fire composite includes all fires recorded by three or more trees.

Controversy has surrounded the relative importance of natural (i.e., lightning, earthquakes, volcanoes) versus anthropogenic fire influences upon past fire regimes (Barrett and Arno 1982; Pyne 1982). The Southwestern Borderlands has extremely high lightning activity associated with the development of summer-monsoon storms (Barrows 1978; Gosz et al. 1994; Sellers and Hill 1974). Lightning detection and U.S. Forest Service records show that lightning-ignited fires have commonly originated across the landscape in both grasslands and higher-elevation pine forests (Krider et al. 1980). In the past, humans also contributed to fire ignitions and particularly near cultural centers and during periods of occupation (Fish 1996; Lewis 1973, 1983). Ecological evidence indicates that widespread fires were not limited completely by ignition sources (McGlaughlin and Bowers 1982; Swetnam and Betancourt 1998). Of greater importance were wet periods and related growth in cover and abundance of grasses and forbs (i.e., fine fuels). Climate and fire reconstructions have shown that when robust fuel conditions were followed by droughts, fires were able to spread across the vegetation gradient, from the grasslands, through canyon pine-oak forests, to mixed-conifer forests (Kaib 1998; Swetnam 1990; Swetnam and Betancourt 1990; Swetnam et al. In Press). Fire-scar chronologies suggest that MFIs were similar across this vegetation gradient. It is probable that relative to the intense lightning activity in this region, a small number of ignitions (i.e., lightning or human) could have burned off extensive areas of interconnected grassland and forest landscapes during these climate influenced fire years. Historical records also characterize these types of widespread fires (Bahre 1991). Fires were also strongly influenced by geographical variation of habitat and fuels, and associated finer-scale patterns. Tree-ring records indicate extensive fires occurred regionally about every 7 to 10 years, while finer-scale fire patterns probably occurred within the lower ends of the ranges of the MFIs listed above for specific vegetation types.

At many of our canyon fire history sites, the Chiricahua Apache encamped in *rancherías* incidentally over several centuries (Castetter and Opler 1936; Sweeney 1991). Periods of elevated fire frequency at some canyon-forest sites may have been influenced by cultural-burning practices (Kaib 1998). Although documentary sources and anthropological evidence reveal that the Apache had a comprehensive understanding of the fire environment, burning practices to improve forest or grassland resources were not recorded. An exception could be the little known wild-game drives; however, no burning practices compare in area extent to the recorded fire uses associated with raiding and warfare. Ethnohistorical records indicate wartime burning practices were commonly used by the Apache. A collection of documents recording historical fires (N=131) show that almost 80% were associated with wartime periods. Additionally, 78% of these wartime period records were related to fires set by the Apache. Also, fires were used in warfare to some extent by the Spanish (8%), Mexicans (3%), and later Americans (11%). Furthermore, written accounts indicate that the Apache were often blamed for visible but distant fires and smokes, regardless of any real evidence. This common historical bias may have unjustly inflated past estimates of the overall fire uses by the Apache and other southwestern Native Americans. Multiple lines of evidence suggest that Native American and Apache burning practices in this region appear to have been very specialized (i.e., requiring special skills, technology, and resources), and temporally and spatially limited, except in raiding and warfare environments. The high risks associated with burning practices and wildfires included detrimental fire influences to the majority of important ethnobotanical resources, and threats to people and lodgings, also suggests limited burning was conducted in the past.

Fire-scar chronologies were statistically analyzed for fire-frequency differences between historical Apache wartime and peacetime periods. The Student's t-test was used to test differences in mean fire intervals between wartime periods: (1680-1710, 1748-1790, 1831-1886), and the intervening peacetime periods (1711-1747, 1791-1830). For the later wartime period, 5 out of 8 sites tested had significantly more fires than the intervening peacetime periods ($p \leq .10$). These sites include Rhyolite, Turkey Creek, and Rucker canyons in the western Chiricahua Mountains, and the Sierra Ajos and Animas ranges. However, in analyzing fire reconstructions across the vegetation gradient and among the regions' fire history sites, anthropogenic warfare fire patterns are only evident for some wartime periods at a small minority of sites. These multiple lines of evidence suggest that wartime-period burning practices may have possibly influenced ecosystem structure in some canyon pine-oak forests likely near lower-canyon grassland ecotones. Historical records suggest that long-term drought and climate patterns are related to the ecology of raiding and wartime periods patterns (John 1975; John and Wheat 1978; Naylor and Polzer 1986; Spicer 1962), and hence possibly wartime fire. The influence of long-term climate variation on anthropogenic fire patterns have not been investigated by these studies.

Consider the application of these findings to watershed and forest management in the Borderlands. Forest and ecosystem management plans should ultimately attempt to return surface fires to at least decadal intervals, in the areas deemed most appropriate for such management. Obviously, some areas are more appropriate than others for the reintroduction of fire, depending on the resource values and management goals. In the forests and grasslands deemed appropriate (i.e., Wilderness and Primitive Areas), fire plans should eventually include broader landscape- and watershed-scale fires (i.e., $> 10 \text{ km}^2$) that are allowed to spread across the vegetation gradient among multiple habitats, ecosystems, and vegetation communities. If such fires were planned or allowed to occur at about 5-10 year cycles, tree-ring evidence suggests that this would approximate the historical variability of past fire regimes.

This interdisciplinary investigation was based primarily on the work by Kaib (1998) in an attempt to further refine our understanding of the dynamic relations of fires, climate, and humans in pre-settlement ecosystems. We would like to cordially thank the folks at the Rocky Mountain Research Station; the Coronado National Forest; the Mexican Secretary for the Environment, Natural Resources, and Fisheries in Hermosillo; the Fort Huachuca Military Reserve; and the Animas Foundation, for their gracious financial and logistical support.

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An Archaeological Research Design for the Malpais Borderlands, Southeast Arizona and Southwest New Mexico

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As part of ongoing, collaborative investigations, the Rocky Mountain Research Station and the Coronado National Forest contracted with the Arizona State Museum in 1995 to produce an overview of Malpais Borderlands archaeology. Four objectives were defined for this overview. First, the existing archaeological site information for the Malpais study area was assembled and organized. Second, a synthesis of study area culture, history, and ecology was developed in order to place local cultural developments in a regional context and to serve as an annotated bibliography to facilitate future investigations. Third, a model of prehistoric human impacts from the particular perspective of fire ecology was constructed in order to frame questions for future archaeological research; a summary of this model was published by Suzanne Fish (1996). Finally, a series of recommendations and stages of investigation were identified to direct future archaeological research by the Malpais Borderlands Research Group. The overview was submitted to the Rocky Mountain Research Station in 1997 and now awaits publication (P. Fish et al. 1997).

Borderlands Archaeological Context

The archaeological manifestations of the Malpais borderlands study area are intermediate between the homelands of several better-defined and relatively well-studied archaeological cultures. To the northwest, the Hohokam represent a persistent cultural expression throughout ceramic times. To the north and northeast, before A.D. 1200, the Mimbres culture created dominant ceramic styles. Thereafter, archaeological cultures in a broadly Mogollon tradition are represented by Salado and Casas Grandes spheres, to the north and south respectively.

Due to a location between some of the more dramatic developments in Southwest prehistory, the Malpais Borderlands have played a key role in regional synthesis and the development of interpretive constructs about frontiers (De Atley 1980), interaction spheres (Douglas 1995; P. Fish and S. Fish 1999), political dominance (Wilcox 1995; Di Peso 1974), and short-term sedentism with cycles of abandonment and migration (Nelson and Anyon 1996; Nelson and LeBlanc 1986). These regional models and related constructs necessarily incorporate fragmentary data from the Borderlands and reflect perspectives on better understood cultural systems in other regional sectors.

Local typological, chronological, and cultural sequences are poorly developed for the Malpais Borderlands. Instead, archaeologists typically have projected established schemes from adjacent cultures. Borderlands research invariably has been designed to address Casas Grandes, Mimbres, or Salado issues, and there has never

been a sustained, intensive investigative focus on locally generated problems. Because the study area has not had significant pressures from urban or agricultural developments with direct federal and state involvement, cultural resource management investigations have been limited to a few surveys. High quality, large-scale excavation programs have not been undertaken.

A Recommended Design for Future Archaeological Research in the Malpais Borderlands

Phase 1 - Spanish and Mexican Archival Study

This initial phase of recommended research has been largely completed. Thomas Sheridan and Diana Hadley reviewed original Spanish and Mexican archives for ecological and culture history information pertinent to the Malpais Borderlands. Colonial and Mexican Period archives are believed to contain information regarding phenomena such as drought, flooding, human use of fire, Apache landuse, and early ranching and farming activities. Sheridan and Hadley's complete report will be published in the near future.

Phase 2 - Malpais Borderlands Conference/Workshop

The second phase of preliminary research has also been completed and is the subject of this volume. A short conference (2-3 days) has been called to acquaint all parties conducting research in the Malpais Borderlands with the work of others. Various natural and social scientists are conducting investigations in conjunction with the Gray Ranch and governmental agencies or have independent research interests. Borderlands investigations of interest to archaeologists include dendrochronological studies, palynology, a wide range of studies of the existing environment, packrat midden analyses, and the Gray Ranch mapping project.

Phase 3 - Survey of Existing Artifact and Field Record Collections

- a. An initial stage should consist of a concentrated effort to obtain valuable knowledge about the study area residing in the collections and recollections of amateurs. Extensive Arizona experience suggests that this effort is particularly crucial for compiling information on Paleoindian through Middle Archaic as well as historic time periods. A reference collection and graphics could be used to aid the recollection and identification of stylistically diagnostic artifacts. Amateurs could provide locations of features such as small springs and caves, in addition to sites. Field visits in the company of amateurs will be an important part of this phase. In this regard, the systematic and accurately located collections by Jeff Shauger of the Gray Ranch are particularly important and comprehensive.
- b. A systematic review of existing Museum collections from excavated archaeological sites in and near the Borderlands study area should be a secondary thrust of Phase 3 investigations. It is likely that Museum of New Mexico and School for American Research collections from McCluney's (1965a,b) and Lambert and Ambler's (1961) excavations, and Harvard's Peabody Museum collections from Kidder and others (1949), will contain material valuable for dating and ecological study. It is also possible that there are collections at the Maxwell Museum and Museum of New Mexico that are

poorly documented in the literature, such as materials from the University of New Mexico's expedition to the Culberson Ruin in the 1930's (Osborne and Hayes 1938)

Phase 4 - Tree Ring Studies Pertaining to Archaeology

Detailed recommendations from both the Fire Ecology and Archaeology Sections at the University of Arizona Tree Ring Laboratory were presented as appendices to the overview manuscript (Dean 1997; Baisan et al. 1997). Specific projects include: 1) re-sample tree-ring sites in the Pinaleno Mountains where the longest chronology for this region was recently developed; 2) extend chronologies that are currently limited to the mid-fifteenth century from the Animas Mountains and Sierra Ajos Mountains; and 3) conduct an in-depth search of archival and historical documents that would augment ecological models proposed from tree ring studies. These investigations will greatly enhance our understanding of regional prehistory through effective integration of archaeological information and paleo-ecological data. Since modest costs are anticipated, we recommend giving these studies very high priority. They should be undertaken prior to archaeological field studies beyond the reconnaissance level.

Phase 5 - Geoarchaeological Assessment

A geoarchaeologist should be employed to delineate geomorphic surfaces of relatively uniform age and to identify processes that are likely to obscure surface indications. In cases of recognized burial, depths to materials of particular age should be approximated. The geoarchaeologist would also construct a geological perspective on environmental history in order to evaluate settlement trends and their effects on the environment. Likely locations to obtain environmental sequences such as packrat middens and pollen cores should be identified. A hydrological assessment should include agricultural potential of drainages and the age of spring locations.

Phase 6 - Reconnaissance Survey

A reconnaissance level survey should be designed to obtain particular types of landuse and cultural information. Existing aerial photographs for the Borderlands study area should be assembled and examined for their potential in revealing information on prehistoric landuse, particularly modifications to the landscape resulting from past agriculture. Major village sites should be revisited with an eye toward identifying additional ballcourts.

Phase 7 - Systematic Survey

A broadscale, systematic survey should be conducted, based on prior stratification of the study area, according to naturally and culturally relevant variables. Preliminary observation of settlement pattern suggests that concentrated ceramic era settlements on basin floors and mountain flanks should be subjected to large block or full-coverage examination. Mid-basin and upper elevation areas might be tied into these blocks through survey transects.

In order to efficiently sample preceramic and other less sedentary occupations including many of the historic period, survey blocks and transects may be designed around springs, playas and their associated high stand lakes, and other attractive features on the landscape. All exposed drainage profiles should be carefully examined, in addition to surface observations. In view of hierarchical tendencies in the late ceramic settlement patterns, block surveys should also be designed

around large sites in areas of dense settlement and around focal villages containing ballcourts.

Phase 8 - Studies in Holocene Environmental Change

Packrat midden studies

Packrat midden studies should be undertaken within the study area. Pollen and plant macrofossil studies of packrat middens have shown these deposits to be highly sensitive barometers of local environment. Reconnaissance during the present study confirms that numerous, well-preserved middens exist in grassland and higher elevation environments at a variety of locations in the study area. Current regional packrat studies are from higher elevation woodland environments, rather than valley floors. Middens located in present-day grasslands should be particularly valuable in testing previous models of post-Pleistocene invasions of shrubby plants into these lower elevation zones (Van Devender 1990).

Palynology

Pollen profiles at the Gray Ranch cienega and at cienegas adjacent to the study area (Davis 1997) could be expanded to include other cienega or spring sequences. Replication of sequences will provide insights into both changing climate and prehistoric human practices involving water and vegetation near the cienegas.

Both the palynological and packrat midden studies must be accompanied by large numbers of radiocarbon dates for chronological control. These dates, combined with specialized botanical studies, make such investigations expensive. Therefore, this research should follow the geoarchaeological assessments and the archaeological surveys, during which deposits for sampling can be identified. It may also be possible to better relate this environmental research to locations selected for detailed archaeological study as a later phase of investigation.

Phase 9 - Problem-oriented Excavations

Data for solving particular problems pertaining to chronology, subsistence and human-induced environmental change ultimately must come from excavation of archaeological deposits.

Geomorphological studies related to hydrology

Such studies include focused trenching to retrieve the environmental and culture histories of cienegas, streams, and playas. Near cienegas, geological histories, and terrestrial sequences of botanical samples to match core records could be obtained; trenches might also reveal damming or ditching for agricultural purposes. History and stratigraphy could also be explored in this manner for playas, important long-term resource zones in regional prehistory. The history of Borderland drainages is also an important element in understanding irrigation and floodwater farming.

Extractive sites

Survey and excavation can be designed to characterize hunting and gathering locations through time. Detailed study will be needed to pinpoint the date of use, duration of use, and resources obtained. Densities of extractive sites by zones such as grassland, high elevation forest, and playa margins provide evidence for magnitudes of resource use and human presence.

Agricultural sites

Study of these sites will include intensive survey and mapping to understand agricultural technology and productivity, dates of use, associated tool assemblages, and field layout, including the location of ancillary facilities such as canals, ditches,

roasting pits, and field houses. Excavations should target both constructed features and field sediments in order to retrieve botanical samples for reconstructing crop variety, weedy flora, and evidence for specific practices such as burning.

Residential sites

Excavations at residential sites can be designed to recover dendrochronological specimens for dating and climatic reconstruction. Modern analog studies will be necessary to support this program. Additionally, construction timber identifications will indicate source and intensity of such wood use. Most Borderlands settlements fall in lower elevations that do not contain tree species suitable for tree ring dating but are adjacent to higher mountain zones where such tree forms exist. Recent research in other desert locations such as the Tucson Basin (Dean et al. 1996) and Casas Grandes (Dean and Ravesloot 1993) demonstrate the importance of timbers of high elevation species such as ponderosa pine and Douglas and white fir in the construction of adobe buildings. Regular procurement of these species in construction suggests currently untapped potential for dendrochronological study in many desert locations, including the Borderlands.

Flotation and pollen samples are needed to indicate subsistence mixes of wild and later cultivated resources and the zonal emphasis and intensity of plant exploitation. These studies should also inform on natural environment, environmental change, and specifically human modifications of the environment. Weedy and succession floras are particularly relevant in these regards. Charcoal from fuel use is another way to monitor wood consumption and such issues as source areas and depletion.

Systematically recovered faunal samples are also critical to an evaluation of the zonal sources and relative mixes of animal resources. These studies may also inform on environmental change and resource pressures, as in the changes in lagomorph (jackrabbit, cottontail) species and reduction of artiodactyls (deer, antelope, etc.) during extended occupations. Hunting patterns may be one of the better ways to monitor resource acquisition at a distance from residential sites, particularly at higher elevations.

Settlement pattern studies

Settlement pattern studies are the means for integrating all of the foregoing kinds of data. Occupational densities and relationships between site locations and resources are needed to evaluate human impacts through time. In particular, it is important to assess the contemporaneity and degree of relatedness of sites in areas of clustered settlement in order to assess population size and environmental pressures. It is important, therefore, to investigate hierarchical relationships among sites and evidence for territorial integration. Based on detailed settlement pattern studies, including all of the foregoing site level information, simulations can be made of landuse patterns, resource consumption, and environmental impacts for various periods of study area prehistory.

Recommendations for priority excavation

1. Caves or rockshelters with high potential for long sequences or chronologically critical intervals should be targeted. There is a need for information from stratified deposits for all segments of the prehistoric sequence, and these can be acquired as efficiently in few other ways. Existing information from cave localities was not acquired using rigorous techniques and biological and chronological information was not previously emphasized.
2. Early villages are virtually unknown from Borderlands investigations. Sites beginning with villages of Late Archaic farmers, if located, and a variety of

pre-Casas Grandes settlements in both the eastern and western sectors should be tested before selections are made for more detailed excavation.

