The New Mexico Botanist
Special Issue 1 September 29, 2008

NATURAL HISTORY OF THE GILA

A SYMPOSIUM

held

October 6-8, 2006

at

Western New Mexico University
Silver City, New Mexico

Contents

Introduction

The Gila region in southwestern New Mexico is an important area for biodiversity and cultural history and possesses unique natural resources that include the Gila River, New Mexico's last major undammed river. The *Gila region* is here broadly defined as the Gila National Forest in southwest New Mexico, as well as surrounding lands and mountains that include the Black, Burro, Mimbres, Mogollon, and Pinos Altos ranges, and all their drainages, including the Gila, San Francisco, and Mimbres rivers. Scientific and cultural research has been conducted in the Gila region over the years, but surprisingly little of it is readily accessible, being unpublished or buried in government agency offices. Recently, scientists in southwestern New Mexico have realized the great need to document, highlight, and share scientific and cultural insights about the region, as well as to identify areas for future research.

Late in 2005, the Gila Conservation and Education Center in Silver City, NM, formed a steering committee to investigate research possibilities in the Gila region and to consider putting together a symposium that focused on past and current research conducted in this region. On October 6–8, 2006, after two years of planning, the first Natural History of the Gila Symposium was held at Western New Mexico University in Silver City. Attended by about 150 people, was a tremendous success, as researchers from regional universities, federal and state agencies, and conservation organizations presented and discussed topics and issues pertaining to the Gila region. The social gathering at the historic Buckhorn Opera House in Pinos Altos will not soon be forgotten, and the field trips the following day highlighting the flora, fauna, restoration efforts, and environmental issues of the region were likewise memorable.

Publication of the symposium proceedings is possible thanks to Kelly Allred's gracious offer of *The New Mexico Botanist* pages. Editorial help and reviews were conducted by Kelly Allred, Paul Boucher, Jack Carter, Richard Felger, Jean-Marie Haney, Kelly Kindscher, William Norris, Dale Zimmerman, and several anonymous reviewers. In addition, Sarah Johnson, a professional editor in Gila, NM, was hired to copyedit the publication. We hope you enjoy the papers and abstracts presented in these proceedings, and look forward to your participation in the second Natural History of the Gila Symposium, scheduled for Oct. 16–18, 2008, again on the Western New Mexico University campus in Silver City.

— Kelly Kindscher and William Norris, editors of the proceedings, on behalf of all steering committee members: Jack Carter, Trish Hurley, Kelly Kindscher, Reese Lolley, Patrice Mutchnick, William Norris, Peter Russell, Martha Schumann, Donna Stevens, and Art Telles

Keynote Address: Natural History of the Gila Symposium—October 6, 2006

Marcia R. Andre

Deputy Director Fire and Aviation, Southwest Region—
USDA Forest Service, Albuquerque, NM

I am pleased and honored to welcome you to this important symposium focusing on something that is so near and dear to my heart—the natural history of the Gila. We are so fortunate today to be joined by the dedicated scientists who have worked so hard to tell the Gila's story, and to help inform management so that better decisions can be made.

I'd like to give a special thank-you to all the groups and individuals who worked so hard to prepare for and sponsor this event. In particular, I'd like to thank Dr. John Counts and all the faculty and staff at WNMU for hosting this event on campus.

Looking ahead at the concurrent sessions today, I suspect that, like many of you, I will have a very hard time choosing among the three venues. This symposium is a tremendous and long-needed opportunity to consider the body of research that has been conducted over the years, to consider together the interaction of all this work, and to evaluate what kind of work will be needed to better inform management direction and decisions for the Gila National Forest. The timing could not be better as we move forward within the next year or two into Land and Resource Management Plan revision.

There are several areas where I expect to see continued focus for the Forest Service over the next few years: the demand for water; the restoration of Fire Adapted Ecosystems (FAE); the protection and restoration of habitat, particularly riparian, for Threatened and Endangered Species (TES); the impacts of non-native and invasive species; and unmanaged recreation, specifically off-highway vehicles (OHVs).

The demand for water from National Forest System lands continues to increase as the population increases. Our riparian areas and watersheds must be in proper functioning condition, have sustainable surface flows, and contribute to groundwater supplies. Subsurface aquifers must not be contaminated. The focus on "who gets the water" must yield to a conservation-oriented focus on how we use water, along with increased emphasis on providing sustainable flows to meet the demands of our thirsty nation.

- The demand for water will increase as the population of our country increases.
- National Forest System lands supply 14% of the total runoff, excluding Alaska.
- In the western United States, over 33% of all fresh water flows from National Forest System lands.
- Our management practices must be carried out in a manner that improves riparian condition and function.
- We must invest in watershed restoration/health today to meet the increasing demand for water tomorrow.
- The study of riparian systems and how we can improve them is still a young science.
- Restoration treatments must focus on increasing the amount of riparian area and the quality of watershed health to maximize sustainable flows throughout the year.

As I look ahead, I am confident that the **restoration of fire adapted ecosystems will continue to be a national, regional, and local emphasis**. Across the nation, there is an emerging realization among our publics and widespread acceptance within academia and among research scientists, agency personnel, and elected officials that decades of fire suppression, along with other management practices, have altered ecosystem structures. Over the last 10 years we've experienced uncharacteristic fires throughout the nation. In some areas, we are experiencing fire behavior unlike anything we've seen in the past. Many of you have been at the forefront in helping us move in a very different direction, and we should be very proud of the work done here in southwest New Mexico. We are viewed nationally as leaders in the restoration of fire adapted ecosystems, in particular our Wildland Fire Use (WFU) program. We are seeing the benefits of fire's hand on the land, as the use of fire for resource benefit is spreading throughout the nation from the swamps in the Okefanokee, through Arkansas, and into the northwest.

There are many associated questions that we need help with. For example:

- Considering prescribed fire, coupled with opportunities for WFU, what should be our rate of treatment? And what are the priorities for treatment? Given that the Gila is roughly 3.3 million acres and much of it historically burned every eight to twelve years, is the current rate of combined treatment really making the difference we think it is, in terms of restoration of fire adapted ecosystems? I ask myself the "lifetime question" very frequently. Will my leadership truly make a positive difference on this landscape in my lifetime, or is the rate and pace of change inadequate? Is it feasible to do more in a manner that is safe for people and resources?

Fortunately, new tools such as LANDFIRE are helping answer those questions, as you will hear in some of the breakouts today. The recently completed Version 1 of the Gila's Signal Peak Landscape Assessment demonstrates the potential broader application of the LANDFIRE data, which can be applied to a large-scale landscape for design and prioritization of work. This will help us answer some of these questions.

- While this symposium focuses on the natural history of the Gila, there is another component that is critical to our success in restoring FAEs, and that is the human component. Air quality continues to be a driving issue in our ability to use prescribed (RX) fire or manage natural ignitions for resource benefit, particularly in the more urban areas of the West. EPA's recent reduction of the PM 2.5 national Ambient Air Quality standard from 65 to 35 micrograms per cubic meter (average over 24 hours) has the potential to significantly impact our RX burning and WFU program. The adverse health effects of high levels of smoke are well known. We're fortunate on the Gila that after many years of intense education efforts, a high percentage of our local publics are supportive of the use of fire to help reduce fuel accumulations. However, this will continue to be the most limiting factor in our ability to use fire. More work is needed, or perhaps a social assessment to identify those populations or individuals who are most concerned or impacted. While we need to continue to educate, we also need better information as to how to mitigate and address these concerns. We need to continue to evaluate what service can be offered to residents during periods of high smoke.

Another area that my crystal ball says will have continued importance to us in the future involves the protection and restoration of habitat for TES. The Gila Trout is a true success story and many of the folks in this audience deserve the credit for that.

- I believe that the work we are doing to restore fire adapted ecosystems will help us protect and enhance habitat for all of those plants and animals that evolved in a fire-dependent landscape. I recognize that there can be short-term adverse impacts. I think that in the long run we will eventually be at a place where our plants and animals no longer face the threat of extinction due to uncharacteristic wildfire, if we continue the emphasis of restoring these habitats with the use of fire. However, we need more information about that to make sure we don't inadvertently create an unacceptable outcome due to management's actions. Some of this will be discussed further in some of the concurrent sessions today. My hope is that this symposium will allow us to synthesize the work done to date, in particular related to the effects to TES, and help us determine what additional work is needed in this area.
- While we've done a great deal of work over the years to protect and restore riparian habitats, focusing mainly on exclusion of livestock grazing and other activities through fencing, other methods are needed. Research is needed as to what degree of riparian use can occur while still preserving the system and species integrity. There is very little information, for example, on the benefits or impacts of limited cattle grazing in riparian areas, in contrast to the many overgrazing-versus-no-grazing comparisons that have been done to date.
- We also need to know more about the potential impacts of non-native or invasive species on the Gila. We are fortunate in this regard compared to many areas in the West. One of our major concerns is in the effects of non-natives (fish, crayfish, and bullfrogs) on southwestern warm water fish species. While we know that predation, competition, and hybridization with non-native trout are major problems our native trout face, great strides have been made in recovery. It is a different story with native warm water species such as spikedace, loach minnow, and the chub complex. Currently, most if not all populations of native fish on the Forest and in the Southwest are declining or remaining static at best. We suspect that non-natives are a major force behind these declines; however, it is not likely a single factor but multiple factors that are the cause of declines. Currently the most imperiled species on the Forest and likely within the Southwest is the spikedace. The Gila is the stronghold for the species, having two of the three known remaining populations within its boundaries. One of these populations is fairly robust; however, the second has seen declines over the last several years. More work is needed in this area.

My fifth and last crystal ball image involves the impact of unmanaged recreation, specifically OHV. On November 9, 2005, the Forest Service published a new Travel Management Rule, governing OHV and other motor vehicle use on national forests and grasslands. The new rule requires each national forest to designate those roads, trails, and areas open to motor vehicle use. For those of you participating in the field trip with Chris tomorrow you will clearly see the reason why a change is needed. OHV damage to vegetation and highly erosive soils is occurring. Disturbance to wildlife is increasing. Unplanned creation of new roads creates conflicts between users and damage to resources. OHV purchases and use are increasing, fueled by expensive media ad campaigns. Our Ranger Districts are preparing preliminary proposals for a designated travel system at this time. Environmental Analysis will occur over the next couple of years with the goal of having final maps of the system published by 2009. This will be a big job for the Gila. It will be highly controversial. It is the right thing to do.

The demand for water; the restoration of FAE; the protection and restoration of habitat, particularly riparian, for TES; the impacts of non-native and invasive species; and unmanaged recreation, specifically OHVs, are just five of the heavy hitters that I chose to include in this presentation today. They are not the only challenges we face on the Gila. Fortunately, with the help of partnership dollars, we have been able to weave wildlife and watershed programs under the FAE umbrella by pooling dollars to implement landscape-level prescribed fire activities.

However, we face tremendous challenges in accomplishing several other program areas where these linkages do not occur. Facility management of roads, trails, recreation facilities, and administrative sites are all experiencing declining budgets. Grazing management continues to be a huge and controversial focus area with more challenges than available funds can begin to cover. Yet there are many partners and permittees who, through good stewardship, are helping us move in the right direction.

Lands and special uses are other areas that challenge us to meet our customer service responsibilities, as does the increasing walk-in-the-door business. The centralization of business processes agency-wide has created a tremendous shift of responsibilities to our field-going personnel.

These are frankly tough times for us and they would be even worse without the help of partners like many of you.

Together we share a passion for this amazing place.

Together we must continue to be mindful of our responsibility to the seventh generation.

Together, we must do all we can to restore the natural role of fire to the landscape so that the amazing diversity of plants and animals on the Gila will continue forever.

Tom Wootten: A Great Friend

Gene Jercinovic

6285 Algodon Road SW, Deming, NM 88030

Tom Wootten will be deeply missed for years to come. He was a humble, committed, gentle, and generous man. Greatness is accrued by some through their quiet ignorance of their own importance, their dedication to service without song, and the simple honesty of their giving. Such was this man.

Tom was born on March 20, 1939, in Chickasha, Oklahoma, about 30 miles southwest of Oklahoma City. It was his grandfather who had established the family there, having relocated from Mississippi. At the dawn of the 1940s, grandfather was again on the move, purchasing a ranch in Union County, New Mexico, not far from Clayton. Tom's father, John Belton Wootten, had always dreamed of being a rancher; in 1942 he decided to move his family to a house in Clayton and from there to manage the nearby ranch. At the time of this move, John and his wife, Marian, had four children—John Jr., William, Tom, and Janice.

The ranch was quite a spread, thousands of acres. At its height, as many as 1000 head of cattle roamed the grassland. In the forties, it provided a good life for the Woottens. However, the fifties brought serious drought and a paucity of grass. John was very proud of his herd and decided to send the cattle to feed in the Flint Hills area near Emporia, Kansas. When he got them back, the bill was so large that he would never repeat the experience. He decided to change his range-management procedures, reducing his herd by half. In that way, in years when the grass was good, he could keep the calves for the year, but if the grass supply was short he would sell the calves. This decision greatly impressed a young Tom. In his words: "More of our ranching community, I think, needs to be more flexible in the way they manage their livestock."

Tom attended public schools in Clayton all twelve years. He felt he was about average scholastically, was good in music, and was a very, very poor athlete. His only interest in plants was in growing vegetables. Biology was his least favorite of the sciences, though he very much liked the Clayton High science teacher, who taught all the school's physics, chemistry, and biology classes. As a sophomore, when he had to write about what he would choose as an occupation, he couldn't decide between ranching and physics. By the time he graduated, in 1957, he was determined to be a physicist.

That fall, he entered New Mexico State University in Las Cruces as a physics major. He actually might have preferred chemistry, but was told NMSU offered no higher degree than a master's in chemistry, but did offer a PhD in physics. Tom didn't do well and didn't really apply himself. He didn't care much for the physics professors or for "messing around in a lab." And somewhere along the line he developed an interest in banking. His older brother John worked in a Clayton bank, which meant working in a nice, clean, cool place, with short hours, meeting lots of people. Tom thought that was "pretty keen." He had always liked people, although he felt shy around strangers. He changed his major to business administration. He also met a coed named Eleanor Gose and fell in love. His grades showed a notable improvement.

Tom graduated at the end of the 1961 spring semester. Since he had been involved with the ROTC program, he was commissioned into the United States Army the following week. The week after that, he married Eleanor. He was supposed to begin a six-month tour of active duty at the end of the summer. Meanwhile, he had gotten himself a job with First National Bank in Kansas City, a bank where his grandfather had done business and which he and his father had visited, meeting some of the staff. The bank was looking for someone with a business degree who had experience out west and familiarity with livestock investing. Tom worked for the bank for three months and then reported to the army. Just before reporting, however, the Berlin Crisis erupted, and his six-month stint was summarily extended to two years. Most of this time was spent at Fort Hood, near Killeen, Texas. In October 1962 the Cuban missile crisis rocked the nation. Tom's unit was ordered to Florida to get ocean experience and practice a beach invasion in a landing ship tank, but the waves were high and the craft merely went out five miles and returned. Tom's military career ended softly.