3. Later ceramic settlements with compound architecture in the western study area should be emphasized. These sites have been neglected more than those with closer stylistic ties to Casas Grandes. At present, it is difficult to predict architectural layout or even to roughly estimate room numbers. Initial efforts should emphasize efficient outlining of walls as well as intensive excavations.
4. Locations of consistent, long-term attraction should be targeted to convincingly monitor environmental impacts. Holding location constant, biological materials from sequential occupations would offer insights into changing magnitudes and kinds of modification. At Slaughter Ranch, for instance, Archaic, early ceramic, and late ceramic occupations could be contrasted with the historic Colonial and territorial archaeology of the locale. Evidence for farming technologies during each of these intervals could be examined concurrently. Consequences of the transition from prehistoric to early historic landuse would be of particular interest. In the eastern portion of the study area, another locale with chronologically varied prehistoric occupation might be in the vicinity of the cienega at Maddox Ranch.

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The Changing Mile Revisited

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The photographic documentation of vegetation change upon which The Changing Mile (Hastings and Turner 1965) was based involved roughly 300 before-and-after photographic pairs taken in the southern Arizona-northern Sonora region. Only about one-third of the photographs were published in the original work, while the remaining two-thirds, a rich source of additional information, was largely ignored.

In our current program to revise The Changing Mile, we have taken advantage of the total photograph assemblage and have revisited and rephotographed all 300 sites. Evaluation of biomass changes at the sites of the original 97 pairs of published photographs has involved a special visit to each site in order to observe conditions in the field and note change in the dominant plants. For the remaining 200 sites, changes through time are being judged by comparison of the three "time-lapse" photographs for each site. At a few of the stations, quantitative data have been gathered as an aid to explain the changes. Our analysis recognized three time periods against which to compare change: I (1883-1916), II (1959-1962), and III (1985-1998).

Photogrammetric analysis of the changes is still in progress but sampling of the incomplete data shows some definite trends to the present. Data are given for velvet mesquite (*Prosopis velutina*), ocotillo (*Fouquieria splendens*), foothill paloverde (*Cercidium microphyllum*), Engelmann prickly pear cactus (*Opuntia engelmannii*), saguaro (*Carnegiea gigantea*), and others. In addition to Turner, others actively involved in the study are Janice Bowers, Dominic Oldershaw, and Robert Webb.

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Recent Environmental Change in the Malpai Borderlands

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Twenty-one years of ecological experimentation and monitoring at my study site near Portal provide interesting perspectives on long-term ecological dynamics. We have found the following:

1. The climate has changed. Winter precipitation has been significantly greater than the century-long average.
2. The vegetation has changed. Woody shrubs with C3 photosynthesis have increased several fold, and there has been a corresponding decrease in grasses with C4 photosynthesis.
3. Species composition of small mammals has changed dramatically. Previously dominant species have gone locally extinct, while previously unrecorded species have colonized.
4. Total abundance, biomass, energy use, and species diversity have remained virtually constant.

These observations provide valuable insights into the role of compensatory population dynamics, including colonization and extinction processes, in maintaining relative constant species diversity and ecosystem processes in the face of substantial environmental change. They also suggest that it will often be difficult to predict ecological consequences of environmental change for purposes of management and policy.

Fire Management in the Borderlands: The Peloncillo Programmatic Fire Plan

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Among concerns that brought the Malpai Borderlands Group together was a common observation that the exclusion of fire was bringing about undesirable ecological changes, and a conviction that high expenditures for aggressive suppression were not justified. All species and biotic communities of the area had developed in a regime of frequent wildfires, but introduction of significant numbers of livestock in the late 1800's resulted in modification of ground fuels to the point that fire spread was inhibited. As ranchers and land management agencies brought livestock numbers under control and range management improved, the agencies developed an ability and desire to suppress most wildfires. The result of this combination of factors was near total exclusion of fire as an ecological factor in the Peloncillo Mountains for almost 100 years (Kaib, 1998).

In 1984 an area in the San Bernardino Valley was treated with herbicides to control undesirable shrubs. After about 5 years of moderate grazing the area was covered with a mix of shrubs and native grasses. A wind-driven wildfire in early summer 1989 had the potential to reverse the trend toward reoccupation of the site with desert shrubs. Over the objections of the grazing permittee and many neighbors, the Arizona State Land Department decided to suppress the fire and requested assistance from the Forest Service. Although the fire was completely beneficial and surrounded by a sea of creosote, with no potential for escape, significant resources were expended to bring it under control. This incident was the catalyst that brought ranchers and environmentalists together to request changes in suppression policies from all fire management agencies. As a result of influence from the emerging Malpai Borderlands Group, limited suppression was undertaken when the same area burned in 1992 and again in 1994.

Regional Fire Planning

Fire planning is currently underway for the entire Borderlands area, with several agencies cooperating in places. The New Mexico side of the planning area is included in the *Boothel Fire Management Plan*, approved in 1997 by New Mexico State Forestry Department and the Las Cruces District of BLM. Planning for the San Bernardino Valley is currently being conducted by Natural Resources Conservation Service and Arizona State Land Department. Planning for federal lands within the Malpai Area is being done under Forest Service leadership.

The Peloncillo Programmatic Plan

All Coronado National Forest Lands, Safford District BLM Lands, and a portion of Las Cruces BLM Lands in the Southern Peloncillo Mountains are included in a planning area of approximately 120,000 acres. This lumping of all federal

lands into one planning area will allow many environmental concerns to be addressed at a programmatic level. This is expected to simplify future decisions concerning management of wildfires, fire suppression, and the use of prescribed fire.

An interagency, interdisciplinary team has been working on the Peloncillo Programmatic Plan since April of 1997. After the team identified issues of concern, a proposed action was subjected to public scoping. Fifty-four individuals and organizations were asked to comment on a scoping report. This resulted in identification of several new issues and the development of four alternatives:

- A. No change from present direction.
- B. A combination of wildfire with resource benefits, prescribed fire, and appropriate suppression.
- C. A combination of prescribed fire and appropriate suppression.
- D. An alternative developed by Hidalgo County, New Mexico, which is similar to Alternative B, but with a greater emphasis on cooperation with local landowners and governments.

The interdisciplinary team identified 91 wildlife and plant species of concern for further evaluation. Eight of these species are federally listed as endangered, three are threatened, and one is a federal candidate species. If it is determined that the proposed fire policy is likely to adversely affect any of the federally listed or candidate species, then formal consultation with US Fish and Wildlife Service (as prescribed by Section 7 of the Endangered Species Act) will be required. Biologists from the Forest Service, Arizona Department of Game and Fish, New Mexico Department of Game and Fish, and U.S. Fish and Wildlife Service are currently evaluating potential impacts on species of concern.

This interdisciplinary process revealed certain data gaps and a survey for Mexican spotted owls, along with habitat studies for the New Mexico ridgenosed rattlesnake, are currently underway. Upon receipt of these data the Forest Service will initiate consultation as required.

Five key issues for analysis have been identified:

- 1. Role of fire in the ecosystem
- 2. Effects of fire on native wildlife and plants
- 3. Effects of fire on air and water quality of the region
- 4. Effects of fire on economic, cultural and social stability of the local community
- 5. Preservation of the unfragmented, open space nature of the landscape

Environmental Analysis Report

An analysis of impacts of the listed alternatives on each key issue will be documented in an Environmental Analysis Report, and needed changes in fire management policies will be recommended to the Coronado National Forest and the two BLM Districts. It is currently anticipated that this report will be completed by summer of 1999.

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Fire Frequency and Spatial Variability of Soil Biogeochemistry and Plant Biochemistry in a Southeastern Arizona Desert Grassland

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Throughout the southwestern United States, vegetation in what historically was desert grassland has changed to a savanna of trees and shrubs with scattered perennial grasses. Knowledge of the rate and spatial distribution of the encroachment process could improve management techniques of the grasslands environment. Management strategies may be thwarted by changes in the distribution and availability of soil nutrients (Schlesinger et al., 1990), which are strongly affected by fire (Wright and Bailey, 1980). Fire has been commonly suggested as a management tool for suppression of *Prosopis velutina* (velvet mesquite) and some other shrubs in the desert grassland, and repetitive burning is beneficial if suppression of mesquite and restoration of grasslands is the management objective (Robinett, 1994). Mesquite is tolerant of fire, but recurring fires keep them small in stature, inhibit seed production, and destroy mesquite seeds at the surface while not affecting the subsurface seed bank (Cox et al., 1993). These seeds may germinate in the years following the fire. The presence of mesquite alters soils in many ways (Virginia and Jarrell, 1983) and affects establishment and growth of other species, particularly grasses (Bush and van Auken, 1991). In addition to retarding establishment and growth of trees and shrubs, frequent fires presumably would deplete soil nutrients by volatilization and erosion, but little is known of the effect of fire frequency on nutrient cycling in desert grasslands. Nutrient availability to plants is determined by the ability of soil to supply nutrients to plant roots and the ability of the plant to absorb and use the nutrients. Soil pH is an important factor in determining the solubilities of N, P, and K in the soil for plant uptake and plant growth (Fageria, 1992). The nitrogen (N) cycle is an open system in grassland ecosystems: N is extremely mobile and leaves the ecosystem through more avenues and in greater quantities than most other nutrients (Woodmansee and Duncan, 1980). In the soils of desert grasslands, nitrate (NO_3^-) is the most abundant available form of nitrogen, with ammonia (NH_4^-) present only in very small amounts (Day and Ludecke, 1993). Soil organic phosphorus is part of the dynamic phosphorus (P) cycle that includes the immobilization, mineralization, and redistribution of P in soil which depends on physical-chemical properties as much as microbial, mycorrhizal, or plant uptake (Stewart and Tiessen, 1987). Bio-available phosphorus is critical to plant biomass production because it controls the accumulation and availability of nitrogen and carbon in ecosystems (Eisele et al., 1989). Phosphorus is available to plants in the form of phosphate ions (PO_4^{3-}) through the slow dissolution of primary P minerals or as biomass P (Stewart and Tiessen, 1987). P is less mobile than N in soils and it is not lost from the root zone by leaching (Day and Ludecke, 1993). Soil organic matter (SOM) is a major component of biochemical cycles of the major nutrient elements. The quantity and

quality of SOM both reflects and controls primary productivity (Fageria, 1992). In arid and semiarid regions, SOM is concentrated primarily in the upper soil layers where most of the root systems are located. Total organic carbon (TOC), although not a plant nutrient, provides a measure of production in an ecosystem. In forage plants, more than 90% of yield, or total dry matter, produced by the individual plants originates during photosynthesis and is stored as carbohydrates (Fageria, 1992). Mesquite significantly alters nutrient cycling in desert grassland because the tree accumulates TOC, P, N, and sulfur in the soil beneath its canopy (Tiedemann and Klemmedson, 1973a; Tiedemann and Klemmedson, 1973b), similar to the "islands of fertility" concept described for grassland areas invaded by shrubs (Virginia and Jarrell, 1983). Retrospective studies are useful in defining the magnitude of the fire effects on nutrient concentrations. Fire frequency and land use on the south gunnery ranges of Fort Huachuca Military Reservation in southeastern Arizona have been well documented since 1973. Currently, the gunnery ranges are characterized as savannas of scattered trees with open canopies and a continuous grass understory. The study area (Biggs, 1997) is on a single geomorphic surface, a Holocene alluvial fan comprised of granitic material with a uniform slope of about 5%. The area is covered by a sandy loam and has a remarkably homogeneous and fine-grained character for a rangeland soil. On the study surface, three study sites with different fire frequency history were established in April 1995. Site 1 has not been burned and is dominated by mature mesquite. Site 2, which has a moderate fire frequency of 2 fires/decade, last burned in 1991. At present, Site 2 is covered by native grasses, forbs, small shrubs, and widely scattered mesquite trees. Site 3, which has a high fire frequency of 4 fires/decade (most recently burned in February 1989), is dominated by native grasses, small shrubs, and shrubby mesquite.

Results

A summary of research results is presented here; for more details, see Biggs (1997). Soil bulk density did not differ among the plots. Soil pH did not differ between the unburned and moderately burned sites, but pH was higher on the frequently burned Site 3. Soil cation exchange capacity (CEC) was about 40% higher in the burned sites, but the variance of CEC was not significantly different among the 3 sites. Of the 4 exchangeable cations, only Ca^{++} was lower on burned sites. The variability of Na^{+} , K^{+} , and Ca^{++} was markedly different among the 3 sites and was lower in the burned sites; Mg^{++} was not significantly different among the sites. The concentrations of soil macronutrients were considerably different among the 3 sites. In comparison to Site 1, TOC was significantly higher on the moderately burned Site 2 and lower on the frequently burned Site 3. Likewise, the concentration of $\text{PO}_4\text{-3}$ was 60% higher on Site 2 but 28% lower on Site 3. $\text{NO}_3\text{-}$ did not differ between Sites 1 and 2, but mean $\text{NO}_3\text{-}$ was 57% less on Site 3 than on Site 1. On Site 1, TOC, $\text{NO}_3\text{-}$, and $\text{PO}_4\text{-3}$ were more abundant under mesquite canopy than in the open areas between trees. Frequent fires apparently decreased the spatial variability of TOC, $\text{NO}_3\text{-}$, and $\text{PO}_4\text{-3}$ on the study sites at Fort Huachuca. Contour plots of the nutrient topography showed significant peaks in all three macronutrients clustered around standing mesquite trees on the unburned site and the single mesquite on the infrequently burned site. Coincident nutrient peaks were also present on both Site 2 and Site 3 that are unrelated to either mesquite or clusters of other C3 plants. These features on the burned sites suggest that nutrient peaks remained from mesquite individuals that had burned or been

removed before 1975. The plant species composition was similar among the study sites, although the abundances of several species changed considerably. Mesquite appeared on the 3 sites between 1935 and 1946; comparison of 1975 and 1994 aerial photographs showed that the burned sites lost several established mesquite, resulting in a more open appearance. In 1995, the canopies of mesquite covered 34% of the unburned Site 1, about 3% of Site 2, and <1% of frequently burned Site 3. Mesquite comprised nearly 98% of the living biomass on Site 1, an order of magnitude larger than on Site 2 and 60 times larger than on Site 3. The biomass of grasses was 350 and 300% higher on the moderately and frequently burned sites, respectively, compared to the unburned site. Litter contributed 12.5% of the total biomass on the unburned Site 1; in contrast, litter contributed 29% and 54% of total biomass on Sites 2 and 3, respectively. For grasses, forbs, and shrubs, the amount of carbon in the plant tissues was higher on the two burned sites compared to the unburned site, although there was little difference between the two burned sites. Conversely, concentrations of nitrogen and phosphorus in the plant tissues of the two burned sites were lower than samples from the unburned site. Nitrogen concentrations in grasses were 32 to 37% lower on the burned sites versus the unburned site. Phosphorus concentrations in plant tissues from the two burned sites were 13 to 35% lower than plant tissue from the unburned site. Concentrations of the exchangeable cations varied with plant group as well as site. Calcium concentrations in grasses were greatest on the unburned site and decreased with increasing burn frequency. Concentrations of magnesium in grasses were about 20% higher on unburned Site 1 compared to the two unburned sites. Potassium concentrations for grasses, forbs, and shrubs on the unburned site were very high compared to plants from the two burned sites, and concentrations of potassium decreased with increased burn frequency. As with the living plants, the concentrations of nitrogen and phosphorus in litter decreased with increasing fire frequency.

Conclusions

On a single geomorphic surface at Fort Huachuca, the occurrence of mesquite and frequency of fires appear to be reflected in the distributions of key nutrient concentrations in soil organic matter and plant biochemistry. The effects of mesquite have been well-documented in the literature and re-confirmed in this study. In a comparison of open areas not under mesquite canopies, the only variable that was significant and linearly related to nutrient concentrations and biomass differences was fire frequency. One effect of fire appears to be the redistribution of macronutrients from under mesquite to the remainder of the landscape. Fires result in the deposition of large amounts of N and P onto the soil surface, where the nutrients are highly susceptible to erosion and leaching losses. Our results clearly reflect this, as soil NO_3^- and PO_4^{3-} increased with moderate fire frequency, but decreased with increasing fire frequency. Based on our data from one geomorphic surface, we agree with Robinett (1994) that the interval between fires in desert grasslands should be greater than 5 yrs to avoid significant losses of macronutrients. Changes in macronutrient variability may be difficult to reverse in some severely disturbed grasslands where fuel loading is too low to carry fires. In areas with higher biomass of fine fuels, fire provides an impetus for restoration. The remnant peaks in nutrient topography of Sites 2 and 3 show that macronutrients do not immediately respond to the change in vegetation; instead, the reduction in high levels of macronutrients is controlled by relatively slow cycling rates.

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Fire Frequency and Soil Nutrient Status on the Southern Gunnery Ranges at Fort Huachuca Military Reservation, Arizona

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Grassland fires have important but often poorly understood effects on soil nutrient levels, which may either aid or hinder plant reestablishment following fires. The objective of this study was to determine the relationship between fire frequency and time elapsed since the most recent fire upon plant-available phosphorus, total organic carbon, total nitrogen, ammonium, nitrate, and aboveground plant biomass in a semidesert grassland in southeastern Arizona.

Eight sites with reasonably uniform physical characteristics but with fire frequencies ranging from less than 1 fire/decade to 5 fires/decade were analyzed at the Fort Huachuca Army Base in the Huachuca Mountains. Soils are noncalcareous coarse to fine sandy loams, classified as Aridisols with a granitic parent material, and a high degree of physical uniformity. The sites contained two geomorphic surfaces: the younger Garden Canyon Series, and the older Lanque Series. Soil samples were collected at 25 random locations within each site and analyzed for total organic C, total N, ammonium, and nitrate. Aboveground biomass samples were collected from 1 m² areas at 15 randomly selected locations within each site; within each area, litter, forbs, shrubs, native grasses, and *Eragrostis lehmanniana* (Lehmann lovegrass) were collected separately.

The trends between total carbon and total nitrogen closely paralleled each other on each geomorphic surface. Total organic C values obtained for the younger geomorphic surface ranged from 0.84% to 1.08%, while total N values ranged between 0.07% and 0.08%; there were positive relationships between percent total N and total C and fire frequency (0, 2, and 4 burns/decade). At the older geomorphic surface, total organic C ranged from 0.67% to 1.10%, while total N ranged between 0.06% to 0.13%. For both total organic C and N the 1 burn/decade site had the highest values; the 3 burns/decade had the lowest values, while the 0, 2, 4, and 5 burn/decade sites had intermediate values.

Ammonium and nitrate concentrations also showed a similar relationship with fire frequency on the younger geomorphic surface. Ammonium concentrations ranged from 0.2 ppm (2 burns/decade) to 1.1 ppm (4 burns/decade), while nitrate concentrations ranged from 1.2 ppm (2 burns/decade) to 3.3 ppm (4 burns/decade). On the older geomorphic surface ammonium concentrations decreased with increasing fire frequency, from 1.7 ppm to 0.2 ppm. The highest nitrate concentration (4.7 ppm) was also at the lowest fire frequency, but on this surface the 3 burns/decade site had the lowest concentration (1 ppm). Overall, these are low values for plant-available nitrogen.

For the three fire frequencies evaluated on the younger geomorphic surface, native grasses constituted about half of the total biomass collected. Lehmann lovegrass biomass displayed a positive relationship with fire frequency, ranging from 0% at the 0 burns/decade site to 25% at the 4 burns/decade site. Shrubs

For the three fire frequencies evaluated on the younger geomorphic surface, native grasses constituted about half of the total biomass collected. Lehmann lovegrass biomass displayed a positive relationship with fire frequency, ranging from 0% at the 0 burns/decade site to 25% at the 4 burns/decade site. Shrubs were virtually nonexistent at the 3 sites. Forbs ranged from a high value of 12% at the 0 burns/decade site to 5% at the 2 burns/decade site. Litter ranged from 41% at the 2 burns/decade site to 25% at the 4 burns/decade site.

On the older geomorphic surface, Lehmann lovegrass also displayed a positive relationship with fire frequency, with greater percentage values than for native grasses at the 4 and 5 burns/decade sites. At the 4 burns/decade site, Lehmann lovegrass constituted over 60% of the total, while native grasses at this site constituted only 7% of the total. This site also possessed the lowest values for shrubs (3%) and forbs (4%). In contrast, at the 1 fire/decade site, native grasses comprised 42% of the total, compared to 3% for Lehmann lovegrass. Shrubs displayed a generally negative relationship with increasing fire frequency; at the 0 burns/decade site they constituted 50% of the total biomass, followed by native grasses (20%), litter (13%), Lehmann lovegrass (10%), and forbs (7%). At the 3 burns/decade site, shrubs constituted just 3% of the total and the 4 burns/decade site contained 2.5%.

Soil pH and plant-available phosphorus remain to be analyzed in the soil samples. However, the existing results suggest that fire frequency plays an important role in determining the species composition of the aboveground biomass. The sharp increase in the percentage of Lehmann lovegrass at the 4 and 5 burns/decade sites on the older geomorphic surface, and the less dramatic increase at the 2 and 4 burns/decade sites on the younger geomorphic surface, suggest that Lehmann lovegrass has a competitive advantage in rapidly establishing after disturbance events.

On the older geomorphic surface, the 3 burns/decade site contained the lowest concentrations of total organic C, total N, and nitrate; this may coincide with the low percentage of shrubs (including nitrogen-fixing plants) and a relatively uniform representation by other plants and litter, ranging from 30% native grasses to 19% for forbs. In contrast, the highest concentrations of ammonium and nitrate occurred on the 0 burns/decade site, possibly coinciding with the relatively high composition of shrubs. To define this relationship more rigorously, more detailed work needs to be conducted to evaluate the role these shrubs play in contributing to nitrogen cycling within this plant community.

Remote Sensing and GIS Techniques for Assessing Prescribed Fire in the Madrean Archipelago

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While fire is generally considered an essential component in the natural development of most ecosystems (Hardy and Arno, 1996), its occurrence on the landscape of the American Southwest has been greatly reduced during the past century. Land management policy decisions (Leopold, 1963; Schullery, 1989; Arno and Brown, 1991) and changes in plant communities due to overgrazing, logging, and nonnative plant invasion (Pyne, 1982; Bahre, 1991; McClaran and Van Devender, 1995) have been influential deterrents. In an effort to reverse the trend of fire suppression while improving techniques for assessing ecosystem health, the USDA Forest Service and the University of Arizona have embarked on research initiatives related to fire and natural resources management in the borderlands region of the Southwest.

The Maverick prescribed fire study is applications-based research to determine the viability and accuracy of using easily accessible terrain and remotely-sensed datasets in a geographic information systems (GIS) environment to map and analyze the 1997 Maverick prescribed fire in the Southwestern Borderlands Ecosystem Research Area in Arizona and New Mexico. Study objectives were to: a) compute topographic data layers (elevation, slope, and aspect); b) produce a map of prefire fuel types within the fire perimeter; c) create a prefire canopy density map within the fire perimeter; d) register the prefire fuels and canopy cover maps to the topographic data layers; e) map the burn severity; and, f) analyze the relationships among fuels, topography, and burn severity. A variety of image processing tools and techniques were used in the study to produce intermediate and final display maps, for use by natural resource and other land managers as visual management aids.

Remote Sensing and GIS

Recording information about fire in wilderness areas is often difficult due to accessibility, weather conditions, safety concerns, and areal extent. Increasingly, remote sensing techniques are being used to effectively gather data on fire activity and ecosystem response. Remote sensing is reconnaissance at a distance – gathering information about an object without touching it.

All objects reflect or emit electromagnetic radiation over a range of wavelengths producing a distinct spectral signature. For remote sensing, the spectral wavelengths are measured in micrometers (mm) and range from ultraviolet (UV) (0.01 to 0.4 mm) to visible (0.4 to 0.7 mm) to infrared (IR) (0.7 to 1,000 mm) to microwaves (> 1,000 mm). In this study, the radiation measurement occurs primarily in 2 regions of the spectrum: the visible range where the component bands produce blue (0.4 to 0.5 mm), green (0.5 to 0.6mm), and red (0.6 to 0.7 mm)

light; and the near IR range (0.7 to 1.5 μm), which is invisible to the human eye. Because vegetation shows the most reflectance in the near IR band, with the next highest reflectance in the visible green band, the near IR band and the upper range of the visible spectrum were the primary bands used in this study.

As wilderness vegetation is altered through natural succession, changes in spectral signatures also occur over space and through time. Disturbance, such as a major fire, amplifies otherwise subtle changes within an ecosystem, and correspondingly, the spectral response may be more extreme. Previous studies have shown that using data from the Landsat Thematic Mapper (TM) satellite is effective to map change from fire disturbance at a scale sufficient to discern ecosystem-level variation (Collins and Woodcock, 1996; White et al., 1996; Patterson and Yool, 1998).

TM imagery is one of several components necessary to accomplish a comprehensive change analysis. Disturbances, such as forest fires, operate within a framework of multitemporal and multispatial scales, whose impact is often unclear (Averill et al., 1994; Rogers, 1996). Consequently, ecosystem response to wildland fires is an integrated response that produces interrelated data for examination and evaluation.

Because a multitude of variables should be considered when assessing vegetation response to wildland fires, a relational database using a variety of unique datasets is a logical approach to the study of wildland fires (Sample, 1994). Such an assemblage of variable data in a layered information structure, which can be simultaneously analyzed and visualized, is a GIS. A GIS provides the analytical framework to map and assess the spatial distribution of topographic features, vegetative fuels, and patterns of fire behavior at the ecosystem level.

The Maverick Fire and Its Geographic Context

Mechanically ignited by the Forest Service on June 24 and 25, 1997, the Maverick fire smoldered into July. Of the total acreage within the primary burn containment perimeter (approximately 17,000 acres), the Forest Service has estimated between 6,000 and 8,000 acres burned, based on aerial inspection. The total area of the study site (primary burn containment perimeter and secondary spill-over containment perimeter) was more than 40,000 acres of public and private land; an unprecedented areal extent for a management-ignited prescribed fire in the Southwest. The purpose of the burn was to reduce invasive trees and shrubs, increase herbaceous plant materials, return the natural forces of fire to the ecosystem (Encinas, 1997), and create a mosaic of burned and unburned areas (Pickett, 1985).

To comprehend the complexity of the burn and the analytical component of this investigation, it is important to understand the location and nature of the study area. The site is in the Peloncillo Mountains of the Madrean Archipelago (Brown, 1994). Bounded by the Chihuahuan Desert to the east and the Sonoran Desert to the west, the site straddles the Arizona/New Mexico border just north of Mexico (figure 1).

The Peloncillos, a subtle north south arc crossing the southern Arizona/New Mexico border, are one of about 40 sky island complexes that comprise the Madrean Archipelago. Stretching along a roughly north south axis from the Mogollon Rim to the Sierra Madre Occidental, the Madrean Archipelago is a complex of alternating mountains (islands) and valleys (seas), that are either barriers or bridges for colonization by various species, depending on dispersion patterns, transport capa-

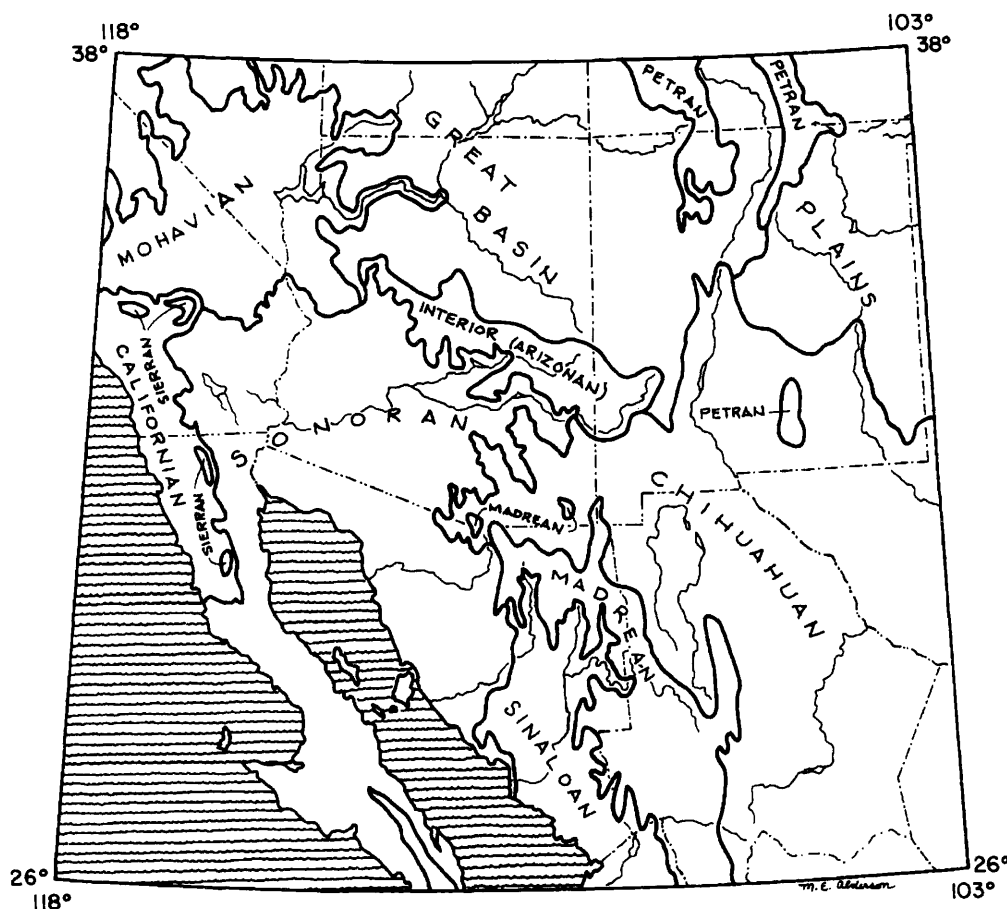


Figure 1. Biogeographic provinces of the southwestern U.S. and northwestern Mexico. From *Biotic Communities, Southwestern United States and Northwestern Mexico*, David E. Brown, Editor, 1994. Reproduced with permission from the University of Utah Press.

bilities, and adaptability (Warshall, 1995). The biodiversity found throughout this complex is unique and extensive (McLaughlin, 1995).

Unlike the timber rich regions of previous fire research, the Maverick site is abundant in plant communities ranging from semidesert mesquite grasslands at lower elevations to dense Madrean evergreen woodlands of oak, juniper, and pinyon at upper reaches with riparian corridors of sycamores and other deciduous tree species interspersed throughout. This stratification is characteristic of sky island complexes. The survival of these plant communities is partly due to the region's cycle of mild winters and warm, wet summers interrupted by a dry spring hiatus. The dramatic geophysical nature of the site, typical of volcanically induced geologic disturbance (McIntyre, 1988), is characterized by elevations from 1289 m to 1964 m, with predominantly west and south aspects, and slopes from flat to nearly vertical.

Data and Methods

A wide range of digital and nondigital data were used for this project including United States Geological Survey (USGS) digital elevation models (DEMs) provided by the Forest Service; TM imagery from June 17, 1995, and June 24, 1997 (prefire), and July 3, 1997 (post fire), obtained through USGS; USGS black and white digital orthophoto quarterquads (digitized aerial photographs corrected for earth curvature distortion); true color low and mid altitude aerial photography provided by the Forest Service; and true color ground

photography. The software that was used for processing and analysis included UNIX-based ERDAS Imagine, IDRISI for Windows, ARC/INFO, and ArcView.

Classification of land cover change as a result of the Maverick fire required preparation of preanalysis theme maps. First, the topographic layers were created by deriving basic elevation, slope, and aspect maps from the DEM. Then, they were reclassified to impose a priority ranking that was weighted relative to fire behavior; slope had the most influence and elevation had the least. An overlay of these 3 maps identified areas of similar topographic pose and depicted the range of topographic variability on the site. Another map layer, derived from aerial and ground photography and other related research efforts in the study area (Sundt, 1997; Muldavin et al., 1998), delineated vegetation composition, distribution, and density. An analysis of prefire vegetation fuels relative to topographic pose is also important.

After preprocessing for radiometric and atmospheric correction and geometric rectification, the TM data will be examined and processed to identify the most successful means of mapping the fire. Processing techniques for this step include the Kauth-Thomas transform (greenness, brightness, wetness indicators), principal components analysis, and computation of various vegetation indices. Once the transformed prefire and post fire maps are created, change detection will be accomplished through subtraction of post fire from prefire maps. For each transformation technique performed, the resulting change map, along with aerial and ground photography and field observations, will be used to develop a classification of burn severity and to estimate total burned acreage. When all data layers are assembled, an in-depth assessment of the relationship among the characteristics of burn severity and fuels, canopy cover, and topographic pose will be performed.

Conclusion

The use of remote sensing techniques in a GIS environment provides an opportunity to study ecosystem disturbance on a broad-scale, while assisting in natural resource management. Analyzing and mapping the spatial distribution of fire behavior in relation to topographic variability and natural fuel composition and distribution is important to understanding wildland fire behavior, and returning it to an ecosystem. This is particularly true in a region where fire has been suppressed for a century or more. Although it is bordered by desert, the Madrean Archipelago still relies on fire to help regulate and maintain diversity.

Employing easily accessible terrain and remotely-sensed data to develop new tools and techniques for visualization of ecosystem development is essential as technology rapidly evolves, natural resource management responsibilities expand, and increased oversight efficiency is demanded. Building a comprehensive program documenting the Southwestern Borderlands Ecosystem Research Area will have a profound impact on understanding ecosystem processes and successfully managing the natural resources in the borderlands area and other environmentally important regions.

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Remote Sensing Fire Studies in the Greater Borderlands

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“The road forward is uphill and hard to march. But the higher the hill the finer the view.”

—Anonymous

Forest fires place lives, property, and natural resources at risk. Yet fire appears to be a natural ally of a healthy forest and a critical element of sound ecosystem management. These conflicting views impede efforts to define the role of contemporary fire in Borderlands ecosystem management. Forest fires are inevitable, but the slow adoption of pro-fire policy is understandable: Fire behavior complexity and incomplete fuels maps promote uncertainty. Forest managers are unwilling to commit scarce resources to major prescribed burning campaigns without some knowledge of likely outcomes. It is therefore not surprising that a single prescribed burn can take years of planning. This essay surveys recent efforts in pyrogeography, a term introduced here to underscore the spatial complexity of fire, and the mapping mandate for effective fire management.

The geographic information system (GIS) provides the unifying geospatial framework within which to practice contemporary pyrogeography. Although there is no substitute for field work, remote sensing provides a key GIS data resource, enabling mapping at scales impossible purely from the field and required for ecosystem management. I highlight for the Southwestern Borderlands some contributions remote sensing and GIS have made to wildfire management at the ecosystem level. Following the Background, in which I lay out key assumptions and introduce terminology, I review contemporary approaches to fire severity sampling, classification, modeling, and the implications for future fire management in the Borderlands region. Specifically, I describe a strategy for automated sample design, then compare discrete and fuzzy classification of forest fire severity. The essay concludes with my view of “the road ahead” for fire mapping using next-generation remote sensors and modeling of surface fuels.

Background

There are spatial linkages among fire regimes, terrain, and associated fuel complexes. Fire effects and post-fire recovery are tied to firescape properties (fuel complex, topography) and regional climate. A firescape, as defined here, is the collection of fire habitats. The term “fire habitat”, introduced here, is defined as the fuels complex, terrain, and fire history at a given site. The fire habitat concept acknowledges that before European settlement, fires were resident in forests. Commercial space-based remote sensing data and GIS techniques can enable exploratory mapping, modeling, and monitoring of fire habitats, but current results are preliminary.

An Orientation to Remote Sensors for Fire Mapping

Remote sensor data collected by the Landsat Thematic Mapper (TM) and the National Oceanic and Atmospheric Administration's Advanced Very High Resolution Radiometer (AVHRR) comprise two primary sources of data for modern wildfire studies. The TM data, which are multi-spectral and carry a nominal spatial resolution of 30 meters, may be used for landscape-scale fire patterns, effects, and recovery studies. The AVHRR data, also multi-spectral with a nominal spatial resolution of 1100 meters at nadir, could provide a broad-scale historical record of precipitation patterns. In addition to providing confirmation of site recovery, the AVHRR data can be used to detect large burn scars and thus monitor regions apparently susceptible to fire. A third data source, the Advanced Visible Infrared Imaging Spectrometer, supplies a rich hyperspectrum of data on the biophysical condition of vegetative fuels. Non-image GIS data, used to model potential fire behavior, include digital elevation models (DEMs), lightning incidence, and fire history data.