In 1963, Tom took Eleanor and their baby, Tom Jr., back to Kansas City. (Three more children would be born there: Marianne (1965), David (1968), and Margaret (1971).) In his early days at the bank, he was involved with livestock inspections, traveling frequently to Wyoming and New Mexico. Being away from home became increasingly difficult and Tom wanted a change. In 1965, he landed a position in the trust department, where he began managing municipal bond portfolios for First National's associate banks. He enjoyed the trust department and did well, moving from the lowest-ranking officer to second highest in the department by the mid-1970s. (He also began to do his own investing, having taken to heart his father's advice, "No matter how little you make, always save some.") With his promotions, he was forced to see more and more of the bank's internal politics, which he didn't really like. He realized when he reached second-in-command that he did not want his boss's job.

Tom's father died in January 1975 and Tom left the bank in August. He had no real plan, but a friend in Carlsbad, New Mexico, convinced him to move there. Tom wanted to get involved with something that would get him outdoors. He considered farming, but felt he wasn't good enough with mechanical things to be successful. By 1976 he had decided to go back to school. He moved the family to Las Cruces and entered NMSU in the fall to pursue a bachelor's degree in horticulture. It was during this time that he became acutely aware of public-lands abuses and developed his interest in environmental issues.

Because he already had a bachelor's degree, and because he wasn't working and could concentrate on his studies (in addition to managing his father's estate and tending a massive backyard garden), Tom was able to pursue his degree through a two-year program. This meant that he took only useful, plant-oriented classes. He studied pest management, entomology, plant pathology, and botany with Professor Sandy Dick-Peddie, with whom he developed a lasting friendship. Through a quirk in scheduling, Tom found that he would be unable to take plant taxonomy. He found this intolerable and decided to discuss the problem with the professor, Richard Spellenberg. Tom went to his office and introduced himself. Dr. Spellenberg asked if he was related to E. O. Wooton, the first professor of botany at NMSU. He wasn't, of course. They worked out an arrangement whereby Tom attended the class part-time for partial credit. So began another long friendship.

After graduating with a Bachelor of Science in Agriculture in 1978, Tom worked briefly with a tree-pruning service in Las Cruces. By this time he had developed definite ideas about the use of water resources and the value of native plants. In his backyard he began growing native plants for landscaping, which he sold at the farmer's market. Tracking down seeds included harvesting his own from nearby areas. He also procured seed from Plants of the Southwest, which had recently opened its doors, and from Mountain States Wholesale Nursery in Phoenix, whose owner, Ron Gass, was inspirational. Tom wished he could work in a nursery business where he could help educate people about native plants. There was no such facility in Las Cruces, so he decided to start his own.

In 1983 he broke ground for Dry Country Plants. The nursery focused on native plants but was not limited to natives. Tom felt that drought-tolerant plants from other areas such as the Mediterranean could do well in Las Cruces and should be used for the benefit of water conservation, as long as they were not invasive. Tom enjoyed a term that originated at Texas A&M and which summarized his philosophy on landscaping: "resource-efficient plants." He used weekly newspaper advertisements to try to educate the public. Each week he highlighted a specific plant with a picture and description. People who stopped by the nursery were given a small notebook in which they could keep this information. And so, little by little, the business grew, but never did more than break even financially. Tom finally closed it in 1990.

Tom's careful investing provided financial security for the family. With the nursery closed, he decided to spend his time doing as much volunteer work as possible, especially with environmental issues. He logged many hours and many miles on foot with the group that became the New Mexico Wilderness Alliance, exploring and documenting public lands with wilderness potential. Another organization that caught his eye was The Nature Conservancy. At that time, TNC in New Mexico was a small organization, based in Albuquerque, whose mission was to purchase small pieces of land for conservation purposes. Tom was not aware of the funding procedures, but when a property became available, the director, John Egbert, would send out an appeal for funds. The New Mexico branch was quite dependent on out-of-state contributions. Tom thought TNC's mission was wonderful and decided to do his best to support the local organization, making sizable contributions. He eventually ended up on the board of trustees. He was on the board when TNC bought the Gray Ranch in Hidalgo County, a purchase that was very gratifying to him.

Still another worthy idea captured Tom's imagination. He was greatly affected by the NMSU biology department and knew that money for research was always hard to find there. He was saddened that there was not more assistance for students who wanted to work in the field. He went to the head of the department to discuss funding student research projects. As a result of this discussion, he and Eleanor founded T & E, Inc. The name has a double meaning, standing for both Tom & Eleanor and Threatened & Endangered. It is essentially a foundation for funding research by students involved with threatened and endangered species or with other aspects of the science or ecology of plants and animals. The focus is on Arizona, New Mexico, and northern Mexico, but it has also funded a few projects in Texas. Each year letters are sent to institutions in these areas asking them to post notices about T&E's mini-grant program. Projects need to be field-related, and proposals must be written in a specific format and are reviewed by a committee. The foundation funds roughly 20 projects per year at UNM, NMSU, University of

Arizona, Northern Arizona University, University of Texas at El Paso, Eastern New Mexico University, and other university and non-university institutions. Tom felt that of all the things he and Eleanor had been involved with, T&E, Inc. was the most rewarding.

In 1998 Tom and Eleanor left Las Cruces, moving to Tucson, near their son David and daughter Margaret. Eventually, however, despite having family nearby and a beautiful home that bordered public land, they tired of the big city and had a house built near the hamlet of Cliff, New Mexico. They moved there in early 2006. Meanwhile, their commitment to ongoing projects continued unabated. Tom, as if without enough to do, decided to begin a musical career, taking up the bagpipes. Perhaps it is fortunate that he never produced a CD, but he began appending his correspondences with bagpipe jokes.

Tom and Eleanor gave their support to many conservation groups, such as the Center for Biological Diversity, The Native Plant Society of New Mexico, and the Upper Gila Watershed Alliance. They took an active role in federal land-management issues. Together they made a major impact on the study of plants and animals and the ecology of New Mexico. They always worked closely together. They felt a special pleasure when Tom was awarded the Aldo Leopold Award by The Nature Conservancy and when they were jointly awarded the Charles Callison Award from the National Audubon Society in Estes Park, Colorado in 1998. When Tom was honored with a lifetime membership to NPSNM on August 4, 2007, at the annual meeting, he said he only wished Eleanor could be there, as she was as much a part of it as he was.

A great communicator, Tom did his best to build bridges between the diverse personalities and forces affecting the environment of this state, from the shortgrass prairie of Clayton to the magnificent forests of the Gila Wilderness. His love for these places has touched us all.

[Editors' Note: A previous version of this biography originally appeared in the New Mexico Native Plant Society newsletter for fall 2007. Tom Wootten, who died suddenly on August 7, 2007, was a major sponsor of this conference and these proceedings. However, his contributions to natural history study and conservation in New Mexico transcend this contribution. He is greatly missed by all who knew him.]

The Vascular Flora of the Gila National Forest: A Database

Jack L. Carter

PO Box 1244, Silver City, NM 88062, 505/388-9221, jmcarter@zianet.com

Charles A. Huff

Abstract

Following three growing seasons of field studies of the vascular flora of the Gila National Forest (GNF) in the early 1990s, a decision was made to develop a database of the field collections and the herbarium collections examined during the study. In the original investigations, 632 species were collected, identified, and mounted, with the first set placed in the GNF herbarium. Additional collections were distributed among the major herbaria throughout NM. Using a FileMaker Pro 6 database that was developed for this earlier work, we have continued to survey the major state herbaria and gather data on species previously collected in the GNF. Since 1995 more than 1250 herbarium collections have been examined in the major herbaria throughout NM. The information contained on these labels is now part of the total database.

The origins of this project were the results of a three-year study of the Negrito Creek drainage of the Gila National Forest (GNF) that includes a large area south and west of Eagle Peak and west of Deadman Spring, on the North Fork of Negrito Creek, and north and west of Bearwallow Mountain and Negrito Mountain, on the South Fork of Negrito Creek. Negrito Creek drains into the San Francisco River three miles south of Reserve, NM. The total area covers approximately 12,900 hectares (32,000 acres) in the northwest region of the GNF. This study resulted in the collecting, cataloging, and mounting of 632 species, with two to four collections of each species. The study was funded by the USDA Forest Service during the growing seasons of 1992, 1993, and 1994, and involved seven students who assisted Jack Carter and Charles Huff. The first set of the collections was placed in the Gila National Forest herbarium, with the second set going to the Dale A. Zimmerman herbarium (Western New Mexico University). Additional collections were distributed among the University of New Mexico herbarium, the New Mexico State herbarium, and the Range Science herbarium (NMSU), with woody species going to the Jack L. Carter herbarium.

As the total volume of information grew and additional data were collected, all in hard copy, the need was recognized for a computer system in which these data could be maintained and made available to a wider audience. This information was placed in a FileMaker Pro 6 database that we developed in 1994. With the FileMaker program it is easy to call up a division, family, genus, or single species.

As the Negrito Creek study was coming to a close in 1994, we recognized the need to pull together not only the records from this study, but also the herbarium records for the GNF from other regional herbaria that we had examined while conducting the study. This included the examination of the herbarium records at the Dale A. Zimmerman herbarium, the Gila National Forest herbarium, and some records from the herbaria of the University of New Mexico and New Mexico State University, with additional records from the Range Science herbarium (NMSU) and the University of Arizona herbarium. A total of 1246 species are now included in the summary. Please see the vascular database summary above (table 1).

Kinds of Information Collected and Maintained on Each Species

The purpose of this study is to catalog by division, family, species, and sub-specific categories the vascular taxa that have been collected and are maintained in the regional herbaria. The authors have examined the herbarium sheets of each included species or have reviewed published and unpublished theses or floristic studies as indicated in the bibliography. Only herbarium records cited in these studies have been included.

Plants are arranged alphabetically by division, family, genus, and specific name. The authorities for all species are included, as well as the synonyms. The common names are listed for each species, and whether the species reproduces by spores, cones or flowers is indicated. Whether the flowers are perfect or imperfect as well as whether the plants are monoecious or dioecious is also included, where these data are available. The range of elevation for each species is included in feet and meters. What is known about flowering dates is included by months, as well as relative abundance as to common, frequent, infrequent, or rare. We note whether a species is threatened or endangered based on information provided by the NM Rare Plant Technical Council. The origin of each species, as to native, non-native, or endemic is included. Species are distinguished as to woody or herbaceous. Species are also identified as to annuals, biennials, or perennials.

Table 1. Summary: vascular flora database—Gila National Forest

Divisions/Phyla	Families	Genera	Native Species	Exotic Species	Species
Lycopodophyta— Club Mosses	1	1	1	—	1
Equisetophyta— Horsetails	1	1	3	—	3
Pteridophyta— Ferns	5	14	26	1	27
Pinotophyta— Pines & Junipers	2	5	17	—	17
Gnetophyta— Joint Firs	1	1	1	—	1
Magnoliophyta— Dicots	85	392	866	79	945
Magnoliophyta— Monocots	13	84	216	36	252
	108 Total Families	**498 Total Genera**	**1130 Total Native**	**116 Total Exotic**	**1246 Total Species**

Data for up to eight herbarium collections may be included for each species. (We limited the number of collections to eight species in an arbitrary manner; this may easily be reduced or expanded.) For each collection we indicate the name of the collector, the collection number provided by the collector, date collected, county in which collected, the general area of the forest in which collected, and the herbarium where the collection is presently located. To date, more than 95% of the included collections have been located in the six herbaria indicated earlier. Practically all the collections housed in the Jack L. Carter herbarium have had duplicates distributed to the major state herbaria. Where possible, vegetation zones and ecosystems are included, although species often overlap several vegetation zones. Also, these data vary with the quality of the information provided by the collector.

All plant names are based on the 1 March 2007 addition of *A Working Index of New Mexico Plant Names* and the associated Web site maintained by Kelly W. Allred.

Please see the following sample pages (figs. 1a and 1b). They show what you would observe in the database program if you were to call up *Azolla mexicana*.

Fig. 1a. Sample database page as it appears in FileMaker Pro 6

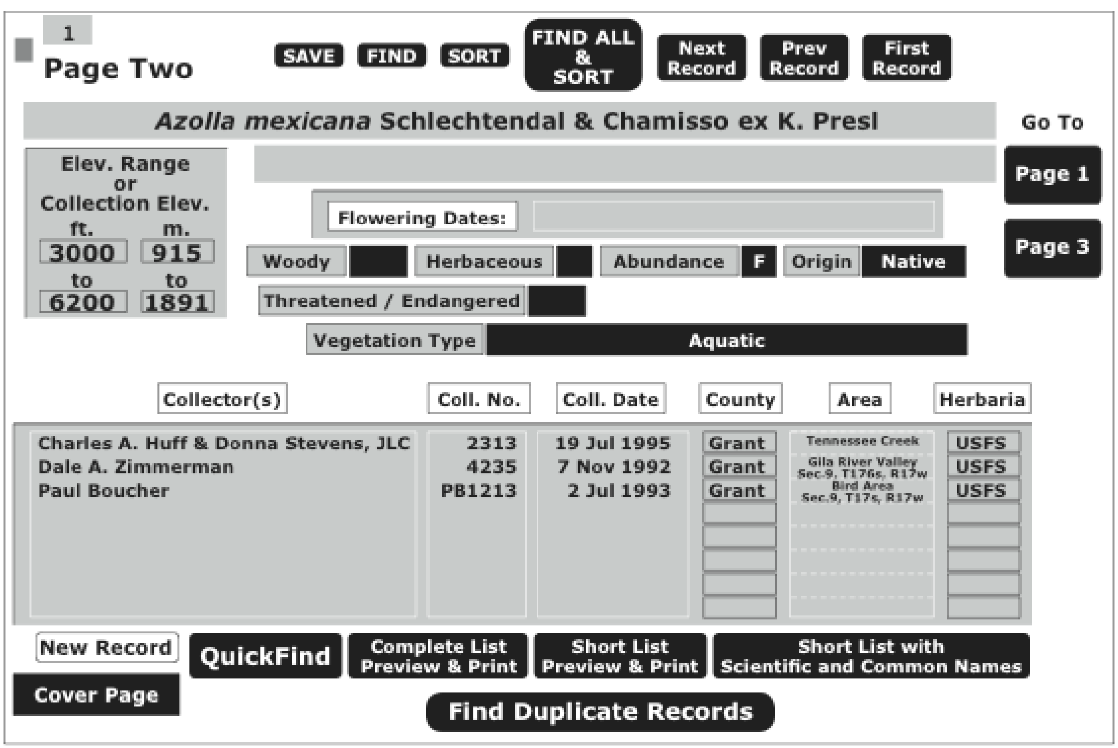

Fig. 1b. Sample database page as it appears in FileMaker Pro 6

There is one additional page that we identify as Page 3—QuickFind (see fig. 2, below). Here you will observe general categories of information that may be helpful to a wide variety of individuals seeking general information. For example, if you are interested in examining a list of herbaceous plants, woody plants, introduced species, or threatened species, you click a specific button for those species. This page allows you to call up collections by counties, including the four counties included in the GNF. This is strictly an experimental page that can be altered or expanded based on the interests of those using the database.