Theoretical Framework for Remote Sensing Studies

It is the correlation between the distinctive multi-spectral response patterns produced by similarly distinctive canopy expression that in theory justifies use of remotely sensed data to discriminate forest fuel species and structure. If we assume forest species and structure relate directly to fire behavior, we could claim remote sensing technology provides fire ecologists with spatial information about past and potential fire behavior, and then we could provide forest ecosystem managers data required to assist management decisions. This claim can only be supported partially at this time.

Multi-Spectral Remote Sensing

Multi-spectral remote sensing has been used to assess a variety of forest attributes. These attributes have included species composition, crown/canopy density, tree height, timber volume, forest stand health, and age.

Multi-spectral remote sensing of forest species and structure, and the extension of this technology to forest fuels, remains in fact an open area of research: In rugged areas, variances in spectral response patterns can be produced by topographic shading and by the unequal scattering of reflected light from forested landscapes. Superimposed upon the radiation "ecology" of the firescape are other complicating factors, including atmospheric conditions, pixel size, sunangle differences, and variations in understory material. Pixel size may not, for example, match the "scale of action" of fuels variability. A number of remote sensors have been used over the years for forest inventory and have included efforts to reduce this "noise." Despite the availability of multi-spectral data and results-driven processing techniques the USFS has, for reasons of scale and cost, generally continued to rely on human interpretation of airphotos to perform resource inventories. I wish to suggest here there are management-driven reasons to commit to space-based data and digital analysis methods.

Methods

Digital Image Processing Techniques for Fire Severity Sampling

Spatial patterns of wildfire disturbance are linked to the spatial configuration, or "poses" of terrain. In ecology, and in fire ecology specifically, it is desirable to identify the range and variability of factors that may affect the phenomenon in

question. Experimental designs and sampling procedures in fire ecology should thus consider terrain variability and its potential relationship to fire behavior.

Terrain-Based Stratification

Digital image processing supplies effective techniques for analysis of complex fire terrain. These techniques carry the power to analyze large areas while providing spatial information at fine spatial scales and are suited particularly to the study of terrain. Terrain data are often stored in raster format, with each grid-cell representing a small area of the earth. Many digital image-processing techniques are also raster-based and can, therefore, be invoked on digital terrain data. Recent work in this area featured automated digital image processing techniques that stratify terrain into homogenous clusters of elevation, slope, and aspect. These stratifications were then used to guide location of sample plots in a classification of wildfire severity.

Discrete Classification of Fire Severity

The discrete classification model assumes uniform fire severity spans every mapped cell. The fuzzy classification model, discussed below, characterizes fire as a patchy, quasi-random process, representing more than one severity class in any one mapped cell. Remotely sensed images are able to capture the spatial variation of fire severity. Satellites such as the TM are able to record different spectral responses resulting from landscape features experiencing different fire severity.

Enhancing the Fire "Signature"

Information on fire severity can be extracted from the image by examining the signatures within certain portions of the electromagnetic spectrum. Briefly, fire will tend to produce lower spectral responses in the visible and near-infrared TM bands because of the removal of vegetation. In the two middle-infrared TM bands, fire tends to produce higher spectral signatures due to the reduction or removal of moisture from vegetation and soil. The TM spectral data can be transformed, enhancing resolution of fire severity. Two such enhancements, the principal components (PC) and Kauth-Thomas (KT) transforms, are weighted linear combinations of the original spectra that appear sensitive to fire-induced changes in chlorophyll and moisture.

The Principal Components (PC) Transform

The PC transform is used commonly to compress remotely sensed data by reducing redundancy among semi-correlated spectral bands. The first three components, for example, can account for 95 percent of the variance in a typical TM dataset. Transform coefficients are derived from the data and are, therefore, biased toward scene majority characteristics (in this case, unburned areas). Analysis of the factor-loading matrix is used to assign biophysical labels such as brightness and greenness to resulting components. A PC-based classification of fire severity from the July 1994 Rattlesnake Fire (Chiricahua Mountains) produced an overall accuracy of 62% for 3 severity classes.

The Kauth-Thomas (KT) Transform

The KT transform was developed in the 1970s using Landsat Multi-Spectral Scanner data for agricultural applications. Now adapted for the Landsat TM, the first three KT features, produced by the linear transformation of the original TM data, are brightness, greenness and wetness, respectively. Brightness is responsive to biophysical factors such as color and moisture, which affect soil reflectance. Greenness is a function of the amount of vegetation present. (This feature re-

sponds to the absorption of visible light and the reflectance of near infrared light.) Wetness is sensitive to the moisture content of soils and vegetation. Fire-induced decreases in vegetation and soil moistures produce changes in the middle infrared bands before and after fire. A KT-based classification of fire severity from the July 1994 Rattlesnake Fire (Chiricahua Mountains) produced an overall accuracy of 73% for 3 severity classes. A multi-temporal KT transform invoked on TM data of the 1996 Baker Canyon Fire (Peloncillo Mountains) produced fire severity map accuracies above 60%, some 10% below accuracies recorded for the Rattlesnake Fire. This disparity underscores performance differences that can be expected in heavily wooded conifer vs. soil-dominated shrubland communities: Background soil can mask the fire signal. It is easier to detect a fire “signature” when vegetation dominates and when spectral distinctions between burned vegetation and soils are large statistically.

A Rationale for KT vs. PC Performance Differences

The KT features outperformed the PC features because the KT features were independent of the post-fire TM scene. The KT wetness feature, for example, coupled directly to the relatively small percentage of “burned” pixels. The PC features were by contrast dependent; they were computed directly from pixels in the post-fire image. Since the majority of pixels were unburned, and the PC coefficients are weighted by the majority of pixels, the PC features appeared less sensitive than the KT features to burned areas.

Fuzzy Classification of Fire Severity

Traditional pattern recognition techniques rely on discrete classification, whereby pixels are assigned to single-label categories. Because of the continuous gradation of burn patterns, discrete classification likely over-simplifies the spatial complexity of wildfire. Accordingly, recent work on fire severity classification has led to fuzzy classification algorithms. Results from fuzzy classifications are intuitively appealing, but depend on the shape of the membership function and resist traditional means of accuracy assessment.

Multi-Dimensional Fuzzy Classification

Improvement in classification accuracy can be expected with more sophisticated multidimensional fuzzy classification algorithms. More sophisticated versions of fuzzy classification define membership functions based on the complete statistical distribution of all the bands of data sets taken together. Some approaches exploit the second order statistics of the training data (variance and covariance). These statistics are then used in a manner similar to a discrete classification. In fuzzy classification, though, the algorithm produces a fuzzy membership value for each pixel that reflects its relative probability of class membership in all categories based on all included data sets. Beyond fuzzy classifiers, another possibility is the application of neural networks.

Digital Terrain Data, Revisited

Whether discrete or fuzzy algorithms are used to classify fire severity, digital terrain data have been used to improve the accuracy of satellite derived fire-induced vegetation mortality classifications. Classification of a large wildfire in New Mexico, for example, showed that combining TM and terrain data provided approximately 40% improvement in accuracy over TM data alone.

The Road Forward

Regional fuel types, including grass, shrub, pine, and mixed conifer have canopies that are typically distinctive. We are thus capable, using current remote sensing technology, of classification accuracies near 80% for regional fuel types. Classifications at the species level usually run 10-15% below regional type classifications. But standing fuels tell only part of the story. Surface structure, including fuel bed properties, is among the least characterized properties of Borderlands or any forests, chiefly because structure is more or less obscured by canopy. This limitation has prompted: a) development of surface spatial models from spectral prediction of species and structural stage; b) spectral mixture modeling to identify spectra contributed by surface materials; and c) exploitation of the synergy of passive and active sensor systems to characterize sub-canopy structures, including surface components. The difficulty with spatial models is the uncertainty associated with databases, including insufficient spatial resolution and inexact or inadequate predictive power. The problems with spectral mixture modeling include: 1) the inability to identify truly pure endmembers; and 2) canopy masking of key endmember spectra. Although fusion of active (i.e., radar) and passive (e.g., TM) remote sensors is promising, there are at this time potential inconsistencies in radar cross sections extracted from rugged terrain.

Geospatial Information and Technology

As fire ecologists ponder what the new millenium will bring, one issue is clear: The Borderlands ecosystem is not more complex than we think; it is more complex than we *can* think. My view is that geospatial information and technology will become increasingly important as we begin to focus together on understanding and managing this fascinating region.

Effects of a Prescribed Burn on Vegetation and Birds in a Semi-Desert Shrub-Grassland

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In the semi-desert scrub and grassland of extreme southeastern Arizona and adjacent New Mexico (southern Peloncillos Mountains), prescribed fire is being used to improve grazing conditions and return the vegetation toward its pre-settlement character in which grasses were likely more prominent and fires more frequent. It is important to measure and interpret effects of burns on vegetation and wildlife. A two-day burn in late June 1995 in Baker Canyon followed a four-year cessation of grazing. The fire burned parts of a 2,430 hectare (6,000 acre) target area. Just prior to the burn and for two years afterward, I studied vegetation and birds at 32 sampling stations on four linear transects, which had a total length of 10 kilometers.

The pre-burn vegetation was shrubby with a ground "cover" dominated by bare ground, rock, and herbaceous litter. Cover by grass and forbs averaged only 10% and 8%, respectively. Shrub species diversity was high, due to the mixing of several vegetation associations. Common woody plants included *Berberis haematocarpa* (red barberry), *Prosopis glandulosa* (honey mesquite), *Acacia constricta* (whitethorn acacia), *Rhus microphylla* (littleleaf sumac), and *Juniperus monosperma* (oneseed juniper). The breeding bird community of 59 species, sampled in late June, featured species characteristic of scrub rather than grassland. The five most abundant species were *Mimus polyglottos* (Northern Mockingbird), *Phainopepla nitens* (Phainopepla), *Callipepla gambelii* (Gambel's Quail), *Myiarchus cinerascens* (Ash-throated Flycatcher), and *Thryomanes bewickii* (Bewick's Wren).

The burn was patchy at two scales. First, 38% of sampling stations experienced some burn within a 100-meter radius. Second, the percentage of area burned within that radius averaged 48%. The survival rate of burned shrubs was high, averaging 80% for all species combined, although only 20% of junipers survived. Sixty-five percent of burned shrubs were completely burned above ground but resprouted the following year and averaged 1 meter of new growth height two years later. More species of birds and individuals were counted one year after the fire (53 species, 745 birds) than just prior to it (45 species, 703 birds) or two years later (41 species, 544 birds). However, the between-year differences did not appear related to fire.

Experimental Fire Studies in the Malpai Region: Research Questions and Initial Results

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The vegetation of many arid grasslands has changed dramatically in historic times. Many arid grasslands have experienced dramatic declines in grass cover and increases in woody shrub density. Hypothesis for these changes include changes in disturbance regime: concomitant with changes in vegetation were increased grazing pressure and reduced fire frequency and intensity (Bahre 1991).

I am conducting three studies to examine how fire, both alone and in combination with cattle grazing, affects both the plants and animals in shrub-invaded arid grassland systems. The three sites differ in plot size, shrub density, grass cover, and duration of study. The Portal, Arizona site contains high shrub density, little grass, and relatively small study plots and has been studied for five years. This site was once a grassland that presumably burned regularly. The site was invaded by shrubs 100 years ago and has experienced little or no fire since. At this site, fire and grazing independently effect most plants. Annual grasses increased in abundance following fire but perennial grasses have not increased in abundance.

To better understand how grazing and fire affect plants and animals in arid grasslands, a similar experiment has been established recently on the Gray Ranch at a site that contains higher grass cover, lower shrub density, and larger plots. Initial results following the initial burn indicate that rodents are not affected by burning: rodents were equally abundant on burned and unburned plots both one week and six months post-fire.

The third study site is also on the Gray Ranch and contains an intermediate level of grass cover and mesquite shrubs. It is well known that single fires rarely kill large mesquite shrubs but less is known regarding the effect of multiple fires on mesquite mortality (Wright and Bailey 1982). In the study at this site, high and low fire frequency plots will be burned every three and six years, respectively, and compared to unburned plots to determine how fire frequency affects mesquite mortality and grass cover.

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Range Restoration Studies in the Southwestern Borderlands of Southeastern Arizona and Southwestern New Mexico

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Semidesert grass-shrub ecosystems cover large areas in southern parts of the southwestern United States. These grassland ecosystems have supported a viable livestock industry for more than 100 years (Martin 1975). However, one of the persistent concerns about the condition of the grasslands and savannas is the increased density of trees (primarily *Prosopis* spp. [mesquite]), increased density of woody shrubs, and the associated decline of native grasses. Public land managers and private ranchers have made numerous attempts to reverse this trend (Martin 1975), but results have been mixed. The USDA Forest Service's Rocky Mountain Research Station and the Natural Resources Conservation Service (NRCS), in cooperation with area ranchers, recently have established two research studies to determine if and how woody components can be managed for the ecological and economic benefit of the landscape. Since these are new studies, this presentation will concentrate on describing the experimental designs, plot layouts, some pretreatment conditions, and early results.

Background

Southwestern semidesert grass-shrub ranges occupy a strip of land from 50 to 100 miles wide along the southern borders of Arizona, New Mexico, and West Texas (Martin 1975). Desert grassland ecosystems cover approximately 15 million acres in southeastern and central Arizona (McClaran and Brady 1994), including much of the Southwestern Borderlands Program Area. Semidesert grasslands are found from 3,000 to 6,000 ft in elevation where annual precipitation ranges from 8 to 20 in, predominately from convective summer storm systems.

The goal of ranchers and public land managers within the Borderlands region is to manage the semidesert grasslands and savannas according to the concepts of ecosystem management with the emphasis on sustaining, and where needed, restoring ecological function, productivity, and health. Goals in the region are to improve and rehabilitate rangelands to benefit a majority of the components. This is anticipated to support rural economies and lifestyles and, in turn, protect open spaces and the biological diversity of the landscape.

Mesquite has always been a component of these grasslands. However, dense stands were generally confined to stream bottoms while uplands only contained scattered individuals prior to Anglo-European settlement. The increase in mesquite has been documented by Hastings and Turner (1965) and by studies on experimental ranges within Arizona and New Mexico. One study by Hennessy et al. (1983), for example, reported that the mesquite cover had increased 10 times

between 1935 and 1980 in south-central New Mexico. The associated decline in grass density has reduced livestock carrying capacity from about 12 to 14 head per section to as low as four head per section. Traditional explanations for the increase in woody species have focused on: climate change, including increases in atmospheric carbon dioxide (Idso 1992) and a shift in seasonal precipitation patterns; decreased fire frequencies because of reduced fine fuels related to livestock grazing and to fire suppression; wild hay harvesting; and seed dispersal by livestock (McClaran and Brady 1994). Excluding climate change, Martin (1975) indicated that livestock have contributed to the problem directly or indirectly. A vigorous grass cover can retard mesquite seedling root growth but grazing will reduce the ability of grasses to compete with the woody species (Van Auken and Bush 1997). Reduced herbaceous cover has been linked to increased erosion (Martin 1975).

Ranchers and public land managers have used a number of methods to control woody plants including machine and hand grubbing, herbicides, cabling and chaining, root plowing, and prescribed burning (Martin 1975). Grass responses to tree control were excellent in moderate to dense stands of mesquite where there was more than 8 in of summer precipitation and a good remnant of perennial grasses (Martin 1975). However, vigorous mesquite sprouting can compromise the longevity of any treatment.

Land managers are attempting to introduce fire into the semidesert grassland ecosystems. Historical records indicate extensive range fires in the region prior to the introduction of large herds of livestock. Surface fires limit mesquite recruitment by killing young plants and damaging older trees. Older trees may sprout, but repeated fires keep them from achieving any dominance on the landscape. Fire has been used effectively in *P. glandulosa* var. *glandulosa* (honey mesquite) - *Hilaria mutica* (tobosagrass) communities in Texas (Ueckert et al. 1978). Fire also benefits midgrass communities dominated by *Bouteloua curtipendula* (side-oats grama), *Eragrostis intermedia* (plains lovegrass), and *Heteropogon contortus* (tanglehead) that can become decadent in its absence, especially during short drought periods (Robinett and Barker 1996). However, discontinuous fine grass fuels currently limit the spread of fires on many ranges; a continuous, healthy grass stand must exist, or be established, before prescribed fire can be economically and biologically successful. Since very hot fires can damage grass plants, burning conditions must be carefully monitored and fire frequencies should be long enough so that grass plants can recover and set seed (Pase and Granfelt 1977).

Objectives

The immediate objectives of the two research studies are to improve the composition and density of perennial grasses, preferably native species, and reduce the influence of mesquite and other woody species. The complete eradication of mesquite is not a goal. The first study, which will be conducted on the Glenn, Roos, and Gray Ranches, will evaluate the effects of mechanically crushing and cutting mesquite, seeding native grass species, and fire on mesquite cover and on grass and forb cover and diversity. Prescribed fire will be evaluated once a satisfactory grass stand develops. The combination of mechanical treatments and prescribed fire is unique to this study. Companion studies have evaluated the bird and small mammal populations within the areas prior to treatment (Fitzgerald 1997, Downard 1998) and should continue afterwards.

The second study is being conducted on an archeologically rich site on the McDonald Ranch. Mechanical methods would damage the cultural resources, and

a strategy to use cattle as a site preparation tool for grass establishment was developed. Treatments began here in November 1997. Both studies are scheduled to be monitored for at least five years following treatments.

Treatments

The Mechanical Treatments

The study is being conducted in cooperation with the Glenn Ranch east of Douglas in Arizona, the Roos Ranch near Rodeo, New Mexico, and with the Gray Ranch, south on Animas, New Mexico. The Glenn Ranch site has an average elevation of about 3,850 ft, the Roos Ranch site has an elevation of about 4,135 ft, and the George Wright Pasture on the Gray Ranch, has an elevation of about 4,760 ft. Each site contains twelve 5.75-acre plots, and each square plot is 500 ft on a side. The exact plot arrangement varies but the plots are adjacent to each other in a rectangular design. The three ranches have different soils and plant cover characteristics. Soils were surveyed by Don Breckenfeld of the NRCS.

Percent vegetation cover and species composition, as measured on 100 ft transects by Peter Sundt, will be the main variable used to evaluate the treatments. Photographs have been taken from established points to additionally document vegetation changes. The average percent mesquite cover (with standard deviation) varied from $9.0 \pm 6.4\%$ at the Glenn Ranch to $14.9 \pm 6.2\%$ at George Wright, while the average percent of bare soil varied from $35.4 \pm 14.2\%$ at the Roos Ranch to $58.1 \pm 7.0\%$ at George Wright.