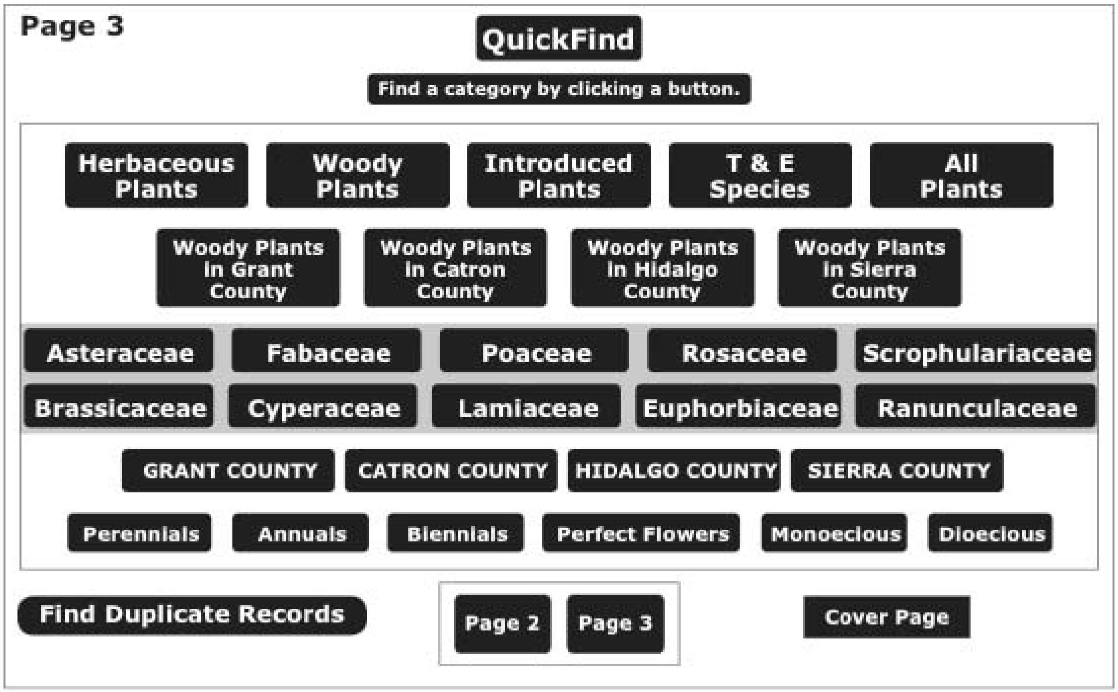

Fig. 2. Sample QuickFind page as it appears in the database

Bibliography of Included Studies

To date, there have been few published floristic studies of the GNF. However, four published and unpublished masters theses and checklists were extremely important to this study. Located publications describing herbarium-referenced species include the following:

Adams, P. T. 1998. An inventory of herbaceous vascular aquatic plants of perennial waters of southwestern New Mexico. MS thesis, New Mexico State University.

Fletcher, R. A. 1978. A floristic assessment of the Datil Mountains. MS thesis, University of New Mexico.

Johnson Fulton, S. B. 2003. A floristic inventory of the vascular plants of the Saddle Mountain area, Catron County, New Mexico. MS thesis, New Mexico State University.

Roalson, E. H., and K. W. Allred. 1998. A floristic study in the Diamond Creek drainage area, Gila National Forest, New Mexico. *Aliso* 17 (1): 47–62.

Families and Genera with Largest Representations

Listed are the larger families and genera and the numbers of species in each. Taxa listed in any family or genus may be retrieved and, if needed, printed.

Table 2. Most diverse families with number of species in each

1.	Asteraceae	214
2.	Poaceae	142

Table 3. Most diverse genera with number of species in each

1.	Carex	22
2.	Muhlenbergia	17

3. Fabaceae	83	3. Senecio	16
4. Rosaceae	43	4. Erigeron	15
5. Scrophulariaceae	45	5. Penstemon	13
6. Brassicaceae	45	6. Brickellia	12
7. Cyperaceae	38	7. Euphorbia	11
8. Lamiaceae	30	8. Potentilla	11
9. Ranunculaceae	27	9. Oenothera	10
10. Euphorbiaceae	37	10. Salix	1

Number of Species per County

Species checklists for the four counties included in the GNF are often requested and are made available to those interested in further studies. As might be anticipated, Grant County has received the greatest attention and has been the most studied. Our records indicate the following numbers of species per county: Grant, 875; Catron, 655; Sierra, 514; Hidalgo, 42.

Rare Species, Threatened and Endangered Species

Of the total number of species collected, 56 have been listed as rare, and 28 have been classified as threatened and endangered. The distinction is relatively clear, and most of the threatened and endangered species are also listed as rare, but several of the threatened and endangered species have been collected several times throughout the forest and their classification should be reexamined. Of equal importance, this information does not indicate if the populations of these threatened and endangered species are decreasing or increasing in size or numbers. Global positioning data would be extremely helpful in monitoring these species.

Introduced and Exotic Species

Currently 116 species are listed as introduced and exotic species. This figure can easily be challenged for several reasons. First, this figure is less than 10% of the total flora and is not realistic for an area so continuously traveled as is the GNF. Second, this figure indicates that no serious study of introduced species has been conducted, since similar studies suggest that perhaps 15% or even 25% of these species may be anticipated. Additional efforts should be taken to monitor these species if we are ever to control even the most serious intrusions.

Additional Limitations of the Program and Suggested Future Studies

Some of the most critical limitations and weaknesses of this study can be rectified and others cannot. The most serious weakness is that, of the 1246 included species, approximately 27% are represented by a single collection or report in the literature. This shortcoming can and should be corrected if we are ever to develop a long-term monitoring program. The critical need for “boots on the ground” examining the flora is not being met. Specialists who have the taxonomic expertise in the families and genera have never had an opportunity to make corrections and annotate the included species.

The labels on many of the older collections, certainly prior to the 1950s, are incomplete, and vital information such as collection sites and ecological data, as well as section, range, and township information, is not available. Additional field work can rectify this situation.

A long-term ecological monitoring program to include studies of the vascular plants, bryophytes, lichens, algae, and fungi would start to provide the information required to protect this small part of planet Earth into the next century. This is our mission.

Sixteen individuals are responsible for collecting, mounting, and conserving 95% of the total of 1246 species included in these findings. These individuals are: P. T. Adams, Kelly Allred, Paul Boucher, Jack Carter, Martha Carter, Eric Roalsen, Reggie Fletcher, Susannah Johnson Fulton, Charles Huff, Donna Stevens, Diego Villalba, Owen Williams, Sheila Williams, Allan Zimmerman, Dale A. Zimmerman, and Marian Zimmerman.

We would appreciate receiving information of herbarium records of species not known to us so we can examine these species and add the available information to the database. We plan to distribute a checklist of the included species to a wide range of interested botanists so that they might examine the included species, make corrections, and suggest changes or additions that would strengthen this information.

Got Water? Modeling the Early Use of Maize in Regions of the Southwest – Gila Mountains and Beyond

Robert D. Dello-Russo

Deputy Director, Office of Archaeological Studies,
Museum of New Mexico, 407 Galisteo St. B-100, Santa Fe, NM 87501
505-827-6472, Robert.Dello-Russo1@state.nm.us

Abstract
The timing of the arrival and earliest use of maize in the Southwest is summarized using radiocarbon dates from early maize samples. A Precipitation Threshold for Forager-Farmers, established at the mean local precipitation level, is proposed as a critical point below which mobile Archaic period forager-farmers altered their subsistence behavior and, in some instances, adopted or intensified their use of maize and other domesticates. Research findings support the idea that Archaic forager-farmers responded to drought-induced changes in food supply by altering the relative dietary contributions of wild seeds and cultivated domesticates. It is also argued that this subsistence strategy underwrote the early adoption of maize and the early development of mixed-economy communities in various parts of New Mexico and beyond.

Introduction
For archaeologists in the American Southwest, some of the most intriguing and enduring research questions revolve around the early development of agriculture (e.g., Huckell 1996; Kennett and Winterhalder 2006; Matson 1991, 2003; Staller, Tykot, and Benz 2006; Vierra 2005; Wills 1988, 2005). While this prehistoric process occurred over a long temporal continuum, archaeological research has generally focused on two developments that are often viewed as endpoints of that continuum: the introduction of domesticated maize and the subsequent development of relatively sedentary farming communities. In the first portion of this paper, the arrival and early use of maize by Archaic period forager-farmer groups are characterized through an examination of radiocarbon dates for both early maize samples and early, mixed-economy communities. The chronometric dates used in this characterization were acquired through recent research in Arizona, New Mexico, northern Mexico, and west Texas. Coupled with their geographic locations, the suite of radiocarbon dates are also used to determine the approximate route or routes by which maize spread from Mexico and arrived in New Mexico.

Three points here require some clarification. First, because Archaic foragers arrived in New Mexico with domesticated maize and other cultigens (see B. Huckell 1995) and thus were utilizing both wild foods and domesticated foods, I refer to them here as "forager-farmers." Second, the term "mixed economy" refers to the subsistence orientation that incorporates both hunting and gathering pursuits, as well as some focus on the farming of domesticated cultivars. Third, the term "early communities" is used to subsume those archaeological sites with evidence of incipient community organization and some degree of extended land tenure, including small clusters of low-investment habitation structures,[1] human burials, increased numbers of storage features, occasional evidence of irrigation (such as canals), and, occasionally, remains of domesticated cultigens.[2]

The second portion of this paper reviews the development of the Precipitation Threshold for Forager-Farmers (PTF), and discusses its possible implications for forager-farmers across the span of the Archaic period. The PTF is a quantified relationship between changes in precipitation[3] and the productivity of economic wild seeds that provides a benchmark against which to analyze the strategic use of early maize and the development of both the earliest and subsequent mixed-economy communities.

Theoretical Background
Archaeologists have traditionally been interested in major cultural transitions, such as the shift from foraging to farming, and discussions revolving around such topics have filled the literature for decades. Previous researchers in the Southwest sought to establish the routes of, and the rationale for, the early movement of maize into the Southwest. For example, Haury (1936) and, later, Ford (1981) suggested that maize arrived via a "highland corridor" wherein domesticated crops were initially dispersed across the Mogollon Highlands of east-central Arizona and west-central New Mexico and were dispersed only later into lower and drier elevations.

In investigating the function of early maize in the subsistence pursuits of prehistoric foraging groups, other researchers have argued that maize was utilized to supplement diets when wild subsistence resources were in short supply (Flannery 1986; Ford 1981; Minnis 1985; Wills 1988). Wild seed resources are known to have been targeted, collected, and stored by Archaic foragers in the Southwest as an overwintering tactic and this behavior is characterized archaeologically by an increasing investment in grinding and storage technology over time (Cordell 1984) and by the recovery of well-preserved plant remains from archaeological sites. While wild seeds were not the only wild plants targeted by Archaic foragers, the increasing focus on the gathering and processing of seeds has been viewed as a hallmark subsistence strategy for Archaic foragers that distinguishes them from their predecessors, the Paleoindians (ibid.).

Yet, like their predecessors, Archaic foragers primarily responded to seasonal changes in the productivity and availability of subsistence resources (both wild game and plants) through a tactic of mobility. That is, they patterned their residential movements across the landscape in concert with the spatial and temporal variations in resource productivity (Binford 1983). It is likely that, as the regional structure and availability of food resources shifted with changes in the Holocene climate, the exclusive use of residential mobility (recurring movements of habitation for entire foraging groups) would have become less effective, encouraging some Archaic foragers to adopt overwintering strategies underwritten by an ability to amass storable foods such as wild plant seeds. When compared to other food resources available for immediate consumption, wild seeds were “expensive” to harvest and process (Simms 1987). But when viewed in terms of delayed consumption, it is likely that their storability made them a valuable resource for winter subsistence (cf. Winterhalder and Goland 1993) and thus worth the effort to harvest.

Finally, archaeologists have also argued that the addition of maize and other domesticates to the Archaic forager diet would have generated a suite of archaeologically visible, subsistence-related changes in foraging behaviors. This restructuring of foraging behaviors would have included an increased tempo of site occupation (Wills and Huckell 1994, 52); longer duration of site occupation, as evidenced by an increased use of temporary structures (Dello-Russo 1999); the utilization of previous wild plant gathering areas as locations for new horticultural efforts (Wills and Huckell 1994, 51); and shifts in landscape mobility strategies (Wills 1988, 49). The changes in mobility would have meant less focus on residential mobility and more focus on logistic mobility (central-place foraging by task groups).

Early Maize in Southwest New Mexico and Beyond

The Arrival of Maize

Early maize dates are now available from a small number of archaeological sites in the Southwest. For example, at McEuen Cave in the Gila Mountains of eastern Arizona, early maize has been dated from 2200 to 2800 radiocarbon years before present (B.P.), and possibly as early as 3690 B.P. (Huckell, Shackley, and Huckell 2001). Fresnal Shelter has produced early maize dated to 2945 B.P. (Tagg 1999), while Tornillo Shelter has early maize dated to 3225 B.P. (Upham et al. 1987). Bat Cave has produced a maize date of 3120 B.P., with a potentially earlier maize date of 3740 B.P. (Wills 1988; but see table 1 footnotes). More recent work at the Old Corn Site in the Fence Lake area of western New Mexico has also produced a very early maize date (3810 B.P.; Huber 2006). Early maize nearer the Four Corners area, at Three Fir Shelter (Smiley 1994) and at sites near Lukachukai (Simmons 1986), range from 3610 B.P. to 3050 B.P. Finally, the purported early maize recovered at site LA10577, near Albuquerque, is argued by site investigators to date to 3370 ± 60 B.P. (Seymour, Hokanson, and Cunningham 1997), although the identification of the maize is considered by some to be controversial (B. Huckell, pers. comm., 2004). These, and other early maize dates, are summarized in table 1; while not exhaustive, they are representative of the trends in early maize dates across the region.

Taken together, the earliest maize dates in table 1 demonstrate that maize first reached the west-central border of New Mexico as early as 3810 B.P., at the extreme end of the Middle Archaic period (5150–3750 B.P.), and then spread north to the Four Corners and into western, central and southwest New Mexico from 3740 B.P. to 2790 B.P. This phenomenon occurred during the start of the Late Archaic period (3750–1550 B.P.) and continued into the Early Agricultural Period (3450–1750 B.P.; cf. B. Huckell 1995, 16).[4] By mapping the geographic locations for each of the early maize samples in the Southwest (including a sample from Guila Naquitz in Mexico [Flannery 1986]), a time-transgressive geographical trend is suggested (fig. 1). Based on this trend, the pale green arrows in figure 1 illustrate probable routes for the movement of domesticated maize from Mexico, through the Gila Mountains of Arizona, and into the Gila Mountains and the west-central highlands of New Mexico. This highland route of introduction is essentially the same route proposed previously by both Haury (1936) and Ford (1981).

Early, Mixed-Economy Communities of Archaic Forager-Farmers

The radiocarbon dates presented in table 1 come not only from the earliest dated maize samples in the Southwest, but also from the earliest mixed-economy communities or sites in the Southwest. The sources for the latter dates include an early irrigation ditch at Zuni, NM (Damp, Hall, and Smith 2002); a paleobotanical sample at the San Luis de Cabezon site in north-central New Mexico (Bargman, Gerow, and Elyea 1999), maize samples from the Cerro Juanaqueña site in northern Chihuahua, Mexico (Hard and Roney 1998, 1999), cultigen samples from early communities in southeast Arizona, including the sites of Las Capas, Los Pozos, Tumamoc Hill, and Milagro (Mabry 2004; Fish et al. 1986; Gregory 2001; Huckell, Huckell, and Fish 1995), and finally, maize samples from the Wood Canyon site (LA99631) in the Burro Mountains of southwest New Mexico (Turnbow et al. 2000, 164).

The locations of the early communities are also illustrated in figure 1. The Keystone Dam site (O'Laughlin 1980) in El Paso, TX is provisionally included because the date ascribed to the maize pollen recovered at the site is derived from an association with dated charcoal. Assuming some temporal bias with the dating of "old wood," it is possible that the maize pollen dates closer to 3300 B.P. So, with the exception of Guila Naquitz in Mexico, the rise of early communities in the American Southwest (as indicated by figure 1 and radiocarbon dates in table 1) occurred during a temporal interval of about 790 years from 3340 B.P. to about 2550 B.P.

Modeling the Use of Maize by Forager-Farmers

Theoretical Background and the Strategic Use of Maize

While Archaic forager-farmers delivered early maize to New Mexico by about 3800 B.P. (or approximately 1850 B.C.), it is clear, when viewed across the span of the Archaic period, that Archaic forager-farmers continued to have access to domesticated maize for upwards of 2000 years prior to the widespread appearance and persistence of mixed economy communities. It is worth noting that various temporal frameworks across the Southwest bracket similar economic developments. For example, some of the earliest mixed economies appeared in southeast Arizona and southwest New Mexico during the beginning of the Early Agricultural Period (1500 B.C.–A.D. 200), while many other community developments in southwest New Mexico and in the Four Corners area of the Colorado Plateau did not appear until the early-middle of the Late Archaic/Early Pithouse period (1800 B.C.–A.D. 600) and the latter half of the Late Archaic/Basketmaker II era (ca. 1800 B.C.–A.D. 500), respectively.

Accordingly, one might ask, "If Archaic forager-farmers had access to domesticated plants, such as maize, how were these domesticates incorporated into the overall foraging economies?" Further, "Because Archaic forager-farmers were partly dependent for successful overwintering on the production of storable plant foods (whether wild or domestic), what determined when domesticated plants were incorporated into the forager-farmer diet?" The following discussion will shed some light on these questions.

Despite the economic advantage of wild seeds, they are not, and were not, uniformly productive over time and space. Reductions in wild seed supplies in the past were related to increases in human population density (i.e., more foragers) or to climatic stress (e.g., drought), both of which would have resulted in more competition for fewer seed resources. When, for whichever reason, Archaic forager-farmers were confronted with diminished supplies of storable wild seed resources, they could have responded as they had done with shortfalls in other subsistence resources: through changes in landscape mobility or through the harvest of other equally productive and storable resources.[5] If local reductions in rainfall (or spatial and temporal variations in rainfall) affected the dry-land productivity of many locally available economic plants in similar ways, it may have been difficult to replace one with the other, thus leaving forager-farmers to search elsewhere or perhaps to consider using domesticates. Yet, from an energetic perspective, it is now known that foraging provided a better subsistence return than farming (cf. B. Huckell 1995, 137), so forager-farmers would typically have sought to collect wild seeds before resorting to domesticates (Cordell 1984, 174–75). When at last the successful accumulation of winter stores was threatened by widespread drought or unpredictability in the timing and location of precipitation, Archaic forager-farmers could have instituted or intensified the cultivation of domesticated plants such as maize.

The preceding scenario, which explains how maize (or other domesticates) might have been strategically used in the forager-farmer diet, serves as the basic premise of this paper. Foraging and farming were not mutually exclusive. They functioned effectively as opposite ends of the storable food spectrum, along which forager-farmer groups positioned themselves. By strategically choosing to alter their dietary mix of wild and domesticated foods, Archaic forager-farmers were able to respond to losses in storable subsistence resources caused, in many instances during the Holocene, by decreases in the amount of precipitation[6] or by increasing temporal and spatial variability in precipitation.

Establishing the Forager-Farmer Threshold

The idea that prehistoric foragers and/or farmers responded to changes in the timing, location, and/or predictability of precipitation is not a new idea (B. Huckell 1990, 1995), but the quantification of such a relationship has not often been presented (Meltzer 1999). The implications of changes in precipitation for Ancestral Puebloan farmers in the Southwest were examined by Dean (1988). His research suggested that variations of 1.1 standard deviations below normal precipitation "indicate climatic conditions that were sufficiently rare and severe to have had processual consequences for physical, biotic, and human behavioral systems on the Colorado Plateaus" (ibid., 138). However, in an archaeological study in the Rio Grande Valley, Dello-Russo (2003) suggested the mean regional precipitation value as the point at which prehistoric Basketmaker II (BMII) forager-farmers altered their subsistence behaviors. This value is referred to here as the Precipitation Threshold for Forager-farmers (PTF). In the following discussion, the development of the PTF is reviewed and then the threshold value is used to investigate the early use of maize in various parts of the Southwest.

A study of the responses of an annual, seed-bearing plant to variations in precipitation utilized plant transect and precipitation data from the Sevilleta National Wildlife Refuge in central New Mexico (Dello-Russo 1999). Sand dropseed (*Sporobolus cryptandrus*) was chosen as a representative wild, seed-bearing plant because it is typically found in paleobotanical samples from Archaic sites throughout the Southwest, indicating that it was a common storable resource collected by Archaic forager-farmers (Toll and Cully 1994; L. Huckell 1995, 76–83). The changes in the productivity of this plant were gauged by quantifying changes in a proxy variable, plant coverage, which, together with precipitation data from an adjacent collection area, was tracked over a seven-year period from 1989 through 1995. Precipitation over that same period had a mean value of 196 mm.

The highest correlations between sand dropseed productivity and precipitation occurred during the March-to-October and February-to-October periods ($r = 0.859$ and 0.828, respectively), indicating that changes in productivity for annuals such as sand dropseed occur during the frost-free season from March to October. A graphic illustration of the relationship between changes in seed productivity and precipitation is provided in figure 2. A straight line, which describes the relationship ($r^2 = 0.737$) between the two variables, has a mathematical expression of $Y = -5.588 + 0.027X$. Application of this formula indicates that precipitation levels below 208 mm produce losses in sand dropseed coverage. This finding has implications for the incorporation of maize, and perhaps other storable domesticates, in the forager-farmer diet because it underscores the likelihood that precipitation levels below the mean annual value (PTF) would have negatively affected the annual production of seed-bearing plants such as sand dropseed.[7]

Testing the Effectiveness of the Forager-Farmer Threshold

To test whether the forager-farmer threshold is an effective tool with which to understand forager-farmer adaptations, an additional study was made comparing precipitation trends in western New Mexico during the BMII period to trends in radiocarbon dates at foraging sites in the Middle Rio Grande Valley (Dello-Russo 1999, 2003).[8] When precipitation data for the BMII period (from A.D. 0 through A.D. 700) is reconstructed from tree rings (El Malpais Long Chronology; Grissino-Mayer 1995), it appears, as shown in figure 3, that precipitation values dropped below the mean between about A.D. 280 and A.D. 500. However, Grissino-Mayer (ibid., 119) characterized this downturn as “the most severe of any long-term drought period in the last 2,129 years” and suggested that the effects of the drought actually spanned the period between A.D. 258 and A.D. 520. Within that 262 year period, Grissino-Mayer (ibid., 102–4, 111–22) specified three major episodes of below normal precipitation: A.D. 258–270, A.D. 300–395, and A.D. 419–489. Together, these total 190 years of significant drought. This trend in precipitation in western New Mexico was found to correlate strongly with precipitation trends in northwest New Mexico (ibid., 84) and along the Middle Rio Grande, near present-day Albuquerque, NM (Dello-Russo 1999, 57–58).

Based on the premise outlined previously for the strategic use of maize, this epic drought during the BMII period would have been a time during which forager-farmers changed their subsistence behaviors. A test of this hypothesis is illustrated in figure 4, where the pattern of radiocarbon-dates from archaeological sites in the Middle Rio Grande Valley study area (Ceja Mesa) during the BMII period reveals a significant drop in the probability of occupation during the aforementioned drought period. This finding suggests emigration out of the immediate area, although not a complete abandonment,[9] and it further suggests that the PTF (mean precipitation value) is a valid tool with which to retrodict changes in forager-farmer subsistence behaviors, at least in the Middle Rio Grande Valley and the northwest portion of New Mexico.

Even though the effectiveness of the PTF is supported in the Middle Rio Grande study area by the strong correlation between the timing of the drought period and the timing of the decrease in site occupation probability, the results beg the question, "If, during the drought, many of the BMII forager-farmers emigrated from the area in search of other subsistence resources, what did those forager-farmers who remained do to bolster their diminishing food supplies?" Archaeological data from Ceja Mesa suggest behaviors, on the part of the remaining BMII population, indicative of resource intensification and incipient farming, including an increased tempo of site reoccupation, a reduced focus on residential mobility, a greater focus on logistic mobility, and an increased use of temporary structures (cf. Wills 1988; Wills and Huckell 1994; Dello-Russo 1999).

It can thus be argued that some of the drought-stricken BMII forager-farmers on Ceja Mesa in the Middle Rio Grande Valley shifted their focus to, or increased their reliance on, domesticates such as maize and began farming. The use of domesticated maize at that time is supported by maize from Boca Negra Cave on the Ceja Mesa, dated to A.D. 370 ± 168 (Reinhart 1968, 347), although the area where the maize was grown at that time is currently unknown. Certainly maize, like the Boca Negra sample, was not grown in a dry cave, but the location of BMII fields for cultivation is another issue, one that is examined in the following discussion.

Where Did the Forager-Farmers Farm?

It has also been suggested that forager-farmers sought out well-watered locales to practice cultivation (cf. B. Huckell 1995). Such locales, or mesic refugia, might have included subirrigated river and arroyo floodplains, cienegas or marsh areas, wetlands, or spring locations. The proposed use of mesic refugia during drought episodes derives from the fact that, while drought periods may have reduced the amount or predictability of precipitation available for the production of wild seed crops in lower elevation dry-land settings, the same climatic trends may not have pertained in more mesic upland or mountain settings (cf. Hall and Periman 2007). Thus, even during a regional drought, some larger arroyos or river channels with sources in mountainous areas could have delivered water to floodplains downstream (cf. Meltzer 1999, 405) and allowed forager-farmers to cultivate domestic plants such as maize. Similarly, the continued delivery of water from mountains to downstream settings could also have maintained some wetlands and springs, and permitted domestic plant cultivation through the use of irrigation channels or subirrigated sediments. Nevertheless, it cannot be argued that mesic refugia were available everywhere at the same time. As an example of such regional variation in the effects of climate and the concomitant variability in suitable farming locations, Hall and Periman (2007) suggest that aggrading floodplains in the Jemez Mountains of northern New Mexico could have been used for cultivation at the same time that arroyo down-cutting was interrupting cultivation in other areas, such as Zuni, in western New Mexico (Damp, Hall, and Smith 2002).

For portions of the Southwest around the Four Corners region, this variability in the locations of mesic refugia might be explained, in part, by a bimodal vs. unimodal model of precipitation proposed by Dean and Funkhouser (1995). Bimodal precipitation peaks during both the summer and winter seasons, while unimodal precipitation represents a summer-dominant pattern. In their model, the bimodal pattern of precipitation is largely restricted to extreme northwest New Mexico and areas north and west of New Mexico (including northeast Arizona, southeast Utah, and southwest Colorado), while the unimodal pattern of precipitation occurs in west-central, north-central, and northwest New Mexico (see also Cordell et al. 2007, 384).

Dean and Funkhouser (1995, 94) applied their model to the period A.D. 966–1988. However, they also suggested that the bimodal-unimodal dichotomy in precipitation regimes existed during BMII times as well (ibid., 85). Furthermore, other related research has suggested that the precipitation patterns in the two regimes (for example, in Mesa Verde, CO and the Cibola area of western New Mexico) were often complementary (Cordell et al. 2007, 392, fig. 3a). For the current research, then, it can be suggested that the BMII drought in the unimodal region of precipitation might have been less intense or nonexistent in the bimodal region. Put more simply, a drought in the Middle Rio Grande Valley might not have occurred in the Four Corners.

So, for example, the region surrounding and including the San Juan Mountains of southwest Colorado could have received sufficient moisture (as winter snowpack) to offset the loss of summer precipitation in the unimodal region during the BMII drought. Melting snowpack could have provided water in the spring and summer for the cultivation of domesticates, such as maize, and thus made the region attractive to immigrant forager-farmers. The hypothesis, then, that the cultivation of maize may have been intensified in the Four Corners by BMII forager-farmers as a response to drought in parts of New Mexico, is suggested by numerous maize dates from the Four Corners region of the Colorado Plateau (table 2). The locations of these BMII dated maize samples are illustrated in figure 5. The dates provided in table 2 are midpoints of standard radiocarbon dates (Mona Charles, pers. comm., 2008).

The 31 radiocarbon-dated maize samples whose midpoint dates fall within the time of the BMII drought (A.D. 258 to A.D. 520) include, among others, one from the Eastside Rincon site along the La Plata River floodplain in northwest New Mexico, dated from A.D. 275 ± 30 or A.D. 385 ± 65 (Rohwer 2006, 18); and several from the Darkmold, South Shelter, and Talus Village sites in the Animas River drainage of southwest Colorado, dated at A.D. 335, A.D. 270, and A.D. 280–360, respectively (Basketmaker II Chronology and Material Culture Database). Finally, there are also maize samples recovered from sites at Navajo Reservoir in northern New Mexico; from the La Sal Mountains; from the Cedar Mesa, Glen Canyon, and Kanab regions of southeast Utah; and from the Black Mesa and Chuska/Lukachukai areas in northeast Arizona. These latter dates range between A.D. 260 and A.D. 500 (ibid.). More revealing is the fact that the number of radiocarbon-dated maize samples per 20 years, for the 262-year period, represents a 27% increase over that of the preceding 250 years (A.D. 0 to A.D. 257).