Treatment prescriptions

The three treatments are control, crushing, and crushing plus grass seeding. The crushing will be done with a tractor drawn Marden brush cutter¹. This technique has been used successfully on some ranches in the region. A rangeland drill will be drawn behind the cutter on seeded plots. Some plots will not be seeded to evaluate the potential of soil seedbank reserves for reestablishment of a satisfactory herbaceous layer. Each treatment is replicated four times at every ranch site, and the treatments were randomly assigned to the twelve plots. However, some plots were reserved for controls or crushing and seeding prior to randomization because of archeological sites, rare plants, or because of pre-positioned wildlife plots. Treatments were assigned so that half of the site can be treated later for the prescribed burning evaluation. The study will be repeated independently on each of the three ranches, although data may be combined later. The final statistical analysis will depend on the nature of variances in the data. The proposed seed mix of four to five native grasses was adjusted for each site because of differences in elevation and soils. Some important species are *Sporobolus cryptandrus* (sand dropseed), *B. gracilis* (Hachita blue grama), side-oats grama, *Hilaria jamesii* (galleta), and *Setaria macrostachya* (plains bristlegrass). The research sites will be fenced after treatment to exclude any compounding influences of livestock grazing.

Progress to date

The actual treatments have not been started, but the plots have been established, vegetation measured, and contracts awarded for the mechanical treatments and for fence supplies and construction. The USDI Fish and Wildlife Service at the San Bernardino/Leslie Canyon National Wildlife Refuge has agreed to assist with the transportation of Government equipment. Treatments are scheduled for February 1999, weather permitting. Climatological measurements have begun and will intensify when automatic weather stations are installed after the treat-

¹ The use of trade names is for the benefit of the reader; such use does not constitute an official endorsement or approval of any service or product by the U. S. Department of Agriculture to the exclusion of others that may be suitable.

ments are completed. The plots will be monitored for several years before any burning treatments are applied.

Site Preparation With Livestock

Range restoration treatments that utilize heavy equipment cannot be used where significant damage may occur to archeological or historical sites. Surveys of the Rising Site on the Sycamore Ranch indicated evidence of late Archaic and late Pithouse Hamlet/early Mimbres Horizon periods (ca. 1500 B.C.E.- 200 C.E. and 900 - 1150 C.E., respectively) (McDonald and Gilman 1997) and historical artifacts from the late 19th century. The earliest human artifacts found on the research site date from about 225 - 410 C.E. (Gilman 1998). The site is at an elevation of about 4,025 ft. The objective of this study, in cooperation with the McDonald Ranch, is to stabilize a degraded archeological site and to improve the range by increasing the cover and composition of native grasses and reducing the cover of honey mesquite by using archeologically sensitive techniques. The specific objective is to evaluate the use of concentrated, short-term cattle grazing to prepare the site for hand seeding of grasses. Hand cutting of mesquite and scattering slash to provide a favorable microsite for grass seed germination is being tested too. Prescribed burning will be used in the future to control woody sprouts. The impacts of the treatment on historical resources are being evaluated by Dr. P. Gilman of the University of Oklahoma and her associates.

The site contains five 2.3-acre plots. Four plots are within a 25-acre area that is surrounded by a three-strand electric fence, and a control plot is outside of the fence. Vegetation has been measured by Peter Sundt using a similar technique to the one used on the mechanical treatment sites.

Progress to date

The electric fence was completed in Fall, 1997 with the assistance of a crew from the Arizona Department of Corrections in Douglas. In early November, 350 bails of *Digitaria californica* (Arizona cottontop), plains bristlegrass, and *Bothriochloa barbinoides* (cane beardgrass) hay from the NRCS Plant Material Center in Tucson were spread throughout the treatment area. The hay serves as a mulch, provides a seed source, and was used to encourage cattle movement throughout the site. Water for the cows was provided within the fenced area. Bill McDonald drove 279 cows into the plot on November 11 and removed them after 2.8 days because of heavy rains and saturated soils. In February 1998, a Department of Corrections crew hand seeded a mixture of *Sporobolus airoides* var. *wrightii* (giant Sacaton), *S. airoides* (alkali Sacaton), side-oats grama, blue grama, and *Atriplex canescens* (four-wing saltbush). Mesquite was cleared by hand on two of the four interior plots.

First season results

The site was visited in late summer and in November 1998. The summer rains had been less than anticipated; however, two major storms occurred in mid-October and early November. The first visit showed little germination but the second revealed more scattered germination. The scattered native grass hay bails produced the best stands of grass. Cane beardgrass, the most common species in the hay, was the most successful followed by plains bristlegrass. Arizona cottontop was successful in scattered areas. Seeded species were less apparent than the hay species; sideoats grama was the most common of this group. No four-wing saltbush seedlings were found. We anticipate that grass cover should increase during the 1999 summer provided seedlings do not freeze or are not eaten by rodents.

and insects. Additional germination of dormant seed is anticipated based on experience from management operations in the region.

Conclusions

Two range restoration research studies have been initiated within the Southwestern Borderlands Region through the close cooperation among researchers, public land managers, and private land owners. The studies are scheduled to be monitored for at least five years. Final and intermediate results should provide an understanding of options for improving the cover and species diversity of the semi-desert grasslands for the benefit of the land and the rural economy. These findings should be applicable to larger areas of the southwestern United States and to similar areas of northern Mexico. Research on the Sycamore Ranch site would be applicable to other vegetation types where preservation of cultural resources is mandated.

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Restoration Through Reintroduction of Fire and Herbivory

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Historical writings, old photographs and paintings, and paleocological studies document that changes typical of desertification have greatly altered the landscape and vegetation of the arid regions of the southwest within the last 125 years (Hastings and Turner 1965, Cooke and Reeves 1976, Grover and Musick 1990, Bahre 1991). Data from long-term ecological studies and remote sensing indicate that these changes have continued, and in some cases accelerated, in the last 20 years (Ray 1995, Betancourt 1996, Brown et al. 1997).

In our studies we investigate how a combination of cattle grazing and fire can be used to moderate or reverse shrub increases in grassland habitats and how disturbance processes structure grasslands. In companion studies, reintroduction of black-tailed prairie dogs (*Cynomys ludovicianus*ssp. *arizonensis*) on the same site are using similar research protocols to measure the effects of these native herbivores on grassland ecosystem function. The fire and grazing studies are supported by the Interagency Fire Center in Boise, Idaho, and the Animas Foundation. The studies are complementary to those with the Jornada Experimental Range. The prairie dog studies are supported by the Animas Foundation, the New Mexico Fish and Game Department, and the Thaw Charitable Trust.

Structure and Dynamics of Arid Ecosystems in Southwestern North America

Four factors ultimately dominate arid ecosystem processes in southwestern North America: 1) temporal variation in climate; 2) spatial variation in topography, geomorphology, and soil; 3) fire; and 4) herbivory.

First, unpredictable timing in the amount of rainfall determines the input of the primary limiting resource: water. The annual precipitation is distinctly bimodal, with winter rains that benefit C_3 forbs, shrubs, and trees, and summer rains that benefit C_4 forbs and grasses and CAM succulents. Second, variation in slope, aspect, exposure, geological parent material, and soil determines the spatial template upon which all ecological processes, including the infiltration and redistribution of water, occur. Third, fires, usually caused by "dry" lightning strikes at the beginning of the summer rainy season, are a major cause of disturbance. And, fourth, grazing by domestic livestock and native species removes biomass and sometimes contributes to ecosystem degradation. While other influences, such as additional human impacts, are important in local circumstances, the above four factors are generally the most important (Sears 1935, Hastings and Turner 1965, Bahre 1991). An understanding of how they operate and interact will greatly improve our ability to predict changes in arid ecosystems due to both natural and human-caused environmental variation.

We study factors influencing ecosystem structure, dynamics, and productivity in the Malpai Borderlands Ecosystem by focusing on how fire and herbivory structure semi-arid grasslands. Given time and resource constraints, it would be impossible to study all variables affected by fire and herbivory. We have chosen to

focus on vegetation because vegetation in turn has important effects on overall biodiversity as well as the Southwest's ranching economy. We will also study small mammal community composition as an additional measure of biodiversity because: 1) the community composition of small mammals as resource consumers provides a good bioassay of resource distribution and availability within the ecosystem; and 2) as keystone herbivores, small mammals play a crucial role in directing and aggregating resources with the ecosystem (Brown and Heske 1990). Additional groups of special interest are birds and reptiles that provide additional assays of resource abundance and distribution.

Experimental Design

The Gray Ranch is a 130,000 ha working cattle ranch located in the bootheel of southwestern New Mexico and forms the western boundary of the Malpai Borderlands Ecosystem. It is in the Mexican Highlands Shrub-Steppe ecoregion. The Gray is covered by grassy plains from 1200 to 2200 m in elevation and by mountains, some of which rise over 2800 m in elevation.

The Animas Foundation has agreed to set aside the 4,483 ha (11,000 acre) McKinney Flats pasture as an experimental area. Ungrazed since at least 1991, the McKinney Flats pasture is located at an elevation of 1650 m. It contains a gradient from Plains-Great Basin grasslands (*Bouteloua* association), to Semi-desert grasslands (*Bouteloua-Hilaria-Sporobolus* association), to Chihuahuan Desert grassland/shrublands (*Prosopis* association).

Given that we are interested in landscape and ecosystem processes, we believe the use of 2,200 acre (916 ha) pastures, encompassing 1 x 1 km study blocks, with 200 x 200 m study areas containing five 150 m transects, is an appropriate scale at which to conduct our study. This scale is large enough to replicate landscape processes and small enough for the blocks to be comparable, while containing enough separation between vertebrate populations to have true replication.

Vegetation Sampling

A number of scaling and data collection exercises were conducted to determine when sample sizes asymptote and what the minimum necessary sampling intensities were. We have gone to a sampling regime that entails 40 x 40 cm quadrats set at every meter along the 150 m sampling lines. Frequency data is compiled from within the quadrats and line-intercept data from each of the four corners of the quadrat resulting in 600 points per 150 m transect. Aerial photography will be used to track the dynamics of larger woody species such as mesquite (*Prosopis* spp.), agave, and yucca.

Birds

Preliminary sampling of bird species in the fall of 1998 documented far higher bird diversities than recorded for most arid grasslands. We are monitoring bird populations in 500 m disturbance and control plots, yet sampling intensity will increase from two to four extended surveys per year. These are being conducted in May and June to determine the abundance and biomass of breeding birds during the most food-limited and food-critical periods for the endangered

aplamado falcon (*Falco femoralis*). Winter sampling is conducted when diverse winter flocks are on the site to determine the effects of resource variation on migratory birds. The May period corresponds with early breeding season of the falcons and when migratory birds have left. The July period corresponds with young-feeding/fledgling period of the falcons and is also when resident birds are coping with reproduction and the most extreme heat and moisture conditions of the year.

Small Mammals

Twice a year (once in the spring and once in the fall), Sherman traps will be placed at 30 m. intervals along the 150 m transects (240 traps per night). We have found that to ensure the traps are all picked up by the heat of the day, only one-half of the site should be trapped at a time. The duration of trapping will be for three days in each location. Due to relatively high mammal densities and diversities on the site (roughly 12 species on the site at a given time and two to 10 captures per 200 x 200 m sampling area), this approach is proving effective at recording mammal density and diversity.

Lizards

To monitor lizard populations, we will place pitfall traps at each of the rodent sampling stakes, thereby allowing direct comparison between lizard and small mammal populations. Pitfall traps will be censuses for five days, four times yearly including the late spring, after adults emerge and become active (early May), in early summer before the hot dry periods prior to the monsoon (early June), in July after the monsoon (when heat and drought sensitive species are likely to be active), and in the early September after the young of the year become active.

Physical Features and Parameters

Aerial photos will be taken of the site during the winter and each winter thereafter to document changes in woody vegetation. Post-fire photography will also be conducted to document the spatial dynamics of fire events. Important landscape features such as kangaroo rat mounds will be documented and mapped using GPS to determine spatial and temporal variations in these nutrient sinks and diversity hotspots.

Pre- and post-fire monitoring will entail measurements of soil chemistry and fuel loads in different vegetation types. Paint chips around target species will document burn intensity, and selective marking of focus species groups (grama grasses, yucca, sub-shrubs, and *Coryphanthra* cactus) will provide additional information on the effects of burning.

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The Rising Site Archaeological Project: Investigating and Preserving a Heavily Eroded Site Near Douglas, Arizona

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Purpose of the Rising Site Archaeological Project

Management of a Heavily Eroded Archaeological Site

The Rocky Mountain Research Station is engaged in a long-term research program titled "Sustaining Ecological Systems of the Southwestern Borderlands." In collaboration with the Coronado National Forest, the Natural Resources Conservation Service, the Arizona and New Mexico State Land Departments, the Malpai Borderlands Group, and the Animas Foundation, the Station is developing methods to restore natural ecosystem processes and improve the productivity of savanna grasslands and woodlands in southeastern Arizona and southwestern New Mexico.

Return of a natural fire regime is believed to be the key to achieving these goals. Research is therefore focused on finding the best methods to re-establish a natural fire regime and on evaluating the actual effectiveness of fire in maintaining savanna grasslands and woodlands. A specific Borderlands research project impacted the Rising site (AZ FF:12:48 [ASM]/ AZ FF:12:3 [CC]) on Arizona State Trust and private land in Cochise County, about 42 km east of Douglas. The land on which the site is located has experienced an invasion of shrubs, particularly mesquite, at the expense of grass. It is also undergoing significant surface and gully erosion. It is not that an archaeological site was chosen for the location of this experiment where other shrubby and eroded locales were available. The area of the Rising site is the most heavily eroded and shrubby of any in the region, and for this reason the experiment was placed there. If the experiment is successful, it will stabilize the site deposits, something that will not happen if the site is left in its "natural" state.

It is necessary to re-establish grass on the Rising site before fire can be used to control mesquite in the area. A grass cover will also reduce erosion. The technique proposed to re-establish an herbaceous cover was first to distribute native grass hay throughout the area, and to follow this with a concentration of cattle on the locality. Specifically, about 300 cattle were concentrated on a 25-acre area for two to three days. A three-wire electric fence was used to hold the cattle. In half of the area, mesquite was hand-cut using chain saws or brush cutters. In the other half, no mesquite was cut. The experiment assesses the effectiveness of using cattle to work grass seed into the soil and fertilize the seed, and the effectiveness of cutting the mesquite to reduce transpiration by shrubs temporarily, thereby increasing the moisture available to the grass. Once grass cover is established, fire will be used to provide long-term control of the mesquite. By way of contrast, conventional methods would have used mechanical equipment (bulldozers and seed drills) to re-

move the mesquite and establish grass cover, heavily disturbing or destroying the contexts of the archaeological materials.

Studies at the Rising site clearly have the potential to produce information useful for archaeological site management. If the revegetation works, the erosion will stop, and we will know that this method might be appropriate on other similarly eroding sites. Further, we gathered quantifiable data on artifact condition and visibility before and after grazing so that we could state the impact the actual revegetation project will have had on the archaeological site.

Archaeological Research on a Heavily Eroded Site

Our archaeological research at the Rising site had two foci. Given the general lack of archaeological investigations in far southeastern Arizona, we placed one research focus on culture history. Douglas (1987, 1990, 1995, 1996) has done most of the archaeological research in this part of southeastern Arizona, and his interests have concentrated on Animas phase materials that are later than those on the Rising site. Douglas and Brown (1984, 1985) also recorded sites from all time periods during an archaeological survey in the region. (Fish and Fish 1996 present a complete history of archaeological research in the Malpai Borderlands region.) In order to augment the earlier part of the archaeological chronology, we emphasized dating individual features and areas within the site. Radiocarbon dating produced dates for both loci on the site, as well as prehistoric and historic dates for the various roasting pits (Gilman 1998).

Our second focus used specific kinds of artifacts to tell us about the economy and movements of people who lived at the site, as well as information about the natural environment in the area. We used ethnobotanical, pollen, faunal, and ground stone remains to suggest dietary patterns. We emphasized obsidian sourcing and the stylistic and petrographic analyses of ceramics to evaluate the possible movements of people or goods into and out of the region. Flotation, pollen, and faunal analyses also suggest the past environmental conditions, which might be considerably different from those of today. Given that two parts of the site probably dated to different time periods, the potential existed for examining changes through time in the activities of people at the site.

Management and Archaeological Results

This project, although brief, demonstrates that we can learn much from a heavily eroded site, in terms of both management and peoples' lives in the past. Our archaeological plan allowed us to assess the impact of the cows on the site, as well as the possible lessening of erosion encouraged by the growth of native grasses. Through archaeological excavation under mesquite trees, we were able to demonstrate that erosion had stripped nearly 20 cm of soil from the site since the current mesquite trees have become established in perhaps the last 20 to 50 years. The excavation of Feature 3, likely the floor of a house with the roof fall above it, showed that material important for radiocarbon dating and for understanding past people's lives was only 5 to 15 cm below the present ground surface. Many cattle hoofprints penetrated 10 to 15 cm into the mud on the site after a heavy rain; had some archaeological investigations not been done before the revegetation project started, we would have lost forever the information that would tell us how people in the past used this land. The long-term impact of the cattle on the archaeological deposits and artifacts is not clear at this time.

The archaeological work at the site provided much information, some of it surprising, about the people who lived here between A.D. 225 and 410, again between A.D. 1005 and 1220, a third time between A.D. 1430 and 1670, and perhaps also in the historic or modern periods, as indicated by radiocarbon dates (Gilman 1998). Clearly, this has been a location useful to people making a living in different ways. Although our sample sizes were generally not large enough to demonstrate it, we would expect people living before the A.D. 1000 to 1200 period as well as during the protohistoric period to be less agricultural, at least until historic/modern times; the evidence from the site suggests that people living between A.D. 1000 and 1200 were not heavily agricultural either.