While the database of BMII maize dates provided by Charles and Cole (ibid.) did not include statistical date ranges for the dated maize samples, it is likely that the probability curves for these maize dates encompass more than the period of drought specifically delineated by tree rings. If so, the period A.D. 200 to A.D. 520 should be a more appropriate block of time to examine. As such, this 321-year period included 46 maize dates, and the rate of maize dates per 20 years represents a substantial increase of 186% over that of the previous 200 years (A.D. 0 to A.D. 199). Thus, given that (1) tree rings provide very precise timing for the reconstructed precipitation record, and (2) radiocarbon dates (nearly 50% of which were not analyzed using AMS), provide coarser timing for the use of maize in the Four Corners, the above findings are certainly provocative and suggest some level of support for the PTF as a climatic benchmark against which to model the strategic early use of maize. Certainly, more refined radiocarbon dates will shed additional light on these findings. Finally, the study of BMII maize dates in the Four Corners also suggests the possibility that BMII forager-farmers in the Middle Rio Grande Valley of New Mexico, in response to the BMII drought there, migrated to the mesic refugia of the Four Corners to cultivate domesticates. This conclusion contrasts with Matson's claim (1991, 2003) that the BMII farmers in the Four Corners were immigrants from southeast Arizona.

Extending the Logic to the Gila Mountains

The PTF has so far only been applied to BMII adaptations in the Middle Rio Grande Valley of New Mexico and indirectly to the Four Corners region to the northwest. Thus it is unclear whether the PTF can elucidate the early use of maize at other times or in other regions such as the Gila Mountains of southwest New Mexico and eastern Arizona. Given the drought-induced changes in subsistence behavior exhibited by BMII forager-farmers in other areas, however, it can be argued that the rise of the early, mixed-economy communities in the Southwest between 3340 B.P. and 2700 B.P., and the initial arrival and use of maize between 3800 and 3600 B.P. (see table 1), were the result of forager-farmer responses to increasing numbers of drought episodes and/or increases in the seasonal variability of precipitation during the middle-to-late Holocene period. Support for the occurrence of such climatic variations at that time is provided by a suite of paleoclimatic proxy records from an assortment of locations in western North America. Using the prehistoric levels of Owens Lake and Pyramid Lake in western Nevada, Benson and others (2002) suggest that drought conditions dominated western and southwestern regions of North America during the middle-to-late Holocene from ca. 6500 B.P. up to 3000 B.P. Glacial and periglacial events in the Sangre de Cristo Mountains of northern New Mexico suggest a drier period between 3700 and 2800 B.P. (Armour, Fawcett, and Geissman 2002), and soil geomorphological records in the San Juan Basin suggest a relatively dry period between 3820 B.P. and 3100 B.P. (Smith and McFaul 1997). Antevs (1955, 1962) argued for an arid Altithermal period from 7500 to 4000 B.P. and, from their work at pluvial Lake Cochise, Waters and Woosley (1990) pointed to a dry period in southeast Arizona sometime between 4000 and 3000 B.P.

In contrast, stalagmite banding data from the Guadalupe Mountains of southeast New Mexico indicate a dry middle-to-late Holocene climate until about 4000 B.P., a climate similar to today's between 4000 and 3000 B.P., and a "distinctly wetter and cooler period from 3000 to 800 years ago" (Polyak and Asmerom 2001, 148). Interestingly, in his study of White Water Draw in southeast Arizona, Waters (1990, 1997) suggested that cienegas developed after 5500 B.P. Finally, in the vicinity of the Burro Mountains in southwest New Mexico, Turnbow and others (2000, 9) suggest that the modern climate had been established by 4000 B.P., "but with higher seasonal variability in precipitation and an increased number of drought years."

Given the coarse resolution and complexity of these paleoclimatic data, as well as the demonstrated variability in the expression and timing of drought across the region of the western and southwestern United States (cf. Meltzer 1999, 404), there is a modest degree of correspondence between the occurrences of the middle-to-late Holocene drought and the interval(s) of early maize use in the Southwest (ca. 3800 B.P. to 2550 B.P.). Clearly, forager-farmers at those times needed to address not only shortfalls in the amount of precipitation but also increasing variability in the timing and location of precipitation. So, in light of earlier revelations about the PTF and the strategic use of maize, it can be posited that, as the increasing variability of middle-to-late Holocene precipitation, coupled with the increasing number of drought episodes, impacted the productivity of wild plant resources in southern and southwest New Mexico and southeast Arizona, it is likely that forager-farmers in those areas also sought out mesic refugia for maize cultivation. The locations of the early, mixed-economy communities cited previously (see fig. 1) probably represent these mesic refugia (cf. B. Huckell 1990, 1995).

Conclusion

The results of this preliminary research support the idea that Archaic forager-farmers in many parts of the Southwest, from the middle through the late Holocene, positioned themselves within a range of subsistence poses characterized by various mixes of hunting and wild plant gathering, on the one hand, and the cultivation of maize and other domesticates on the other hand. Such a mixed subsistence strategy was adopted to maximize their opportunities to gather sufficient storable resources for the winter and was controlled, in large part, by variations in local and regional precipitation. Further, the use of the Precipitation Threshold for Forager-Farmers as a quantifiable climatic benchmark may provide archaeologists with a tool to further investigate the timing and nature of responses by early farmer-foragers to changes in precipitation.

Archaeological evidence points to the rise of mixed-economy communities both during the BMII drought (in the Middle Rio Grande Valley and around the Four Corners region) and during a middle-to-late Holocene period of increasing drought and increasing spatial and temporal variability in precipitation (in southeast Arizona; in north-central and northwest New Mexico; and in parts of southern New Mexico, Texas, and northern Mexico). Because the earliest maize was transported into New Mexico through the Gila Mountains by forager-farmers, it is reasonable to expect that early, mixed-economy communities might have developed there as well. Certainly, the large drainage basins in the uplands of the adjacent Gila Wilderness have supplied the Gila River with abundant water for maize cultivation in the more recent past, and may have done so during the middle-to-late Holocene drought. The early, mixed-economy occupations during the Early Agricultural Period at the Wood Canyon site are instructive in that they were overlain, archaeologically, by another mixed-economy occupation during the Early Pithouse Period. Accordingly, another place to search for an Early Agricultural development might be at or near the Early Pithouse Period site of Diablo Village (LA6538; Honea 1963, Hammack 1966) along the West Fork of the Gila River.

Clearly, then, in order to better establish any relationship between forager-farmer adaptations and climate during the middle-to-late Holocene, continued research must be undertaken to bring forth higher temporal and spatial resolution in paleoclimatic data. Renewed archaeological efforts in the Gila Mountains, together with more refined paleoclimatic reconstructions in the region, may ultimately provide us with a better understanding of why and when foragers farmed.

Notes

[1]Low-investment habitation structures, such as wickiups, are built of readily available materials, such as reeds or scavenged wood, and are occupied for relatively short periods of time. According to Kent (1991), there is a direct relationship between the amount of labor people invest in building a habitation structure and the amount of time they anticipate staying in a given area.

[2]While complex hunter-gatherer communities developed in the Pacific Northwest and coastal California without the use of irrigation or domesticates, the early communities of the American Southwest could not take advantage of richly abundant and predictable subsistence resources such as anadromous fish or shellfish. While some southwestern plant communities did produce relatively abundant food resources, the seasonal and spatial variations in precipitation across the Southwest during the Holocene period made it likely that the development of some early communities was underwritten, at least in part, by the cultivation of domesticates.

[3]This research seeks to examine the strength of a possible relationship between wild seed production, changes in precipitation, and the use of maize by Archaic foragers. No claim is made here that Archaic foragers gathered only wild seeds. Other wild plants, such as piñon, acorn, black walnut, and mesquite pods, are amenable to storage and have been found in archaeological sites in the American Southwest. While it is assumed that fluctuations in precipitation affect the productivity of all wild grass seed resources in similar ways, the effect of such fluctuations on the productivity of other wild plants is not examined in this research.

Fluctuations in precipitation were not the only climatic signals that affected forager-farmer behavior. Catastrophic freezes could easily have decimated wild seed crops in some years. Furthermore, nonclimatic impacts to food supplies, such as increased competition from other forager-farmers, were operating at times in the past as well. This research examines only the effects of changing precipitation on prehistoric forager-farmer subsistence behavior.

[4]The term Early Agricultural Period has been applied by Turnbow et al. (2000) to cultural developments identified in southwest New Mexico. While the term, and the dates assigned to it, currently seem to encompass the advent of mixed economies over much of the Southwest, and may have greater regional relevance as additional early, mixed-economy communities are identified (such as San Luis de Cabezon in New Mexico), the use of the term has not yet been universally embraced by all researchers in New Mexico.

[5]Other adaptations by forager-farmers to reductions in food supply could have included intensification of gathering efforts, trading, and/or sharing, for example. While such behaviors may have occurred, the focus of this paper is on the intensified use of domesticates, such as maize.

[6]The effects of climate change can be regionally variable. A downturn in the amount of precipitation sufficient to reduce or eliminate the dry-land productivity of wild seed resources in one area, such as the Middle Rio Grande Valley, does not necessarily imply a drought of similar proportions in other areas, such as the Colorado Plateau. Nor does drought in lowlands negate the possibility of precipitation falling in mountainous areas nearby.

[7]Current-year precipitation during the spring growth period (March–May) is a good predictor of changes in annual plant coverage (or productivity). Moreover, the growth of tree rings at the El Malpais National Monument is strongly correlated with the Palmer Drought Severity Index (PDSI) for the spring (March–May) growth period (Grissino-Mayer 1995, 87). Together these relationships suggest that precipitation reconstructed from tree rings can be used with data on the productivity of annual seed-bearing plants, such as sand dropseed, in a single scientific study.

[8]The forager-farmer behavioral threshold was developed from plant transect and precipitation data collected at the Sevilleta National Wildlife Refuge, north of Socorro, NM. The test of the threshold was accomplished using precipitation data reconstructed from tree rings at the El Malpais National Monument, south of Grants, NM, and archaeological data from the Ceja Mesa, northwest of Albuquerque, NM.

[9]The suite of archaeological sites from which the radiocarbon dates were recovered remained the same for periods prior to, during, and after the BMII drought period. The changes in the probability of occupation in the Ceja Mesa study area were based on increases and decreases in the number of occupational events at those sites. Virtually all study-area sites were reoccupied numerous times by prehistoric foragers, underscoring the productive nature of the plant communities in the study area.

Acknowledgments

My thanks go to the professional scientists whose assistance or comments, either as interested colleagues or as anonymous reviewers, helped improve the quality of this paper. They include Dr. Eric Blinman, Mona Charles, Dr. Stephen Hall, Dr. Charles Hilton, Dr. Ed Huber, and Patricia Walker. Any errors or omissions are the responsibility of the author.

References

Antevs, E. 1955. Geologic-climatic dating in the West. *American Antiquity* 20:317–35.

———. 1962. Late Quaternary climates in Arizona. *American Antiquity* 28:193–98.

Armour, J., P. J. Fawcett, and J. W. Geissman. 2002. 15 k.y. paleoclimatic and glacial record from northern New Mexico. *Geology* 30(8): 723–26.

Bargman, B. A. C., P. A. Gerow, and J. M. Elyea. 1999. LA 110946 San Luis De Cabezon site. In *Data recovery along the 1995 MAPCO Four Corners pipeline: Sites in the San Juan Basin/Colorado Plateau, Sandoval, San Juan, and McKinley counties, New Mexico*, comp. K. L. Brown, 11–46. Albuquerque: University of New Mexico, Office of Contract Archeology.

Basketmaker II Chronology and Material Culture Database. *http://faculty.fortlewis.edu/CHARLES_M/BM%20II%20Database.pdf* (comp. M. Charles and S. Cole, Anthropology Dept., Fort Lewis College, Durango, CO).

Benson, L., M. Kashgarian, R. Rye, S. Lund, F. Paillet, J. Smoot, C. Kester, S. Mensing, D. Meko, and S. Lindstrum. 2002. Holocene multidecadal and multicentennial droughts affecting northern California and Nevada. *Quaternary Science Reviews* 21(4–6): 659–82.

Binford, L. R. 1983. Long-term land use patterns: Some implications for archaeology. In *Lulu linear punctated: Essays in honor of George Irving Quimby*, ed. R. C. Dunnell and D. K. Grayson, 27–53. Vol. 72 of University of Michigan Anthropological Papers.

Cordell, L. S. 1984. *Prehistory of the Southwest*. New World Archaeological Record. New York: Academic Press, Inc.

Cordell, L. S., C. R. Van West, J. S. Dean, and D. A. Muenchrath. 2007. Mesa Verde settlement history and relocation: Climate change, social networks, and ancestral pueblo migration. *Kiva: The Journal of Southwestern Anthropology and History* 72 (4): 379–405.

Damp, J. E. 2001. Zuni agricultural origins. Paper presented at the 66th Annual Conference of the Society for American Archaeology, New Orleans.

Damp, J., S. A. Hall, and S. J. Smith. 2002. Early irrigation on the Colorado Plateau near Zuni Pueblo, New Mexico. *American Antiquity* 67:665–76.

Dean, J. S. 1988. Dendrochronology and paleoenvironmental reconstruction on the Colorado Plateaus. In *Anasazi in a changing environment*, ed. G. J. Gumerman, 119–67. New York: Cambridge University Press.

Dean, J. S., and G. S. Funkhouser. 1995. Dendroclimatic reconstructions for the southern Colorado Plateau. In *Climate change in the Four Corners and adjacent regions: Implications for environmental restoration and land-use planning,* ed. W. J. Waugh, 85–104. CONF-9409325. Grand Junction, CO: U.S. Department of Energy.

Dello-Russo, R. D. 1999. Climatic stress in the middle Rio Grande valley of New Mexico: An evaluation of changes in foraging behaviors during the Late Archaic/Basketmaker II period. PhD diss., University of New Mexico.

———. 2003. The responses of Basketmaker II foragers to climatic stress in the Middle Rio Grande Valley of New Mexico. In *Anasazi Archaeology at the Millennium*, ed. P. F. Reed, 23–28. Tucson, AZ: Center for Desert Archaeology.

Dick, H. W. 1965. *Bat Cave.* Monograph No. 27. Santa Fe, NM: School of American Research.

Fish, P. R., S. K. Fish, A. Long, and C. Miksicek. 1986. Early corn remains from Tumamoc Hill, southern Arizona. *American Antiquity* 51(3): 563–72.

Flannery, K. V. 1986. *Guila Naquitz: Archaic foraging and early agriculture in Oaxaca Mexico.* New York: Academic Press.

Ford, R. I. 1981. Gardening and farming before A.D. 1000: Patterns of prehistoric cultivation north of Mexico. *Journal of Ethnobiology* 1 (1): 6–27.

Gregory, D. A. 2001. *Excavations in the Santa Cruz River floodplain: The early agricultural component at Los Pozos.* Tucson, AZ: Center for Desert Archaeology.

Grissino-Mayer, H. D. 1995. Tree-ring reconstructions of climate and fire history at El Malpais National Monument, New Mexico. PhD diss., University of Arizona.

Hall, S. A., and R. D. Periman. 2007. Unusual Holocene alluvial record from Rio Del Oso, Jemez Mountains, New Mexico: Paleoclimatic and archaeologic significance. In *New Mexico Geological Society Guidebook, 58th Field Conference, Geology of the Jemez Mountains Region II*, 459–68.

Hammack, L. C. 1966. Diablo Highway salvage archaeology. *Laboratory of Anthropology Note 41* (prepared by the New Mexico Office of Cultural Affairs, Museum of New Mexico, Laboratory of Anthropology, for the New Mexico State Highway and Transportation Department, Santa Fe).

Hard, R. J., and J. R. Roney. 1998. A massive terraced village complex in Chihuahua, Mexico, 3000 years before present. *Science* 279:1661–64.

———. 1999. Cerro Juanaqueña. *Archaeology Southwest* 13 (1): 4.

Haury, E. 1936. *The Mogollon culture of southwestern New Mexico.* Medallion Papers No. 20. Globe, AZ: Gila Pueblo.

Honea, K. 1963. The Diablo Complex of the San Pedro stage at Gila Hot Springs, New Mexico. *Laboratory of Anthropology Note 284* (prepared by the New Mexico Office of Cultural Affairs, Museum of New Mexico, for the New Mexico State Highway and Transportation Department, Santa Fe).

Huber, E. K. 2006. Early maize at the Old Corn Site (LA137258). In *Archaeological data recovery in the New Mexico transportation corridor and first five-year permit area, Fence Lake coal mine project, Catron County,* *New Mexico,* ed. E. K. Huber and C. R. Van West, vol. 4. Technical Series 84. Tucson, AZ: Statistical Research, Inc.

Huckell, B. B. 1990. Late preceramic farmer-foragers in southeastern Arizona: A cultural and ecological consideration of the spread of agriculture in the arid southwestern United States. PhD diss., University of Arizona. Ann Arbor, MI: University Microfilms.

1995. Of marshes and maize: Preceramic agricultural settlements in the Cienega Valley, southeastern Arizona. *Anthropological Papers of the University of Arizona* No. 59. Tucson, AZ: University of Arizona Press.

———. 1996. The archaic prehistory of the North American Southwest. *Journal of World Prehistory* 10 (3): 305–73.

Huckell, B. B., L. Huckell, and S. K. Fish. 1995. *Investigations at Milagro, a late preceramic site in the eastern Tucson basin*. Technical Report 94-5. Tucson, AZ: Center for Desert Archaeology.

Huckell, B. B., M. S. Shackley, and L. W. Huckell. 2001. The 1997 test excavations at McEuen Cave (AZW:13:6 ASM), Fishhook Wilderness, Gila Mountains, south-central Arizona. Field report submitted to the Safford District Bureau of Land Management.

Huckell, L. W. 1995. Farming and foraging in the Cienega Valley: Early agricultural period paleoethnobotany. In B. B. Huckell 1995.

Human Systems Research. 1972. *Human Systems Research training bulletin.* Tularosa, NM.

Kennett, D. J., and B. Winterhalder. 2006. *Behavioral ecology and the transition to agriculture*. Los Angeles: University of California Press.

Kent, S. 1991. The relationship between mobility strategies and site structure. In *The interpretation of archaeological spatial patterning*, ed. E. M. Kroll and T. D. Price, 33–60. New York: Plenum Press.

Mabry, J. B. 2004. Las Capas: Early irrigation and sedentism in a southwestern floodplain. *Anthropological Papers* No. 28. Tucson, AZ: Center for Desert Archaeology.

Matson, R. G. 1991. *The origins of southwestern agriculture*. Tucson, AZ: University of Arizona Press.

———. 2003. The spread of maize agriculture into the U.S. Southwest. In *Examining the farming/language dispersal hypothesis*, ed. P. Bellwood and C. Renfrew, 341–56. Cambridge, UK: University of Cambridge, McDonald Institute for Archaeological Research.

Meltzer, D. J. 1999. Human responses to middle Holocene (altithermal) climates on the North American Great Plains. *Quarternary Research* 52:404–16.

Minnis, P. E. 1985. *Social adaptation to food stress: A prehistoric southwestern example*. Chicago: University of Chicago Press.

O'Laughlin, T. C. 1980. *The Keystone Dam site and other Archaic and formative sites in northwest El Paso, Texas*. Publications in Anthropology 8. El Paso, TX: El Paso Centennial Museum.

Piperno, D. R., and K. V. Flannery. 2001. The earliest archaeological maize (Zea mays L.) from highland Mexico: New accelerator mass spectrometry dates and their implications. *Proceedings of the National Academy of Sciences* 13:98 (4): 1324–26.

Polyak, V. J., and Y. Asmerom. 2001. Late Holocene climate and cultural changes in the southwestern United States. *Science* 294:148–51.

Reinhart, T. R. 1968. *Late Archaic cultures of the Middle Rio Grande Valley, New Mexico: A study of the process of culture change*. PhD diss., University of New Mexico.

Rohwer, J. E. 2006. *Interpretation of the San Juan College 1989 field school at the East Side Rincon Site, north of Farmington, San Juan County, New Mexico*. Report No. 2006-SJC-114 (submitted to the Bureau of Land Management, Farmington Resource Area Office, and the New Mexico Department of Game and Fish by the Cultural Resource Management Program, San Juan College, Farmington, NM).

Seymour, D., J. Hokanson, and V. J. T. Cunningham. 1997. *Excavations at Lru-Kish Kachreu and other sites at the Sandoval County landfill.* Lone Mountain Technical Series Report 1. Albuquerque, NM: Lone Mountain Archaeological Services.

Simmons, A. H. 1986. New evidence for the early use of cultigens in the American Southwest. *American Antiquity* 51(1): 73–89.

Simms, S. 1987. *Behavioral ecology and hunter-gatherer foraging: An example from the Great Basin.* Oxford: BAR International Series 381.

Smiley, F. M. 1994. The agricultural transition in the northern Southwest: Patterns in the current chronometric data. *Kiva* 60:165–89.

Smith, G. D., and M. McFaul. 1997. Paleoenvironmental and geoarchaeologic implications of late Quaternary sediments and paleosols: North-central to southwestern San Juan Basin, New Mexico. *Geomorphology* 21:107–38.

Staller, J., R. Tykot, and B. Benz, eds. 2006. *Histories of maize: Multidisciplinary approaches to the prehistory, linguistics, biogeography, domestication, and evolution of maize*. New York: Academic Press.

Tagg, M. D. 1999. Fresnal shelter. *Archaeology Southwest* 13 (1): 7.

Toll, M. S., and A. C. Cully. 1994. Archaic subsistence and seasonal population flow in northwest New Mexico. In *Archaic hunter-gatherer archaeology in the American Southwest*, ed. B. J. Vierra, 103–20. Portales, NM: Eastern New Mexico University Contributions in Anthropology 13(4).

Turnbow, C. A., J. E. Van Hoose, L. S. Reed, L. W. Huckell, J. A. Railey, R. M. Reycraft, G. A. Duncan, et al. 2000. A highway through time: Archaeological investigations along NM 90, in Grant and Hidalgo Counties, New Mexico. U.S. Forest Service Report 03-06-98-005b (prepared for the New Mexico State Highway and Transportation Department, Cultural Resource Technical Series 2000-3, TRC, Albuquerque).

Upham, S., R. S. MacNeish, W. Galinat, and C. M. Stevenson. 1987. Evidence concerning the origin of maiz de ocho. *American Anthropologist* 89:410–19.

Vierra, B. J., ed. 2005. *The late Archaic across the borderlands: From foraging to farming*. Austin, TX: University of Texas Press.

Waters, M. R. 1990. Late Quaternary alluvial stratigraphy and early Holocene archaeology of Whitewater Draw, Arizona. In *Archaeological Geology of North America*, ed. N. P. Lasca and J. Donahue. Geological Society of America, Centennial Special 4:315–22.

———. 1997. The Sulphur Springs stage of the Cochise culture and its place in southwestern prehistory. *Kiva* 64 (2): 115–35.

Waters, M. R., and A. I. Woosley. 1990. The geoarchaeology and preceramic prehistory of the Wilcox Basin, SE Arizona. *Journal of Field Archaeology* 17:163–75.

Wills, W. H. 1988. *Early prehistoric agriculture in the American Southwest.* Santa Fe, NM: School of American Research Press.

———. 2005. Early agriculture and sedentism in the American Southwest: Evidence and interpretations. *Journal of World Prehistory* 2 (4): 445–88.

Wills, W. H., and B. B. Huckell. 1994. Economic implications of changing land-use patterns in the Late Archaic. In *Themes in Southwest Prehistory*, ed. G. Gumerman, 33–52. Santa Fe, NM: School of American Research Press.

Winterhalder, B., and C. Goland. 1993. On population, foraging efficiency, and plant domestication. *Current Anthropology* 34:710–15.