Locus B, the earliest part of the site, contained only plain ware pottery along with a concomitantly early radiocarbon date of A.D. 225 to 410. A Late Archaic (1500 to 1 B.C.) San Pedro projectile point fragment and a possible Middle Archaic (3000 to 1500 B.C.) Gypsum Cave projectile point fragment from the area hint that this part of the site was used during the Archaic period, but excavation data provide information only for use during the early ceramic period. Petrographic analysis (Gilman, Miksa, and Wiley 1998) suggests that the plain ware pottery sherds from Locus B were made from different sands than either plain or painted sherds from the later Locus A, and that the earlier sherds were not made from sands in the washes nearest the site. A concentration of slab and basin metate fragments with a large complete basin metate, a mano, mano fragments, and fragments of indeterminate ground stone in Locus B is intriguing. Many of the fragments were large enough to be used for grinding, and so this is probably more than just a trash dump. The ground stone and a nearby bedrock mortar may represent the food processing activities that occurred in Locus B, but there is currently no evidence for what people actually ate in terms of ethnobotanical or faunal remains.

Locus A, the main part of the site, dates chronometrically and by the most common painted ceramics from about A.D. 1000 to 1200. There is thus a several hundred year gap in apparent site use between Loci A and B, although there are a few red-on-brown and red-on-white sherds from Locus A that date before A.D. 1000. Remains on this part of the site included a possible house or outside activity area (Feature 3), another possible house represented by a concentration of adobe chunks (N2049.5, E524, E530-538), a hearth or roasting pit (Feature 5), and perhaps a midden (trash) area around N1987, E488.

The petrographic analysis (Gilman, Miksa, and Wiley 1998) suggests that none of the Locus A sherds was tempered with sands from the adjacent washes, a surprising fact, and that some of the sherds were tempered with granitic sand that may occur 40 or more kilometers away (Arizona Bureau of Mines 1959). The petrographic analysis supports the idea that, even in this time when other groups in the Southwest were heavily agricultural, people might have been moving around the landscape over relatively long distances. This statement is upheld by the obsidian sourcing data which show that, even though there was a source within 60 kilometers, people were also obtaining obsidian from more distant sources including Los Vidrios about 390 kilometers to the west, Mule Creek 75 to 100 kilometers to the north, and two sources probably in northern Mexico (Gilman and Shackley 1998). Of course, it is possible that people traded for the obsidian rather than obtaining it directly, as they may also have done for the temper or the pottery vessels.

The ground stone data suggest that people using Locus A were practicing relatively little agriculture compared to other groups to the northeast (the Mimbres Valley) and the northwest (the Hohokam region), and so they could easily have

been residually mobile across the landscape. The use of only medium-grained ground stone materials, the dominance of circular/oval manos, and the use of only slab and basin metates support this contention. Further, the most common ground stone material is granite, which was probably also imported into the site.

Although the only evidence of domesticates at the site is two grains of corn pollen (Fish 1998) from the area of highest artifact density, these are too few to draw any conclusions. It is worth noting that the majority of the animal bone from the site, which were mostly cottontails, jackrabbits, and artiodactyls (Schmidt 1998), came from the areas around Feature 3 and the adobe chunks. Both of these may have been houses at one time, and so the animal bone may be from midden deposits within or near these structures.

Feature 1, a large roasting pit, represents a protohistoric use of the site. The radiocarbon date from charcoal in the pit was A.D. 1430 to 1670, and so the pit could be from either Apache or Sobaipuri use of the area. No burned seeds or animal bone indicated the pit function, although the kinds of wood (sycamore, mesquite or other legume, and a small amount of saltbush) burned in the pit were different from those in Feature 6 (Minnis 1998).

Feature 6 was also a large pit, and the radiocarbon date (A.D. 1525 to 1950) spans the protohistoric, historic, and modern periods. Again, there were no burned seeds or animal bones that would indicate the pit function, but the kinds of wood (mesquite or other legume, saltbush, and one piece of oak) burned suggest that the plants available near the site were different from the time when Feature 1 was used (Minnis 1998). Specifically, the lack of sycamore in Feature 6 hints that it had been denuded from the nearby wash, and so the pit may have been used in historic or modern times. The charcoal from these two features may be suggestive, but the sample size is certainly not large enough to support any statements about environmental change.

Clearly, there remains much that we could learn from the Rising site, even given its heavily disturbed and eroded state. A larger sample of materials from both parts of the site, but especially from Locus B, would help us compare both how people made a living and the natural environments during each time period. Discerning the context of the ground stone concentration in Locus B would be particularly valuable. A further search for roasting pits and other features might augment the post-A.D. 1200 samples, again with an eye to variations in past economic patterns and the environment. Finally, a broader understanding of other sites in the area and the regional botany, zoology, and geology would illuminate some of the patterns noted here.

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Effects of Prescribed Fire on Montane Rattlesnakes: Endangered Species and Ecosystem Restoration

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Using radio telemetry, we evaluated the effects of the Maverick Prescribed Fire on mortality and behavior of three montane rattlesnake species (One *Crotalus molossus*, five *C. lepidus*, and three *C. willardi obscurus*) in the Peloncillo Mountains of Arizona and New Mexico. Of particular concern were effects on federally threatened *C. m. obscurus* or its habitat. The Peloncillo population of *C. m. obscurus* is one of three island populations [the Sierra San Luis (Sonora and Chihuahua) and Animas Mountains (New Mexico) contain the other two populations]. Before this study, 11 *C. m. obscurus* had been documented in the Peloncillo Mountains—eight of these within the primary fire perimeter and three within the secondary perimeter.

Radiotelemetry was performed between 5 May and 30 July 1997 within the primary perimeter at two locations approximately 3 km apart. Following surgical implantation of transmitters, snakes were released at point of capture and located once every day for a total of 483 observations. Observations were brief (<10 min.) to minimize disturbance. Location was recorded using a handheld Global Positioning System (GPS) receiver (Trimble Geo Explorer II). Data were stored as GPS files and mapped from differentially corrected Universal Transverse Mercator (U.T.M.) coordinates. Each snake's milieu was categorized as:

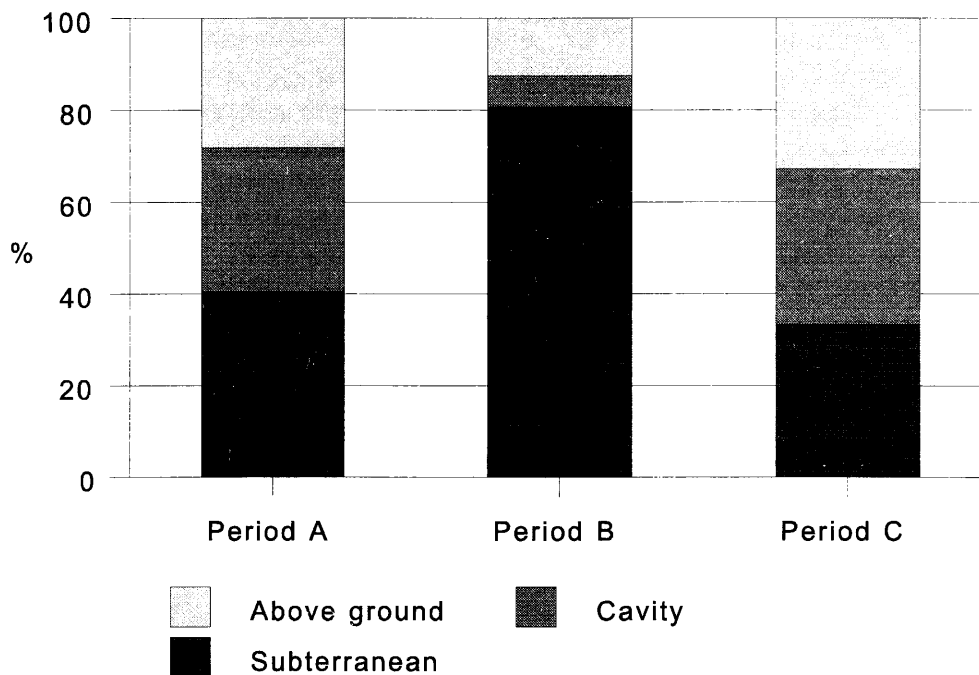
- (a) subterranean (deep within a refuge, may or may not be visible);
- (b) cavity/crevice (near the surface, <50% of body exposed); and
- (c) above ground (>50% of body exposed).

Observations were divided into three periods: A = initiation of telemetry to time fire affected each snake; B = post-fire to onset of monsoon (17 July 1997); and C = onset of monsoon to end of study (30 July 1997).

The north site burned 24-25 June. The fire was particularly intense on slopes and ridges where high fuel load and prevailing winds enhanced pre-heating and convection. On the plateau, where fuel load was reduced due to recent grazing and previous fires, a less-intense fire left some areas unburned. At the south site, fire on 27 June was of lower intensity and resulted in a mosaic of burned and unburned areas. At each site, all snakes were located <18 hours pre-fire and <24 hours post-fire. Eight snakes exposed to low-intensity fire survived, while a snake exposed to intense fire died. Pooled data on spatial descriptors of snake activity (daily activity area, movement rate, movement magnitude) showed no significant differences in pair-wise comparisons of activity before and after the fire (Wilcoxon's

Signed-Rank Test, $P > 0.05$). However, snakes moved significantly less frequently after the fire (Wilcoxon's Signed-Rank Test, $N=8$, $P=0.04$) and were found in subterranean retreats more frequently after the fire than before the fire (Figure 1). Wooded canyons and wooded steep slopes burned intensely because of high fuel accumulation, resulting in habitat loss for *C. w. obscurus*. This snake is exceptionally scarce in the Peloncillo Mountains, with habitat naturally fragmented into isolated canyons. This form may thus represent a metapopulation, with low levels of interdemic migration and gene flow. If isolated demes are extirpated, recolonization from adjacent canyons may take decades, even if vegetative recovery is rapid. The fate of each habitat patch is thus critical to conservation of this threatened rattlesnake. While reintroduction of fire is essential in maintaining a mosaic of habitats and ecosystem function, fires intense enough to effect type conversion may have severe long-term consequences for *C. w. obscurus* populations. Prior to reintroduction of large-scale summer fires, consideration should be given to reducing unnaturally high fuel loads to preserve *C. w. obscurus* habitat and reduce mortality.

Figure 1. Milieu of nine radio tagged rattlesnakes during each of three periods of observation: A=before fire; B=between fire and monsoon season; C=after onset of monsoon season. For periods A, B, and C, $n = 289$, 125, and 69 observations respectively.



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Effects of Prescribed Burning on the Palmer Agave and the Lesser Long-Nosed Bat

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The U.S. Forest Service conducted a prescribed burn (known as the Maverick burn) over a two-day period in June 1995 in the Peloncillo Mountains of southeastern Arizona and southwestern New Mexico. A pilot study was conducted to obtain baseline information on how prescribed burning might impact nectar and pollen production and the reproductive success of the Palmer agave (*Agave palmeri*)—the primary food source of an endangered species, the lesser long-nosed bat (*Leptonycteris curasoae*). The study also examined how fire may impact the use of agaves by bats.

Nectar and pollen studies were conducted after the fire in August 1995 during the peak flowering period of the Palmer agave and when migrating lesser long-nosed bats are normally present in Arizona and New Mexico. Two sites within the primary burn area were selected: the Cowboy Flats site, which was within 1/4 mile of a potential lesser long-nosed bat roost, and the Geronimo Trail site. To determine if fire negatively affected the main food source of the lesser long-nosed bat, 24-hour nectar accumulation, nectar sugar percentage, and pollen production were measured in burned and unburned plots at each study site. Flowers in the dehiscent stage were used for all nectar and pollen studies because we assumed that dehiscent flowers would be most attractive to bats (nectar production is greatest in dehiscent flowers and pollen is produced only in the dehiscent phase). Standing nectar and pollen crops were also measured to indirectly determine the degree of agave use by bats. To evaluate if fire impacted the reproductive output of agaves, fruit set of plants was determined in burned and unburned plots at both study sites. To estimate agave use by bats and to examine foraging behavior in burned and unburned areas, observations of bat visitation using night vision goggles and videotaping techniques were made. Nocturnal visitation rates were determined by observing 1-2 umbels with dehiscent flowers on 1-3 plants in burned and unburned plots for a total of eight nights. One plant was observed continuously from 2000-0500 hours by two observers switching watch every four hours. Plants were observed from a distance of 10 m with night vision goggles with supplementary infrared lighting. Due to late equipment arrival, videotaped observations were limited to only one night in the unburned Cowboy Flats site.

Twenty-four hour nectar accumulation in burned plants was significantly higher at the Cowboy Flats site and significantly lower at the Geronimo Trail site than unburned plants. However, nectar availability was not found to be a limiting factor for lesser long-nosed bats in the Peloncillo area during the study period. Nectar accumulation in flowers in burned and unburned plots was well within the normal range of nectar production reported in previous studies. Nectar production was also observed to increase as burn damage increased. Nectar sugar percentages ranged from 16.5-29.6%, and although sugar concentrations were not significantly different between burn treatments, burned plants tended to have higher sugar concentrations. The increased nectar production and nectar sugar concentrations in burned plants may be an initial physiological response to burn damage and stress but may not continue over the entire flowering period of the inflorescence. A significant linear decrease in nectar production was observed

over a three-day period, suggesting as flowering proceeds and fruit and seed production increase, fewer resources are devoted to nectar production. No significant differences were found in pollen production between burn treatments or sites.

No significant differences were found between exclosed and standing nectar or pollen crops in plants in unburned plots or the burned plot for the Geronimo Trail site, implying that little nectar or pollen was utilized by bats across the landscape during the study period. The lack of detectable significant differences between exclosed and standing crop flowers is presumably a result of low bat visitation and bat foraging behavior in the Peloncillo area. Although lesser long-nosed bats were positively identified in a cave near the Cowboy Flats site, population numbers were estimated to be less than 50, and the mean visitation rate for all plots was low (1.6 visits/plant/hour). Nectar production was significantly lower in standing crop flowers in the burned plot at the Cowboy Flats site and may be due to the proximity of the known roost.

Bats had small bursts of activity shortly after dusk until midnight, but peak visitation to agaves occurred between 0100-0400 hours. Of the total interactions with agaves, about half were hits (stigma contact) and half were passes. No significant differences were found in visitation between burned and unburned plots. Lesser long-nosed bats are powerful fliers and are capable of flying at least 25 km one-way to forage. The mosaic burn pattern that resulted from the fire did not produce large contiguous areas without flowering agaves that are beyond the foraging distances of bats.

Resource limitation is the primary factor that affects fruit set in paniculate agaves (Sutherland 1982). Fruit set for all plots was approximately 20%, similar to fruit set of three previously studied populations of Palmer agave in Arizona (Slauson 1996). No significant differences were found in fruit set between burn treatments at either study site.

Results of this study are preliminary and suggest additional research is needed to more clearly define the interrelationships between burning and how resources are partitioned in agaves between nectar production, nectar sugar, pollen production, and fruit set over the flowering period. Additional study is also needed to understand bat foraging behavior more clearly and the long- and short-term effects of various burning frequencies and intensities on agave population biology. Based on the limited results of this study, burning did not impact the overall resources available for bats or agave fruit set.

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Mutualists Out of Synchrony: Agave Flowering and Nectar Bat Visits in the Southern Peloncillos and Chiricahua Mountains in 1997

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The impetus for this research was to provide basic data relevant to a land-use management question: Would prescribed burns in the Peloncillos Mountains be likely to harm an endangered bat species, *Leptonycteris curasoae* (Lesser Long-nosed Bat) by reducing the supply of one of its foods, the nectar and pollen of *Agave palmeri* (Palmer's Agave)? I worked in the Baker Canyon area (an area burned in June 1995) and adjacent Guadalupe Canyon in the southern Peloncillos and made comparative observations at Portal in the Chiricahua Mountains. Flowering agaves were observed with night-vision binoculars at intervals of one or two weeks. During the first three-quarters of the flowering period (July 1- August 15) no nectar bat visits were seen in the Peloncillos, and dawn standing crops of nectar indicated no nocturnal consumption. From August 25 to September 12, nectar bats visited at rates averaging 30 visits/plant/hour. Two species were captured and identified: Lesser Long-nosed Bat and *Choeronycteris mexicana* (Long-tongued Bat). In the Chiricahuas, the timing of agave flowering and bat visits was very similar to that observed in the Peloncillos except that nectar bats were seen once in July. Nectar reward levels were similar in both mountain ranges. Literature review suggests that bat-adapted agave populations in the United States often are unvisited by bats for large portions of the flowering period, although there are examples of consistently high visit rates.

Flowering stalks of Palmer's Agave were widespread in the Baker burn area in 1997, averaging 10/hectare. If prescribed fires are patchy (as in 1995), it seems unlikely that they would depress the food supply at a scale that would harm nectar bats.

Herpetofauna Studies and Management in the Arizona Borderlands

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We have established a long-term study of reptiles and amphibians in Arizona including the San Bernardino National Wildlife Refuge (SBNWR), the Malpai Borderlands region, and the Sulphur Springs Valley (SSV). In addition to survey and monitoring of all species, and population studies of aquatic insects, we have established a program of active habitat and population management for the Chiricahua leopard frog.

Faunal monitoring is based on museum record surveys, extensive fieldwork, and intensive study initiated at SBNWR in 1985 and in SSV in 1993. This provides a baseline on faunal structure, with indications of change, and complements ongoing study in more pristine habitat west of Tucson. Methods include pitfall trapping, intensive site surveys, road-driving, and breeding amphibian survey.

Population investigations include long-term mark recapture studies of the Mexican garter snake (which is declining critically) and other aquatic reptiles. We are conducting standardized population monitoring of the Chiricahua leopard frog, which may be listed as a Threatened Species.

Leopard frog management has been carried out at the Magoffin Ranch, at SBNWR, in the Douglas Public School system, and at Buenos Aires National Wildlife Refuge. Management efforts in the lower San Bernardino Valley have prevented the extinction of leopard frogs in that region. This frog species often thrives in ranch ponds, and we endorse a program of public-private partnership that can benefit the frog and the local ranching economy. We are preparing a Chiricahua leopard frog conservation plan for the Malpai Borderlands region.