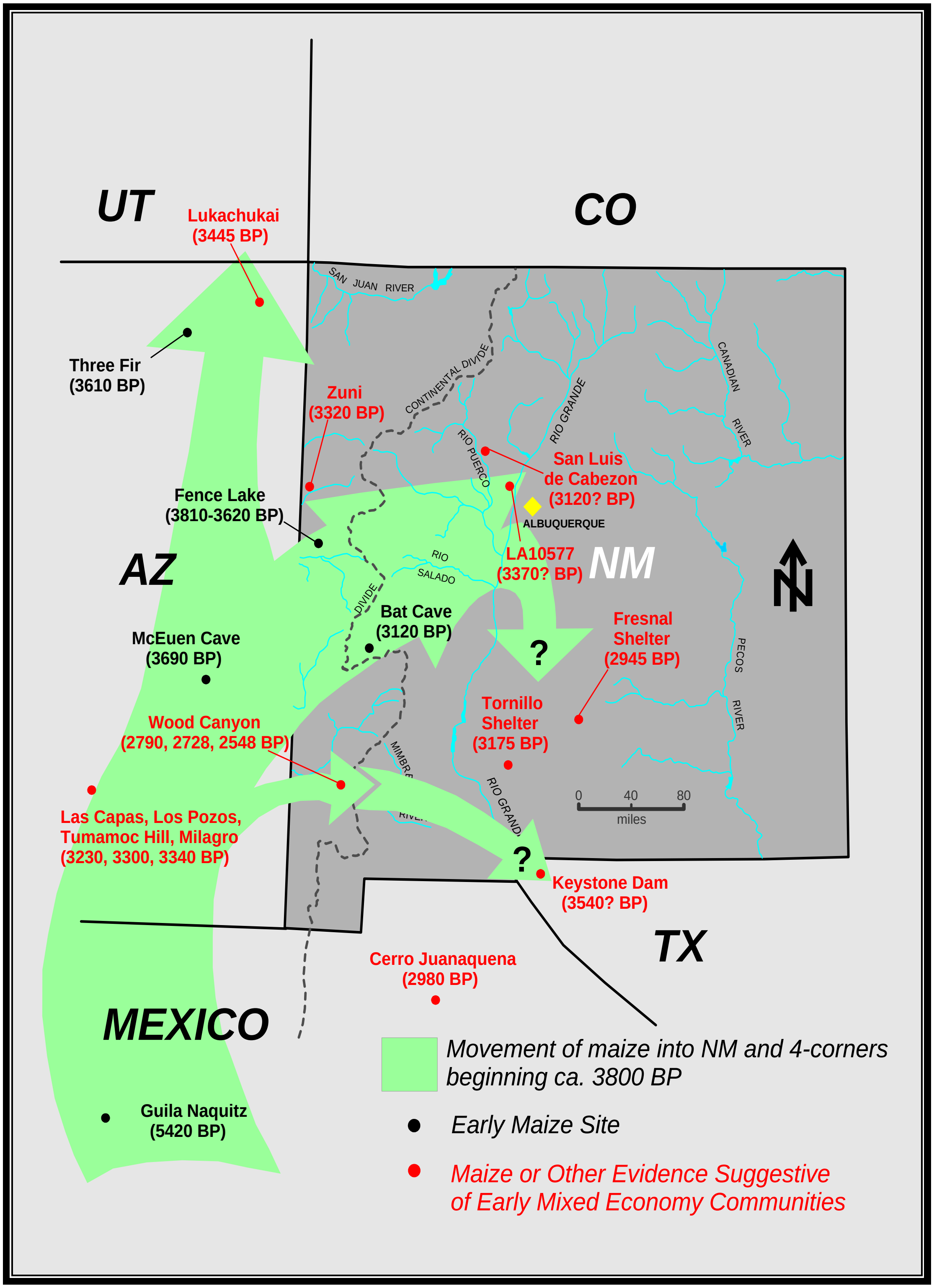

Fig. 1. Locations of early maize dates and early mixed-economy communities

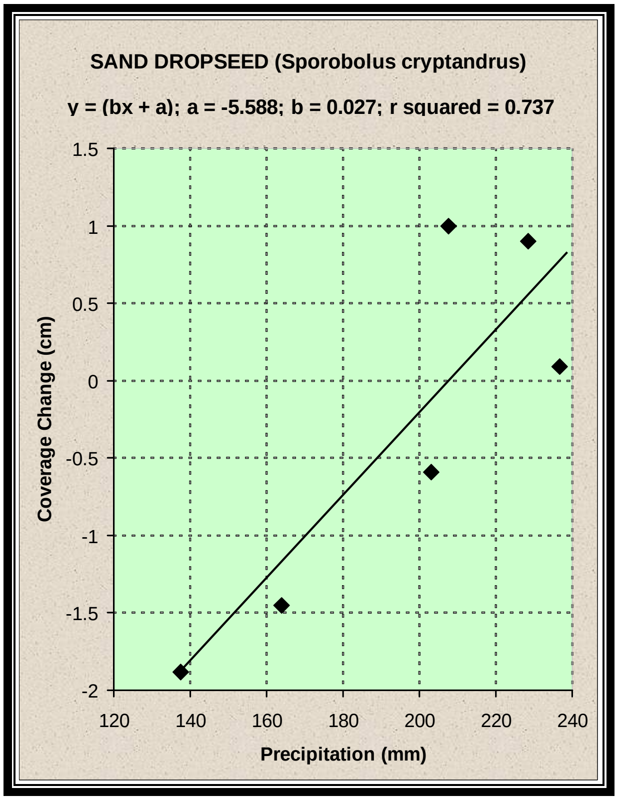

Fig. 2. Sand dropseed productivity as a function of precipitation

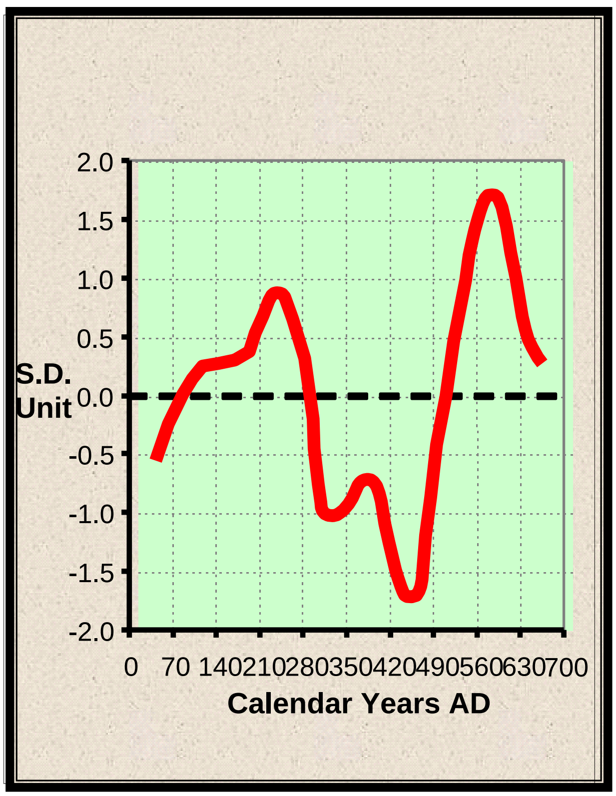

Fig. 3. Smoothed precipitation curve from El Malpais long chronology, AD 0–700

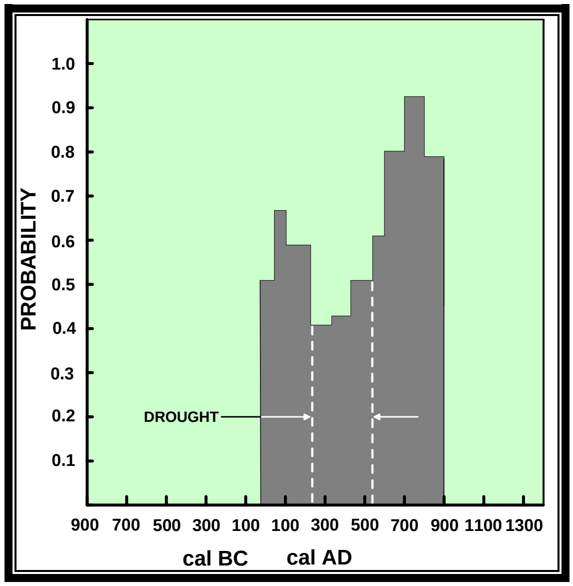

Fig. 4. Probability curve for Basketmaker II radiocarbon dates, Ceja Mesa, Middle Rio Grande Valley

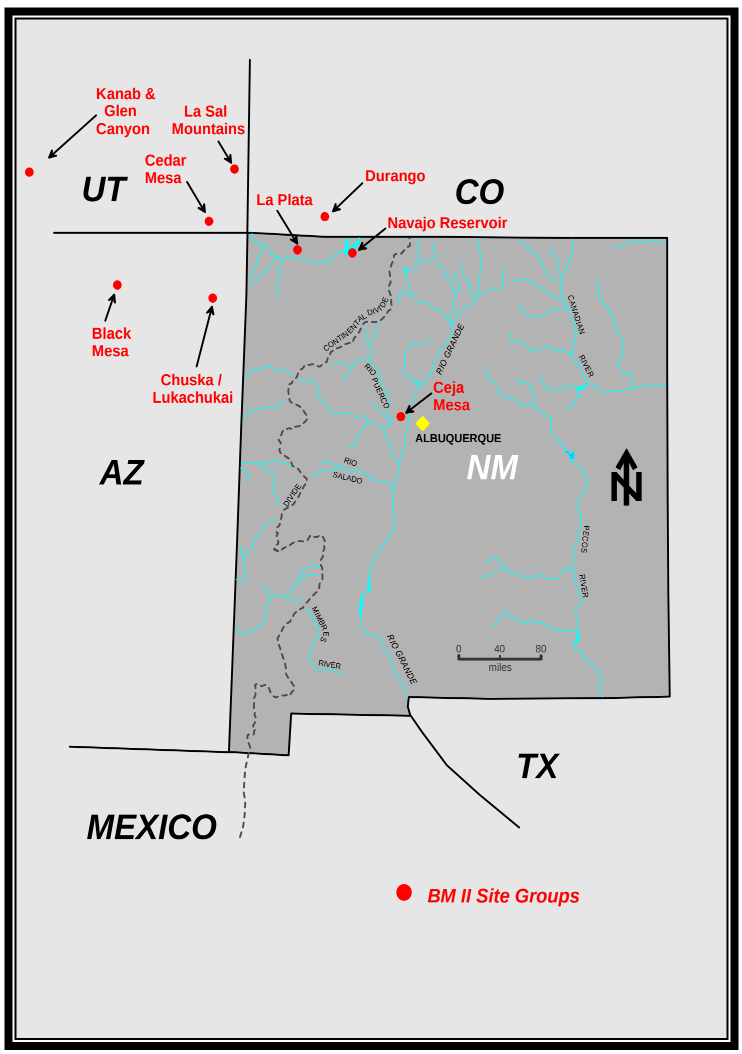

Fig. 5. Locations of maize during Basketmaker II drought (AD 258–520)

Table 1. Radiocarbon dates for early maize and early communities in the Southwest

Location	Calibrated ^{14}C Age (BP)	Dated Material	References
Guila Naquitz, Oaxaca, Mexico	5420	Maize (Zea)	Piperno and Flannery 2001
Old Corn site, Fence Lake, NM	3810 ± 50 to 3620 ± 40	Maize	Huber 2006
Bat Cave, NM	3740 ± 70[1] 3120 ± 70 3060 ± 110	Maize	Wills 1988
McEuen Cave, Arizona	3690 2800 to 2200	Maize	Huckell, Shackley, and Huckell 2001
Three Fir Shelter, AZ	3610 ± 170	Maize	Smiley 1994
Keystone Dam, TX	3540?	Charcoal[2]	O'Laughlin 1980
Lukachukai, AZ	3445 ± 45 3135 ± 45 3050 ± 50	Maize	Simmons 1986
LA10577	3370 ± 60	Maize (?)[3]	Seymour, Hokanson, and Cunningham 1997
Las Capas, Los Pozos, Tumamoc Hill, Milagro, AZ	3340 ± 60 3300 ± 60 3230 ± 50	Maize, irrigation canals	Mabry 2004; Fish et al. 1986; Gregory 2001; Huckell, Huckell, and Fish 1995
Zuni, NM	3320, 2690	Charcoal in irrigation canals	Damp, Hall, and Smith 2002
Tornillo Shelter	3175 ± 240	Maize[4]	Upham et al. 1987
San Luis de Cabezon site, NM	3120 ± 40	Maize (?)[5]	Bargman, Gerow, and Elyea 1999
Fresnal Shelter, NM	2945 ± 55 2880 ± 60	Maize	Human Systems Research 1972; Tagg 1999
Cerro Juanaqueña, Mexico	2980 ± 50 2930 ± 50 2890 ± 50	Maize	Hard and Roney 1998, 1999
Wood Canyon, NM	2790 ± 55 2728 ± 38 or 2573 ± 88 2548 ± 188	Maize	Turnbow et al. 2000

[1]The date for maize is questionable due to possible contamination (see Wills 1988, 126).
[2]The date for maize pollen at this site is derived from its association with dated charcoal. The possibility that old wood was dated suggests a corrected date for the charcoal of ca. 3300 BP.
[3]The identification of the dated maize cupule recovered at this site has been questioned by some researchers.
[4]This maize date resulted from a conventional radiocarbon assay on a composite sample of eight cobs.
[5]This date was returned on organic materials from hearth Feature 24, which included maize fragments but was dominated by *populus/salix*.

Table 2. Radiocarbon-Dated Maize Samples from the Four Corners Area[1]

Region	Site Name	Site No.	14-C Maize Date[2]
La Plata River Valley, NM	Eastside Rincon	LA3131	**AD 330 (avg)**
Durango, CO	Talus Village	5LP4223	20 BC
Durango, CO	Talus Village	5LP4223	280 BC
Durango, CO	Talus Village	5LP4223	AD 230
Durango, CO	Talus Village	5LP4223	**AD 280**
Durango, CO	Talus Village	5LP4223	**AD 360**
Durango, CO	South Shelter	5LP1434a	**AD 270**
Durango, CO	North Shelter	5LP1434b	181 BC
Durango, CO	North Shelter	5LP1434b	368 BC
Durango, CO	North Shelter	5LP1434b	377 BC
Durango, CO	Darkmold	5LP4991	AD 162
Durango, CO	Darkmold	5LP4991	**AD 335**
Navajo Reservoir, NM	n/a	LA71610	**AD 435**
Navajo Reservoir, NM	n/a	LA72747	**AD 440**
Navajo Reservoir, NM	n/a	LA83051	**AD 475 (avg)**
La Sal Mountains, UT	Mountain Boomer	42GR2945	AD 138
La Sal Mountains, UT	Culvert	42SA24047	**AD 390**
La Sal Mountains, UT	White Basketmaker	42GR2929	AD 240
La Sal Mountains, UT	Split Twig	n/a	160 BC
La Sal Mountains, UT	Cottonwood Cave	5MN519	270 BC
Chuska / Lukachukai, NM	Dog Leg	LA6448	264 BC (avg)
Chuska / Lukachukai, NM	Dog Leg	LA6448	261 BC (avg)
Chuska / Lukachukai, NM	Dog Leg	LA6448	202 BC
Chuska / Lukachukai, NM	Dog Leg	LA6448	187 BC
Chuska / Lukachukai, NM	Dog Leg	LA6448	187 BC
Chuska / Lukachukai, NM	Dog Leg	LA6448	137 BC
Chuska / Lukachukai, NM	Dog Leg	LA6448	106 BC
Chuska / Lukachukai, NM	Dog Leg	LA6448	50 BC
Chuska / Lukachukai, NM	Insulator Site	LA6444	382 BC (avg)
Chuska / Lukachukai, NM	Insulator Site	LA6444	259 BC (avg)
Chuska / Lukachukai, NM	Insulator Site	LA6444	202 BC
Chuska / Lukachukai, AZ	Salinas Springs	AZ-I-63-7	330 BC
Chuska / Lukachukai, AZ	Salinas Springs	AZ-I-63-7	201 BC
Cedar Mesa, UT	Boomerang	n/a	80 BC
Cedar Mesa, UT	Boomerang	n/a	AD 230
Cedar Mesa, UT	Boomerang	n/a	AD 240
Cedar Mesa, UT	Boomerang	n/a	**AD 280**
Cedar Mesa, UT	Boomerang	n/a	**AD 470**
Cedar Mesa, UT	Six-Toe Shelter	n/a	30 BC
Cedar Mesa, UT	Six-Toe Shelter	n/a	AD 70
Cedar Mesa, UT	Six-Toe Shelter	n/a	AD 220
Cedar Mesa, UT	Turkey Pen	42SA3714	30 BC
Black Mesa, AZ	n/a	D:7:254	AD 250
Black Mesa, AZ	n/a	D:11:152	AD 40
Black Mesa, AZ	n/a	D:11:449	AD 200
Black Mesa, AZ	n/a	D:11:1162	**AD 500**
Black Mesa, AZ	n/a	D:11:2126	AD 250
Black Mesa, AZ	n/a	D:11:3133	**AD 500**
Black Mesa, AZ	Three Fir Shelter	D:7:618	280 BC
Black Mesa, AZ	Three Fir Shelter	D:7:618	250 BC
Black Mesa, AZ	White Dog Cave	n/a	100–300 BC
Black Mesa, AZ	Kinboko Cave I	n/a	500 BC
Glen Canyon, AZ	The Pits	n/a	255 BC
Glen Canyon, AZ	The Pits	n/a	220 BC
Glen Canyon, AZ	The Pits	n/a	215 BC
Glen Canyon, AZ	The Pits	n/a	205 BC
Glen Canyon, AZ	The Pits	n/a	18 BC

Glen Canyon, AZ	The Pits	n/a	10 BC
Glen Canyon, AZ	The Pits	n/a	AD 10
Glen Canyon, AZ	The Pits	n/a	AD 92
Glen Canyon, AZ	The Pits	n/a	AD 112
Glen Canyon, AZ	Kin Kahuna	n/a	250 BC
Glen Canyon, AZ	Kin Kahuna	n/a	250 BC
Glen Canyon, AZ	Kin Kahuna	n/a	220 BC
Glen Canyon, AZ	Kin Kahuna	n/a	198 BC
Glen Canyon, AZ	Kin Kahuna	n/a	142 BC
Glen Canyon, AZ	Kin Kahuna	n/a	70 BC
Glen Canyon, AZ	Kin Kahuna	n/a	AD 17
Glen Canyon, AZ	Kin Kahuna	n/a	AD 77
Glen Canyon, AZ	Kin Kahuna	n/a	AD 203
Glen Canyon, AZ	Kin Kahuna	n/a	**AD 268**
Glen Canyon, AZ	Kin Kahuna	n/a	**AD 285**
Glen Canyon, AZ	Kin Kahuna	n/a	**AD 290**
Glen Canyon, AZ	Ditch House	n/a	87 BC
Glen Canyon, AZ	Panorama House	n/a	**AD 278**
Glen Canyon, AZ	Panorama House	n/a	**AD 290**
Glen Canyon, AZ	Panorama House	n/a	**AD 328**
Glen Canyon, AZ	Panorama House	n/a	**AD 335**
Glen Canyon, AZ	Desha Cave I	n/a	AD 203
Glen Canyon, AZ	Desha Cave I	n/a	**AD 290**
Glen Canyon, AZ	Sin Sombra	n/a	AD 198
Glen Canyon, AZ	Sin Sombra	n/a	AD 205 (avg)
Glen Canyon, AZ	Sin Sombra	n/a	AD 230
Glen Canyon, AZ	Sin Sombra	n/a	**AD 280**
Glen Canyon, AZ	Atlatl Rock Cave	n/a	**AD 335**
Glen Canyon, AZ	Mountainview	n/a	AD 230
Glen Canyon, AZ	Mountainview	n/a	**AD 270**
Glen Canyon, AZ	Mountainview	n/a	**AD 280**
Glen Canyon, AZ	Scorpion Heights	n/a	AD 243
Glen Canyon, AZ	Polly's Place	n/a	**AD 280**
Glen Canyon, AZ	Polly's Place	n/a	**AD 470**
Glen Canyon, AZ	Polly's Place	n/a	**AD 500**
Kanab, UT	Cave du Pont	42KA1765	**AD 260**
Kanab, UT	Cave du Pont	42KA1765	**AD 320**
Kanab, UT	n/a	42KA3575	AD 240
Kanab, UT	n/a	42KA3684	**AD 365**

[1]All dates, except one, are reported by Charles and Cole (Basketmaker II Chronology and Material Culture Database), where original references for each date are listed. Rohwer (2006, 18) reported the date from the Eastside Rincon site. Approximately 50% of dates are not AMS dates. No 1-sigma or 2-sigma date ranges are reported by Charles and Cole.
[2]**Bolded** dates fall into the BMII drought period, AD 258–520.