Borderland Blacktails: Radiotelemetry, Natural History, and Living With Venomous Snakes

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The problem of repeatedly locating free-living snakes for observation has been solved for some species by surgical implantation of miniature radio transmitters (Reinert, 1992; Greene, 1994). Using that technology, we are studying black-tailed rattlesnakes (*Crotalus molossus*) in the Chiricahua Mountains, Cochise County, Arizona. Blacktails occupy upland habitats from Arizona to Texas and south onto the Mexican Plateau; adult males reach 1.33 m in total length (Hardy and Greene, 1995) and weigh up to 1.4 kg, whereas females are somewhat smaller (Lowe et al., 1986). Our primary goals are to assemble a detailed behavioral inventory for that species, as part of an effort to understand the ecological and evolutionary diversification of snakes (e.g., see Greene, 1992, 1997), and to publish an extensively illustrated, monographic account of its biology. We also hope to inspire others to study and appreciate such secretive, beautiful, and often unpopular predators. This interim report describes some emerging generalizations about blacktail natural history and comments on the integration of our scientific activities with local human concerns.

Methods

We work in Silver Creek Canyon, about 3.3 km NW of Portal, literally and figuratively on the road to Paradise; the site is about 1.6 km wide and 2.5 km long, 1550-1800 m in elevation, and bordered on the NE by Limestone Mountain. Initially we located snakes by random encounters, and because blacktails are exceptionally cryptic, our sample at first grew slowly. However, telemetered males locate females and those females attract more males; since 1988, we have studied 39 snakes for periods of a few weeks to more than eight years.

We want to observe normal behavior and minimize stress to the study animals, but snakes evidently interpret manual restraint as a predatory attack, in response to which they struggle, may be injured, and may be psychologically traumatized. We therefore handle them gently with tongs, hooks, and plastic tubes (Murphy, 1971), and use inhalation anesthesia for examination and transmitter implantation (Hardy and Greene, 1999). We locate each snake about once a month during the winter, every week or two in the spring, and at least once a day from late July until September. Observations are made with binoculars from a distance of several meters, and snakes seldom overtly react to our presence. Until recently we identified untelemetered snakes on the study area with drawings of unique head markings. Since 1998 we have used passive integrated transponders or "PIT tags" (small glass covered bar codes, injected intraperitoneally) for permanent identification.

Preliminary Findings

Home ranges average about 300 x 700 m for adult males, 150 x 250 m for non-gravid females, and 2 square meters for gravid females; home ranges are irregularly elliptical, with winter sites at their upslope boundaries. Blacktails occupy idiosyncratic and highly repeatable areas, returning year after year to particular rock shelters, rodent nests, prickly pear patches, and so forth.

Chiricahua blacktails prey mainly on mammals, as is the case elsewhere (e.g., Klauber, 1956). We have recorded desert cottontails (*Sylvilagus audubonii*), rock squirrels (*Spermophilus variegatus*), and cliff chipmunks (*Eutamias dorsalis*) in the diets of adults, but their staple is the white-throated woodrat (*Neotoma albigula*). During warm weather blacktails are typically in shade or out of sight beginning at late morning, but in late afternoon and shortly after dawn we often find them hunting in a tight coil and ready to strike: tail hidden, neck in an S-shape, head forward and level with the ground (Fig. 1). Putative ambush coils usually are near

Figure 1. Black-tailed rattlesnake (male No. 9, now under study for eight years) hunting next to a cottontail runway (foreground), having perhaps waited there all night. From a color slide by D. L. Hardy Sr., 0800 hr, August 9, 1996.



an obvious runway, trail, or nest entrance, and we presume hunting sites are identified from prey odors (Ford and Burghardt, 1993). We watched one unsuccessful strike at a cottontail and the trailing of another envenomed rabbit over a distance of about 90 m. Blacktails seek shelter after feeding and sometimes enhance digestion by exposing to sunlight only that section of the body with the food lump.

Blacktails emerge from winter inactivity by early April but, presumably due to dry surface conditions, are often inactive until summer. With the onset of monsoon rains in July, males may move hundreds of meters daily, often in fairly straight lines and evidently searching for pheromonal trails of females. A courting male exhibits a crescendo of "forward body jerks" along a female's back for 30-45 sec, then makes rapid tail-searching movements against her vent. Usually the female beats back his tail with hers and moves away, with the male quickly following her, and these bouts are repeated many times. Persistent males copulate with receptive females, and the latter store sperm in their oviducts until the following spring, when they ovulate, fertilize, and gestate. Males may engage in ritualized combat when near a female, with each male attempting to rise above and topple his rival, but this is rare or at least rarely observed.

We have watched five telemetered females, from mating through postnatal attendance of the young. Upon spring emergence, inseminated females settle at individual shelters, 50-150 m from their hibernacula; these birthing sites are in rodent excavations under boulders, characterized by a dirt floor and an E or SE exposure. Gravid females bask in the early morning, sometimes with only the posterior portion of the body exposed to the sun and the remainder in shelter, then withdraw out of sight for the remainder of the day and night. Births occur in late July or early August, after the first heavy monsoon rains. Female No. 21 delivered two litters of six young each, separated by two years of non-breeding, at different but nearby birthing sites. During the second gestation, we replaced her failing transmitter without problems; young of that litter averaged longer and heavier than those in three other litters. Postpartum females remain in place until the young complete their first sheds, about 8-10 days after birth. Mothers and babies bask in the morning, and retreat into shelter if approached closely; elsewhere a female with young rattled and stood her ground (Savary, 1998). One to three days following neonatal ecdysis and dispersal, postpartum females move to summer ranges and hunt.

Maternal care is widespread in pit vipers, and a likely role for blacktails is protection of the clumped young. Neonate rattlesnakes are sensitive to desiccation because of small size and formation of the new layer of skin, and aggregation reduces water loss (Duvall et al., 1985). Moreover, their eyesight and infrared pit function are probably hampered by the shedding cycle, and they surely are less capable of defense against a large predator than are adults. Seven species of mammalian carnivores as well as various raptors inhabit Silver Creek Canyon, and a gray fox (*Urocyon cinereoargenteus*) and pups denned within a few meters of one blacktail birthing site. Thus, although she might well otherwise catch a meal, a blacktail could substantially enhance survival of her young by attendance during the ten-day neonatal aggregation.

We are particularly interested in the behavior of young snakes, so in August 1998 we gently captured and PIT-tagged litters of 3, 4, and 6 young for future study. Two neonates were also implanted with transmitters, and returned to their siblings and mother without incident the following day. Both juveniles were secretive during the ensuing four months, and moved 150 and 650 m from their birthing site. Young snakes hunt formidable prey, as illustrated by a three-week-old, 20 g blacktail in Portal that had eaten a 26 g brush mouse (*Peromyscus boylii*).

Silver Creek blacktails hunt until mid-October and by early December have migrated to winter refuges, high on the canyon slopes. Most individuals return to the same sites year after year, and two males have used the same refuge for seven years. Some snakes move 100-200 m up slopes adjacent to their summer ranges; others travel up to 1.5 km east into an adjacent side canyon, utilizing sites at similar elevations to those of the first group.

Some Closing Thoughts

Our ongoing field studies of blacktails, like those of several other species (e.g., Duvall et al., 1985; Reinert et al., 1984), illustrate that direct observation of secretive, wary, venomous snakes can be conducted with minimal disturbance of the animals or risk to investigators. We have recorded diverse maintenance and social behaviors of this species, and accumulated thousands of color slides representing most aspects of its natural history. Our strongest, admittedly subjective, impression from this close contact is that snake behavior in nature is far more complex than previously realized. We suspect that blacktails learn about specific habitat features as they grow and enlarge their home ranges, and that this experience facilitates their advantageously repetitious use of the landscape. It is for that reason we focus on long-term observations of individual animals, and that we now seek to emphasize studies of young rattlesnakes.

Dealing with rattlesnakes near dwellings is problematic, in that while some people might commendably not kill the snakes, many also would not like a dangerous animal hiding in the immediate vicinity. A common response (e.g., in Tucson) is to define all rattlesnakes near homes as “problems” and relocate them many miles away. However, most experimentally translocated timber rattlesnakes (*Crotalus horridus*), even in ecologically appropriate new sites, fail to thrive and slowly perish (Reinert et al., 1999). Because blacktails repeatedly and idiosyncratically use multiple habitats, they probably profit from experience in a specific landscape and also would do poorly if translocated. We prefer that people cautiously accommodate resident blacktails and displace them no more than a few hundred meters away from the immediate vicinity of houses, children, and pets. If the snakes cannot be tolerated in the general area, immediate euthanasia might be a more humane fate than translocation.

Portal is a small community, and most citizens as well as some nearby ranchers are aware of our study. In cooperation with local resident Barney Tomberlin, we routinely respond to calls to move rattlesnakes away from houses; we escort interested individuals to view telemetered snakes and we have given several slide shows to local groups about our work. People often seem surprised that rattlesnakes are preoccupied with diverse and interesting activities; we show our guests that blacktails sleep, drink, bask, shed their skins, hunt rodents, eat astonishingly huge meals, mate, fight with each other, give birth, attend to their young, and avoid danger—but that these shy snakes are defensive only when directly threatened, and even then only if they cannot otherwise escape. Our subjective but strong impression is that folks are less likely than they were ten years ago to view rattlesnakes with instant alarm, and they are more willing to tolerate and even grudgingly admire these creatures.

Acknowledgments

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Bird Habitat Relationships in Desert Grasslands

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Grassland-associated bird species have experienced declines greater than any other group of birds in the United States, including neotropical bird species of forested habitats. Numerous studies have focused on grassland bird conservation but primarily in plains grasslands of the Midwest. Less attention has focused on bird species associated with desert grasslands of the southwestern United States. Bird species known to occur in this region have also experienced similar long-term declines.

The focus of this study is to examine how bird species and assemblages distribute themselves across a vegetation gradient in desert grasslands of southeast Arizona and southwest New Mexico. We also wish to determine the range of vegetation types that particular bird species select and if habitat preference differs between seasons. This study was conducted in the San Simon and San Bernardino Valleys of Cochise County, Arizona, and the Animas Valley of Hidalgo County, New Mexico. Our specific study questions were:

1. What characteristics of the vegetation influence the distribution and abundance of particular bird species?
2. Where, along a gradient of decreasing woody cover and increasing grass cover, does a shift in bird assemblages occur?
3. How do characteristics of the vegetation in desert grasslands affect distributional patterns of bird assemblages?
4. How do characteristics of the bird community along our gradient differ between summer and winter seasons?

During the autumn of 1996, we placed 28 1-km transects across a range of vegetation types that represented the diversity of desert grassland within the region. Twenty-two of the transects were placed in Cochise County, Arizona, and six in Hidalgo County, New Mexico. Each transect represented a study site. Our goal in selecting sites was to sample as much of the range in grassland conditions as existed within our study region. All transects were at least 500 m apart to avoid interdependence of samples, and all transects were at least 200 m from riparian corridors to avoid misinterpretation of bird community-vegetation relationships. We attempted to position each transect in generally uniform areas to permit bird-vegetation associations in the larger area surrounding the transect.

During the spring of 1997, two of our 28 sites were burned unexpectedly. We replaced these two sites at the beginning of the summer sampling period. These sites were not included in our between-season comparisons of the bird community.

Bird surveys were conducted from November to February 1996-1997, and May to August 1997. These sampling periods represented winter and summer breeding seasons respectively. Surveys were conducted using the variable-width-strip transect method. Each transect was visited four to five times within each season.

During the fall of 1996 we sampled vegetation along the 28 transects to determine foliage structure and plant species composition. We randomly placed ten 40-m transects perpendicular to the 1-km survey transects. Measurements were taken at 1-m intervals along each 40-m transect. Using the line-intercept method, we measured horizontal cover as a percent by class. Mean percent cover by class and mean vertical height diversity at each study site was calculated as the estimate obtained for each 40-m transect divided by the total number of transects sampled ($n=10$). To obtain a measure of vertical height diversity, we recorded the height class at which vegetation intercepted a vertical line. We detected a total of 49 bird species during November to February 1996-1997 and May to August 1997. Of these species, 22 (45%) were migrants.

A total of 33 bird species were detected during winter. Of these, 13 (39.4%) are known to be wintering migrants to the region. Sparrow species made up 53.8% (7 out of 13) of the migrants. At more than 25% of our sites we detected more than five sparrow species (range = 0-10). Grasshopper sparrows, eastern meadowlarks, horned larks, and vesper sparrows were the most commonly occurring species among study sites. Grasshopper sparrows and horned larks were detected only at sites with <11% woody cover and reached their highest mean frequencies at sites with no woody cover. We detected eastern meadowlarks at all sites.

A total of 36 bird species were detected during summer. Of these species, 11 (30.6%) are known to be summer migrants to the region. Eastern meadowlarks, lark buntings, scaled quail, black-throated sparrows, and mourning doves were the most commonly occurring species among study sites. Horned larks and grasshopper sparrows were confined to those sites with <11.0% woody cover and reached their highest densities at sites with no woody cover. We detected eastern meadowlarks at all sites.

Breeding was observed for 19 bird species during the summer breeding season. All species included in our analyses were confirmed breeding except for Botteri's sparrow and ash-throated flycatchers. Those species not included in our analyses but confirmed as breeding included lark sparrows, rufous-crowned sparrows, and verdins. Black-throated sparrows were confirmed breeding across the widest range of woody cover levels. Horned larks exhibited the narrowest range of breeding areas relative to woody cover.

Results of this study, along with earlier work in desert grasslands of Arizona and New Mexico, show that woody plant cover strongly influences the presence and relative abundance of particular bird species. We focused on a range of sites that did not include high densities of tall (>1.5-m) tree species such as mesquite and acacia. Woody plants on our study areas consisted primarily of shrubs, subshrubs, and small trees (<1.5-m) and did not exceed levels >15% except at one site. This feature was demonstrated by the low occurrence of species such as thrashers, verdins, black-tailed gnatcatchers, kingbirds, and other birds associated with the presence of tall, dense tree species such as mesquite.

We conclude that a gradient of increasing woody cover and shrub species richness along with decreasing grass cover is the primary gradient of our study to which the bird species responded to on a regional scale. Our conclusion is supported by the high number of correlations between bird species and woody plant related variables revealed for both the winter and summer seasons.

Bird species occurring within our study region were similar to those found in studies conducted in the Sonoita and San Rafael Valleys, >90 km to the west. Thus, our study area apparently provides habitat for a number of desert grassland associated species. The region clearly contains vegetation types that range from pure native grasslands (semidesert/plains grassland) and grasslands intermixed

with shrubs, sub-shrubs, and small trees. Notable properties of the bird communities we studied were the rarity of species associated with high levels of woody cover, the presence of sensitive grassland birds, and a relatively rich array of wintering migrant sparrow species. Our results suggest that woody cover plays an important role in determining the presence and abundance of bird species within our study region. Thus, a gradient of woody cover may reveal recognizable shifts in bird assemblages at some level. Levels of woody cover <10% did appear to support sensitive grassland species such as grasshopper sparrows and chestnut-collared longspurs, and levels >10% support a different and richer set of species. During summer we confirmed breeding status for grasshopper sparrows and horned larks. The majority of confirmations were at sites with low levels of woody plant cover (<4%). Thus, within this region there were areas where adequate habitat exists for these sensitive grassland species.

Our results show numerous bird species such as grasshopper sparrows, rufous-crowned sparrows, horned larks, and scaled quail inhabit this region and reproduce. How much these bird populations contribute to desert grasslands as a whole in southeast Arizona is unknown but may be substantial. Some species characteristic of desert grasslands such as rufous-winged sparrows and Sprague's pipit were detected rarely or not at all. This fact is either an inability of our sites to represent the full range of grassland types in the region or merely the rarity of the species. Regardless of the reason, our study has provided valuable information on the grassland bird communities inhabiting the region where Arizona, New Mexico, and Mexico meet. This study provides valuable information on desert grassland bird communities inhabiting a region that has received little attention. Because of the influence this region may have on trends in desert grassland bird populations, we recommend that long-term surveys are initiated to assess the role this region may have in future conservation of sensitive desert grassland bird species.

Regional Fire Planning: Future Directions in the Malpai Science and Resource Management Programs

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Historical Role of Fire in the Borderlands

It has been well documented at this conference and in the literature that natural fire has been a significant influence in developing current landscapes and biotic communities of the Borderlands (Swetnam, et. al. 1996). With the exception of a brief 100-year interlude, fires have frequently impacted these ecosystems and it is logical to assume that all native species have evolved with a great deal more fire than in the recent past.

Since about the turn of the century, a combination of fuels modification by livestock grazing and agency suppression has excluded most fires from the region (Allen, 1996). Partly as a result of encouragement from the Malpai Group, all local agencies are currently using a "confine, contain" strategy of fire suppression and several prescribed burns have been accomplished in the area. The 1995 *Federal Wildland Fire Management Policy and Program Review* encourages federal agencies to reexamine their approach to fire management and suppression.

Species Management vs. Ecosystem Management

Certain parts of the Endangered Species Act have been interpreted to require a single-species approach to preserving threatened and endangered species. Proponents of this viewpoint advocate a species-by-species analysis of effects of any proposed management action, without consideration of broader ecological impacts. This can lead to interesting paradoxes. For example, proponents of the Mexican Spotted Owl often advocate total protection of forests from disturbing factors such as fire and timber harvest. This produces a thick, old growth forest (for a while) and is totally detrimental to habitats for many special interest species, including the prey of the Mexican wolf and jaguar.

We, in the Malpai Borderlands Group, believe in an ecosystem-based approach to all land management decisions. The basic philosophy is that "if we take care of the ecosystem, the species will take care of themselves." Habitat quality for all species of native wildlife and plants can best be maximized through the great degree of biodiversity that results from the natural role of fire in the ecosystem. It is neither practical nor desirable to attempt to restore some mythical pre-Columbian condition; but the restoration of natural ecological processes is an attainable and worthy goal.

The Malpai Science and Resource Management Effort

As the various partners in the Malpai Borderlands Group have strove to sustain open space and healthy ecosystems through profitable rural enterprises, barriers have arisen involving perceived impacts on environmental values. A great deal of time, resources, and emotion has been invested in satisfying the many concerns about potential impacts on endangered species and other environmental parameters. If ecosystem management on this million-acre area is to move forward, more efficient ways of addressing these many concerns must be developed. A programmatic approach to planning and environmental analysis shows promise to simplify these processes. A similar ecosystem approach to endangered species evaluations would also be of great benefit. A current climate of distrust among disciplines and between agencies is a major detriment to innovative management for the Region. The Malpai Borderlands Group has the potential to bring the many factions together in a spirit of collaboration, but this will require a willingness to compromise and re-evaluate positions on everyone's part.

The Malpai science effort will, of necessity, continue to focus on effects of fire and grazing on special interest species of plants and animals. As the regional fire plan is completed, emphasis will shift from planning and evaluation to monitoring. Careful monitoring of the results of management will contribute greatly to future planning. Only through adaptive management can we expect to positively impact such a large, complex landscape.

In addition to a continuing investigation of ecological/biological factors, we must find better ways to address the social/political forces that have such a great impact on management of natural resources throughout the west. Any movement toward a more enlightened fire management policy will require acceptance, not only by the myriad of regulatory agencies, but also by the many interested publics of the region.

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Panel Session: Condensed Notes

Gerald J. Gottfried, Research Forester, USDA Forest Service, Rocky Mountain Research Station, Flagstaff, AZ, and

Cathy E. McGuire, Tucson Soil Survey, USDA Natural Resources Conservation Service

Peter Warren, *The Nature Conservancy: Moderator*

There is a wide variety of information and we need to put it together for collaboration for managing this planet. There is a tremendous amount of value in the Borderlands landscape, and the people attending this meeting care about keeping the land more or less the way it is now. Most of us, whether biologists, ranchers, or agency land managers, are committed to the idea of managing the landscape and keeping it healthy. We need to integrate all of the different points of view into the process and make good decisions so that we can get the outcome we want within a few years. It takes time to gather good information to assess how we are doing. It requires a long-term commitment. Each of us approaches management with certain constraints imposed on us by regulations, economics, or ecology. To be successful, we must understand each other's constraints. Understanding each other's constraints and approaches will help us do a better job of managing and living with this landscape.

John Cook, *The Nature Conservancy*

I have worked with the Malpai Borderlands Group for the last three or four years. The people at this meeting represent the future of this area, and the decisions that are made and the ability to work together will determine the fate of one of the most important places in the United States and beyond. Most people have their own preconceived ideas about landscape management but they need to be able to look at landscapes differently.

The number one threat to everyone attending this meeting is the fact that as land prices rise from agricultural values to development values, we will continue to lose these incredible areas right here as we have everywhere else across the United States. At night I can look west and see the lights of all of the towns in southern Arizona, while to the east, it is almost completely black. That's the goal, to keep it black. It is not easy and will take a long time.

There are two key issues. One is species management; managing for the individual needs of a thousand different species on several million acres will not work. It is the habitat that counts. How do we go from a species view to a systems view? The other issue is regulatory decision making. Sometimes, decisions must be made within a 120-day period mandated by Federal law, which is driven by litigation. These 120-day decisions can have a major impact on a huge part of the landscape. How do you make decisions about how management of an allotment will affect a species during a 30-year drought cycle or how do you evaluate large system interactions such as fire and burning interactions? We do not have 30 years to figure this out. Change, driven by land values, is acting on the landscape so fast that if we do not figure it out, we will not have this land to study, manage, and call our home in the future.

Larry Allen, Coronado National Forest

I am going to talk about the future direction of fire planning. The landscape is changing because of a number of factors, one being the exclusion of fire. There are no simple reasons for the reduction of fire in this ecosystem. We have a new federal fire policy that encourages us to innovate and to look at fire management differently than in the past. I am encouraged by this policy; it is a real step forward. However, as we start to apply it on the ground, we must consider other regulations, and it becomes difficult to do things differently in this litigious society. Many challenges have to do with environmental concerns, particularly the endangered species. The single species approach makes it difficult. There is a perception that we have to examine the impacts of our actions species by species. It is difficult to manage a unit of land for two endangered species that have different, conflicting habitat requirements. We must focus on the system rather than the species. The term ecosystem management has different meanings to different individuals. The idea that habitat counts is fairly well accepted. We are here today to get the right scientific information to make the right decisions.

We have been doing a great deal of research on fire planning, management, and effects. Research will continue into the future; funding appears adequate. The Peloncillo Plan should be finished next summer and the one for Arizona state lands has a similar timetable. Fire planning for this area will be done before research results are available. We need to switch from scientific investigations to monitoring to see if our activities are meeting their goals—in other words, practicing adaptive management. Do what you think is right, and if it does not work, change it. Scientific work in the Borderlands will continue and we will learn more and have more symposia. We need a tremendous amount of monitoring.

***Randall Smith, Natural Resources Staff Officer,
Coronado National Forest***

The amount of research coming out of the greater Malpai area has increased phenomenally over the past five to 10 years. It is going to directly help our management processes. It is important for all of us to understand the regulatory landscape that we all have to operate within as a matter of law. I am speaking about the livestock grazing authorizations and where we are with them. There are 13 allotments in the Malpai area, so quite a few operators depend on Forest Service lands for their livestock operations. Some of the fundamental goals of the Malpai Group cannot be achieved without these allotments. They are fundamental to where we go in the future.

Livestock grazing authorizations are for 10 years. There are many laws that cover authorizations but I will focus on the three principal laws. They are the National Environmental Policy Act (NEPA), the National Forest Management Act (NFMA), and the Endangered Species Act (ESA). The Coronado National Forest covers about 1.8 million acres and contains 200 allotments with more than 30,000 head of cattle.

Two-thirds of the 200 allotments are not in compliance with NEPA, and only five to 20 are in compliance with ESA. We are in good shape with respect to NFMA. We comply with NEPA by preparing an environmental assessment document for the grazing authorization. In the case of ESA, we need a formal or informal consultation, whichever is appropriate, for the species that are present. The Coronado is unique because of its landscape diversity and number of listed rare species. There are more than 26 listed species in the Forest including snakes, bats, plants, and large mammals. The number of listed species on the Coronado is greater than any other forest in the Southwestern Region.

We are trying to figure out how we can be legally compliant with ESA in an efficient, expeditious manner. In the past, we have tried to bring compliance within a 10- to 15-year schedule by focusing on completing environmental assessments. An allotment would be ESA compliant once an assessment was done. But, we found that this procedure was not expeditious, especially in the context of national courtroom rulings. Grazing is an ongoing activity, and by law, ongoing activities must be in compliance with both ESA and NEPA. A 10- to 15-year schedule is not working, and litigation has reinforced the notion that it is not working. In 1997, we had a lawsuit on two of our allotments, but in 1998, a lawsuit was filed on 47 allotments. The existing process is not working, but there are no easy solutions. We must find a way to be creative, make progress, and become legally compliant so that we can get on with the job of ecosystem management and with the other things we want to do.

The Coronado has decided to do things differently. We have taken the 12-year NEPA schedule and compressed it to a three- to four-year schedule. This has resulted in a three- to fourfold increase in our workload. In some cases, we are grouping allotments, thus using more of an ecosystem approach. We have formed a dedicated core team, with individuals whose primary job is to prepare documents and get the job done.

It will still take four years before ESA requirements are covered. We needed to do a better job with ESA. We decided to do a forest-wide assessment of all 200 allotments. Last year, our team worked on this job. It was a tremendous effort, but we got it done.

There has been some concern expressed about this consultation, and some people have expressed resentment about it. However, some permittees view the consultations differently. A permittee in the Nogales area was concerned that her operation would be at risk because the Forest Service had not done its job required under the law, and was glad that the Coronado was about to take care of the situation. Our goal is to try to redeem our responsibilities in the most efficient, practical manner possible. It took an enormous effort, especially as our time line got compressed. In case of an injunction, our attorney said that the best way to show faith to the court was to show that consultations were initiated and that we are doing our job and to request that we be allowed to continue.

The Coronado has received feedback on the notification letter. The letter went to permittees that had a "may adversely affect" situation for one or more species, and directed that a consultation take place. The feedback was that the tone of the letter was harsh and bureaucratic, especially the words "may adversely affect." The letter scared people. Unfortunately, the choice of words in the letter is dictated by laws. The language in the letters must be carefully crafted and worded with the aid of lawyers, especially when the Forest Service is under litigation.

We had intended to include more information in the letter and speak in a more person-to-person manner. However, I am still working on these enclosures with our attorneys. The threshold for an adverse effect under the ESA is low. If there is an identified potential risk for some level of impact, we have a "may adversely affect" trigger that requires a formal consultation. The language in the ESA indicates that there is a potential for impact and does not consider the degree of impact. The impact could be low and just affect a few individuals.

A determination of adverse effect does not end the discussion, but begins it. The purpose of the formal consultation is to discuss the level of risk and what it means in a particular situation. An example is the ridge-nosed rattlesnake map. We can provide it to the Fish and Wildlife Service during the consultation period once it becomes available. We can discuss the use of the information with them and see how it is used in the formal opinion.

Here is what was done in this example. The information has been collected for almost a year. During that time, there were numerous informal communications between district and supervisor's office personnel and the permittees. In August, when we knew that we would soon complete the assessment process, we sent an official letter of notification to all permittees letting them know that we hoped to complete the effort by October 1 and initiate consultations. We did not start consultations until November. Then, we sent another written letter to all permittees letting them know what the decisions were and whether they had an adverse call on their allotment. We invited the permittees to supply information and provided them with a potential for applicant status. The Coronado also has a full-time coordinator liaison in the Malpai area to provide the permittees with information during the process.

Three out of the 11 listed species in the Peloncillo Mountains have been identified as having adverse effects and two are bats, which have similar requirements and are considered together. So for discussion purposes, we have two species under formal consultation: the ridge-nosed rattlesnake and lesser long-nosed bat. Neither species falls into the category of having complex, difficult issues ahead within this 1.8 million-acre area.

As to how research and management can cooperate, we have a catch-22 situation. We often have little information about rare species because they are rare. However, they often get listed because we lack sufficient information. The Forest Service must follow regulations once a species is listed; it cannot wait for new data but must use any available information. A time lag occurs because research usually is funded only when a species is listed, but it then takes a couple of years to gather the information.

We almost have a final opinion with respect to the lesser long-nosed bat on the two allotments that were in litigation. The main thrust is that we want research to gather the information so that we can make intelligent decisions about its future. We want to find out about the effects of grazing on agave reproduction and demography. If new information necessitates a re-initiation of consultation, then we will visit it at that time. The benefit is that you have the regulatory agency saying that the proposed action—livestock grazing—is all right at this time, and that we approve it and think that the risks are low enough. We set aside money last year to get research underway and are working to get a program going. The Tonto National Forest has indicated that they will contribute some money too. We want to be further along in achieving the goals that John Cook mentioned. It is vital to all of us; however, at the same time, we have to operate within the laws and regulations.

Patricia Roller, Biologist, Fish and Wildlife Service

I am going to talk to you about my view of protection of endangered species and what my goal is in the Malpai area. I primarily work with fire projects, so I will talk about fire, the conservation of endangered species, and incorporating a systems approach. The first phase of the Endangered Species Act is: "...to protect the endangered species and the systems that support them." Some species in the canyons of the Malpai support Mexican spotted owls, ridge-nosed rattlesnakes, mountain skinks, maybe green rat snakes, and a multitude of very important rare plants. These canyons have some of the highest historical fire frequencies. I try to incorporate those things and think about how we protect and manage multiple species. We need to focus on the whole system. The systems are dynamic and complex, so this is difficult—especially when you are trying to do it within the law.

Law is discrete. We have had to make adverse effect calls on recovery actions. I have to figure out how to reduce short-term adverse effects in order to get long-term benefits. Most fire actions are recovery actions, at least where fire played an historical role. I have to come up with a way to get fire back, reduce the short-term adverse effects, and do it in a timely manner, covering all of the bases so someone does not sue.

The Maverick Burn is an example of a recovery project. I wrote the biological opinion. I am working on the Peloncillo Fire Plan with Larry Allen. We are going to have to come up with creative ways to put fire in the landscape. I am working on some other plans too; it takes time and communication. I am committed to fire and communications down here. It takes communication and commitment to common resources to sustain this landscape.

What is the difference between formal and informal consultations? Formal is a permit to do something; we are giving you a legal document in a formal biological opinion saying that this use of the land is legal. It will not jeopardize the continued existence of these species. My job is to help land managers come up with ways to make effects less severe. The trigger for a formal consultation is very light. It is an effect on any scale—if you harm one fish of a listed species during a stream restoration project, you need a permit, even if stream restoration is beneficial. If you do not have the permit, the public knows how to make sure that you will get one.

Bill McDonald, Rancher

The full text of Bill McDonald's comments during the panel has been incorporated into his earlier presentation.

James Brown, Professor, University of New Mexico

I am going to talk about the role of science in the Malpai Borderlands Area. I am here because I love this area with its huge amount of open space, the enormous variety of wild habitats, and the incredible biodiversity. I want to keep it that way.

I want to make two points to give you an idea of the diversity of this area. The Coronado National Forest has the highest species diversity of any National Forest in the United States. My little 50-acre study area in the southern part of the San Simon Valley has more species of native rodents than occur in the entire states of Pennsylvania or Michigan. The other point is that we have heard that aquatic and some of the riparian habitats in this part of the world have been seriously degraded and impacted by preemption of water, introduction of exotic species, and so forth. On the other hand, the terrestrial habitats for the most part are in good shape. They have been grazed for over a hundred years and still support high diversity. We want to figure out how to keep that diversity going.

My role as a scientist is not to tell you what you want to hear. A scientist's role is to get the facts about nature to the best of his/her ability and to interpret those facts so that we can understand how nature works. A scientist then makes those facts available to the rest of the scientific community and to managers so that they can be applied to guide their policy.

My first remarks are directed to the scientists. We have heard a great deal about very interesting research that is being conducted in the Borderlands, much of it in the past few years, much supported by some very futuristic, visionary actions by a number of agencies and individual scientists. It is important that this research be published in peer-reviewed scientific literature, to ensure that it matches the standards of accepted scientific editing. Ignore the rejections, and get them

published. The agencies and organizations that are supporting the research should pressure their scientists to publish in a peer-reviewed form. It will make a difference in the long run in the credibility of the research that we are doing down here.

As for endangered species, I agree that some of our strongest environmental laws require that we deal with one species at a time, whereas we really have to manage environments on an ecosystem and landscape scale where we have multiple species and multiple concerns. We need to get scientific information into what species are listed and what species are de-listed. There are species, such as the ridge-nosed rattlesnake, holding on in small populations because of unique features of their biology. If the environment changes because of human management or natural processes, those species are at risk.

There are other species that should not be on the endangered species list; a prime example is the lesser long-nosed bat. There are hundreds of thousands summering in the United States. We must make sure that scientific information gets translated into sensible decisions about how these species are treated. We often tend to think that all human effects are bad and that problems would be solved if we would return to a period when humans were not on this landscape—about 15,000 years ago.

It is important to consider not only what effects cattle have on the landscape but also what are the consequences of removing cattle. An example occurred in the desert of California where the Bureau of Land Management fenced the area around a spring where cattle used to congregate to protect a pupfish. Within two months, the vegetation had grown and had dried up the spring through the increased evapotranspiration. The pupfish population became extinct, the result of removing the livestock. We have seen the same point made by Phil Rosen with respect to the Chiricahua leopard frog. We need to consider the positive as well as the negative effects of cattle.

We need to consider the long-term outlook as well as the short-term future. We must worry about the long-term effects of different grazing regimes on the landscape, the long-term effects of fire, and how we can put fire back into this landscape. Even though fire may kill a few things in the short-term, it has been part of this system for a long time, and if we do not put it back, we are going to continue to create a more unstable, potentially disastrous situation.

I want to address how scientific information is used. The fact that we are here today and that this dialog has gone on is largely attributed to Bill McDonald and the ranching community that he represents. I am encouraged by the open and good understanding that has developed between the ranching and scientific communities. I am concerned that we do not yet seem to have some government agencies in the loop in the way that we would like.

The scientific community faces surprises just like the ranching community. We see decisions that appear to be made on grounds that should depend on science, yet scientists were not consulted. Frankly, I think that in some cases the science put forth in decisions is suspect. I know that the agencies have to deal with the laws and are concerned about litigation; however, it should be possible to do the right thing and cut out a lot of this stuff. I want to see that the science we have talked about this morning gets converted into activities here on the Borderlands. I want to see science not just in the decisions that ranchers make daily but also incorporated into agency decisions, particularly with respect to endangered species. It is clear that there is still room to improve communications. I hope that we can, because if we do not, this coalition that we have formed here is not going to be able to do what we hoped and may not stay together.

Open Discussion

An open discussion followed the panel presentations. One topic concerned the roles of government entities and taxation policies in encouraging the maintenance of an unfragmented landscape. Several of the presenters felt that more government intrusions were not the answer. The economic well being of the local population is key to maintaining undivided open spaces. Another issue was the relationship between economics of ranching and the impacts of the prescribed burning program. While most of the participants favored the program, discussion centered on where to take livestock when areas are being rested. The temporary loss of some pastures could cause an economic hardship. The need for more local cooperation between ranchers and government agencies on grazing issues also was brought up. There was a feeling that there was a potential of forming groups similar to the Malpai Borderlands Group in other parts of the West. The Malpai Borderlands Group has been successful in getting its message out at a national level; while much of the reporting was helpful, some television shows appeared to have an anti-grazing bias. There needs to be more communications between the ranching and environmental communities; both are against landscape fragmentation. One person stated that there was more common ground than differences among the meeting participants. The common grounds are love of the area and the recognition of the need for: functioning ecosystems; an economic viable ranching economy; good science; and the need to do something. We agree that no one wants species extinction and that we must adhere to the laws. The final comment was that success depends on open communications.

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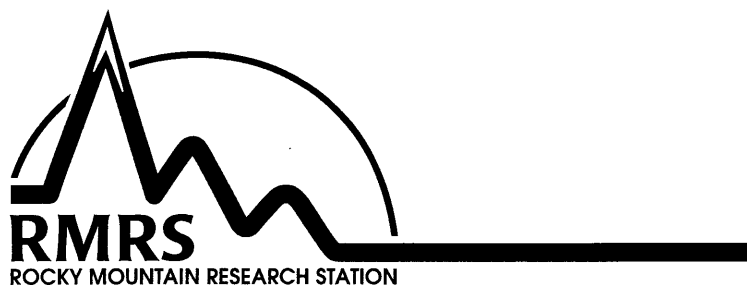
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