Status and Ecology of Mexican Spotted Owls in the Gila Region, New Mexico

Joseph L. Ganey

Research Wildlife Biologist
USDA Forest Service, Rocky Mountain Research Station, 2500 S. Pine Knoll, Flagstaff, AZ 86001
928/556-2156, 928/556-2130 (fax), jganey@fs.fed.us

Arthur J. Telles

Forest Biologist
USDA Forest Service, Gila National Forest, Silver City, NM

Marikay A. Ramsey

Black Range Wildlife Staff
USDA Forest Service, Gila National Forest, Truth or Consequences, NM

Abstract

The highlands of New Mexico's Gila region provide an important stronghold for the Mexican spotted owl (*Strix occidentalis lucida* Nelson). Historical data document that this region supported spotted owls in the past, and recent studies indicate that owls are both relatively common and well distributed in this region at present. Spotted owls are most numerous in mixed-conifer forests within the Gila region but may also occur in other forest types, particularly where rocky cliffs and outcrops are present. These features provide owls with nest and roost sites as well as habitat for common prey species. Spotted owl diets in the region typically are dominated by a few types of nocturnally active small mammals. The Gila region features a convergence of topography, geologic substrates, and forest types that provide suitable habitat for Mexican spotted owls and their prey, and contains large roadless areas that result in minimal disturbance due to land management. These large roadless areas also provide unique opportunities to manage wildfire at landscape scales, thus providing an opportunity to evaluate relationships between spotted owls, forest habitats, and fire. Despite their abundance and widespread distribution in the region, however, studies between 1990 and 2005 suggest that some local owl populations may be declining in the region. This is a concern because the Gila region likely serves as an important source population of spotted owls. Uncertainty over population trends suggests a need for continued monitoring of owl populations in this region.

Introduction

The highlands of New Mexico's Gila region serve as an important center of biodiversity and support important populations of many species of special interest (e.g., Povilitis 1996), including the Mexican spotted owl (*Strix occidentalis lucida* Nelson). This medium-sized owl inhabits canyonlands and forested mountains throughout the southwestern United States and the highlands of northern and central Mexico (Gutiérrez, Franklin, and LaHaye 1995; Ward et al. 1995). It is frequently associated with mature or late-successional forests (Ganey and Balda 1989; Ganey and Dick 1995; Gutiérrez, Franklin, and LaHaye 1995) and was listed as threatened in the United States under the Endangered Species Act, largely due to concerns over loss of such forests to timber harvest and stand-replacing wildfire (USDI 1993). Here we summarize current information on the status of the Mexican spotted owl in the Gila region. We review historical information (defined as prior to 1989, the year when organized surveys for this species began throughout the Southwestern Region, USDA Forest Service) on the presence of these owls in the Gila region; synthesize recent (1989–present) data on spotted owl status and ecology in this region; and speculate on the importance of this region to recovery of this threatened owl. We show that spotted owls were present historically in the Gila region and argue the likelihood that this region currently serves as an important population center for Mexican spotted owls and should continue to do so into at least the near future. We also argue that the nature of the Gila region, coupled with a relatively high population of spotted owls, provides unique opportunities for studying this bird and aspects of its ecology.

The Gila Region

Our primary focus in this paper is on lands administered by the Gila National Forest in west-central New Mexico (fig. 1). This region falls within the Upper Gila Mountains Recovery Unit (fig. 2), one of six recovery units recognized within the U.S. range of the owl (USDI 1995).

The Gila National Forest is dominated by a series of rugged mountain ranges separated by river valleys. Elevation ranges from 1370 to 3350 m, and habitats range from semi-desert grassland to alpine forests. This forest includes more area in wilderness than any other national forest in the Southwest.

The Gila National Forest is contiguous with similar forest lands administered by the Apache National Forest to the west, and is nearly contiguous with the forested San Mateo and Magdalena mountains (Cibola National Forest) to the northeast (fig. 1). Thus the Gila region, broadly defined, could easily be extended beyond the boundaries of our primary focus area within the Gila National Forest.

Natural History of Mexican Spotted Owls in the Gila Region

Distribution and Abundance

Historical information on Mexican spotted owls throughout their range is sparse and anecdotal, but clearly documents that these owls were present in the Gila region and suggests that they were not uncommon. For example, Ligon (1926, 422) observed spotted owls throughout much of New Mexico, but observed them "most commonly through south central New Mexico in the Sacramento Mountains, San Mateo Mountains, Black Range and Mogollon Mountains and in corresponding latitudes in eastern Arizona." With the exception of the Sacramento Mountains, this describes the Gila region and immediately adjacent areas. Bailey (1928) also lists several locations where spotted owls were observed in and around the Gila region.

Skaggs (1988) compiled available records of the spotted owl in southern New Mexico from his personal observations, the ornithological literature, museum specimens, and sight records by agency biologists and experienced New Mexico bird-watchers. He grouped these records into three broad geographic regions (Basin and Range, Sacramento Mountains, and Mogollon Highlands). The Mogollon Highlands area corresponded to the Gila region and the adjacent San Mateo Mountains (see Skaggs 1988, fig. 1), and contained 77% of the historical records of spotted owls in southern New Mexico. Skaggs noted that differences in regional coverage might bias these results, but also stated, "There is no question in my mind that the Mogollon Highlands contain the greatest proportion of suitable spotted owl habitat in southern New Mexico."

No historical data on abundance or density of spotted owls are available for the Gila region. As noted, however, Ligon (1926, 422) indicated that these owls were more common in this region than elsewhere, and added that they were "by no means as scarce in favored sections of their range as one unfamiliar with their habits might believe."

Thus, historical data document that spotted owls were present, and likely not extremely rare, in the Gila region. Because of their threatened status and the association between spotted owls and older forests, considerable attention has focused on these owls in recent years. As a result, we know considerably more about current status than we do about historical status.

Although we still have no rigorous estimates of population size for Mexican spotted owls in the Gila region, several lines of evidence suggest that these owls are more abundant in this region than elsewhere. For example, the Gila National Forest had established 269 Protected Activity Centers (PACs) for spotted owls as of 2008, far more than any other national forest within the Southwestern Region (fig. 3). These PACs are established around discrete areas occupied by pairs of owls or single owls, in accordance with recommendations in USDI (1995). It is not possible to estimate numbers of owls from numbers of PACs, because not all territories are occupied simultaneously, not all occupied PACs are occupied by pairs of owls, and portions of the forest have not been surveyed thoroughly for owls. Nevertheless, the relatively large number of PACs implies a relatively large population of spotted owls in the Gila region.

Data on relative occupancy and density of spotted owls from standardized surveys across the Upper Gila Mountains Recovery Unit also suggest that these owls are more numerous in the Gila region than in the overall Recovery Unit. Ganey et al. (2004) used standardized methodology to estimate abundance of spotted owls in 25 randomly located quadrats, ranging in size from roughly 40 to 80 km^2, across this Recovery Unit (fig. 4). Resident owls were found in 8 of 10 quadrats within the Gila region, versus 53% of 15 quadrats located outside of the Gila region.

Not only were owls found in greater proportions of occupied quadrats in the Gila region than elsewhere, but observed density of owls in occupied quadrats was greater there as well. Median owl density in occupied quadrats in the Gila region was more than double the median density in occupied quadrats elsewhere, and only one quadrat outside the Gila region even approached the median density observed within the Gila region (fig. 5). That quadrat was located within the Kachina Peaks Wilderness on the San Francisco Peaks (Ganey et al. 2004), an area seemingly similar to much of the Gila region in that it encompasses a roadless area dominated by montane forests.

Spotted owls also appear to be well distributed throughout the Gila region (fig. 6). PAC locations combined with locations of owls discovered in the quadrat surveys (Ganey et al. 2004) suggest that owls are found throughout the higher-elevation montane areas across the forest; there are records from the Black Range and the Jerky, Mangas, Mogollon, Pinos Altos, San Francisco, and Tularosa mountains and surrounding areas. Again, current knowledge may underestimate actual owl distribution, because surveys have not been conducted thoroughly across the entire forest.

Habitat Use

Data on habitats historically occupied by spotted owls are also sparse and anecdotal. Ligon (1926, 422) observed these owls in "deep, narrow, timbered cañons where there are always cool shady places, at elevations ranging from 6,500 to 9,000 feet" (approximately 1980 to 2745 m). He typically observed them roosting either in trees or in a cave or crevice in canyon walls. Skaggs (1988, 3) summarized breeding-season records of spotted owls in southern New Mexico as ranging from 1370 to 3000 m (mean = 2210 m). The dominant vegetation type at 89% of 18 known breeding areas he examined was mixed-conifer forest (dominated by Douglas fir ([*Pseudotsuga menziesii* Mirb., Franco], white fir [*A. concolor* Lindl. ex Hildebr.], and ponderosa pine [*Pinus ponderosa* Dougl. ex Laws]), with the remaining sites in ponderosa pine forest and pinyon (*P. edulis* Engelm.)–juniper (*Juniperus spp*.) woodland at lower elevations. Most nest and roost sites he observed had " moderate to high densities of understory trees, typically Gambel oak (*Quercus gambelii* Nutt.) and bigtooth maple (*Acer grandidentatum* Nutt.)." Cliffs were present at 15 of 18 (83.3%) sites, and vertical relief was pronounced in the areas surrounding observed roost and nest sites.

Three data sets provide information about recent habitat use. USDI (1995) compiled available information resulting from agency surveys for spotted owls throughout the southwestern U.S. from 1989 to 1993. The resulting data included 238 visual observations of spotted owls within the Gila National Forest. The vast majority of these locations were in mixed-conifer forest (fig. 7). Data were gathered from large portions of the forest, but (1) data represented an unknown number of owls and territories; (2) representation was unequal among owls and territories (i.e., multiple observations were included for some owls and territories but not for others); and (3) survey areas were not selected randomly or systematically. All of these factors could bias the results, with both direction and magnitude of that bias unknown.

Two other studies examined habitat use at different spatial scales in a single study area in the Tularosa Mountains. These studies did not cover as wide a geographic area as USDI (1995), but had the advantage that only one observation per individual owl territory was included in analyses, eliminating potential biases caused by including multiple observations for some territories.

Seamans and Gutiérrez (1995) compared fine-scale habitat characteristics between known owl roost and nest sites and randomly located sites. Owls selected roost and nest sites in mature, closed-canopy mixed-conifer forests, particularly where those forests had a well-developed oak component and contained large trees. Most nest sites (78%, n = 28 nests) were in Douglas fir trees, and the most common nest structures (61%) were platforms in witches' brooms caused by dwarf mistletoe (*Arceuthobium* spp.) infections. Nest trees were older, larger in diameter, and taller than randomly located trees within the nest stand (table 1). Only one cliff nest (4%) was found.

Peery, Gutiérrez, and Seamans (1999) compared landscape composition and pattern between owl nest and roost areas and randomly located areas at eight spatial scales ranging from 79 to >5000 ha (n = 40 discrete territories included). At all scales evaluated, owl sites contained significantly greater amounts of mature mixed-conifer and pine forest than random sites. After controlling for area in mature forest, no differences were observed between owl and random sites in various indices of landscape pattern.

Thus, historical data suggest that owls were most common in mixed-conifer forests, often in areas associated with rocky cliffs. Recent surveys throughout the Gila region also support a strong association between owls and mixed-conifer forest, and recent studies in the Tularosa Mountains suggest that they select mature mixed-conifer forest in that area. These results generally are consistent with habitat use of Mexican spotted owls elsewhere (see review in Ganey and Dick 1995). However, historical data may overestimate, and recent results underestimate, the association between spotted owls and rocky cliff areas. Both Ligon (1926) and Skaggs (1988) noted a strong association between spotted owls and cliffs, and Ligon regarded cliffs as a range requirement. Ganey et al. (2004) did not evaluate habitat use, but some of the highest densities of owls were observed in quadrats where owls inhabited forests interspersed with cliffs and caves (JLG, personal observation). Owls in these areas used cliffs and caves for both nest and roost sites, and rocky areas may provide good foraging opportunities as well. Spotted owls thus appear to be strongly associated with both mixed-conifer forests and rocky cliffs in the Gila region, and the presence of rocky cliffs and caves may allow them to exist outside of the mixed-conifer zone if significant cliffs are present. Recent studies in the Tularosa Mountains reported no strong association with cliffs, however, which suggests that cliffs and caves, although important in parts of the region, are not a habitat requirement for spotted owls in the overall Gila region.

Diet Composition

Again, little historical information is available on diets of spotted owls in the Gila region. Ligon (1926) reported that they fed "almost exclusively on small rodents," and most stomachs he examined contained parts of woodrats (*Neotoma* spp.). A juvenile spotted owl captured near Reserve and kept in a barn overrun with mice and rats quickly "cleaned the barn of these pests" (Steele 1927). This owl refused to eat offered birds and chicken parts, but readily accepted rodents from the author.

Three recent data sets estimated diet composition of spotted owls in the Gila region. The largest of these data sets was from the Tularosa Mountains study by Seamans and Gutiérrez (1999), discussed above. The others resulted from a USDA Forest Service contract study across the Gila region and adjacent areas (Reichenbacher and Duncan 1992). Patterns were similar throughout: Owls consumed a wide variety of animals, but diet biomass was dominated by relatively few types of small mammals (fig. 8). These typically included woodrats, mice (*Peromyscus* spp.), rabbits (*Sylvilagus* spp.), voles (*Microtus* spp.), and pocket gophers (*Thomomys bottae* Eydoux and Gervais), with woodrats being the dominant prey in all three areas.

These results are generally consistent with studies of diet composition of Mexican spotted owls in other geographic areas, which also typically show diets dominated by a few species of nocturnally active small mammals (e.g., Ganey 1992; Ward and Block 1995). The relative proportions of prey species differ among geographic areas, likely reflecting differences in habitats present and relative distribution of prey taxa. In general, woodrats tend to dominate diets in areas where rocky cliffs are present (Ganey 1992; Ward and Block 1995). The primary woodrat taken in most montane areas is the Mexican woodrat (*N. Mexicana* Baird; Ganey 1992; Ward and Block 1995). In New Mexico, this woodrat occurs primarily in montane mixed-conifer forests (Findley et al. 1975), often in association with rock outcrops, rocky slopes, and cliffs (Cornely and Baker 1986). Thus, the relative dominance of woodrats in diets of spotted owls in the Gila region is consistent with the habitat of these owls. Areas where rocky cliffs or outcrops are present within montane mixed-conifer forests may provide optimal foraging conditions for spotted owls.

Population Trend

No historical data exist on population trends of Mexican spotted owls. Recent studies suggest that populations may be declining in the Gila region. Stacey and Peery (2002) studied populations of owls in four mountain ranges from 1991 to 1999. One of these ranges (Black Range) was within the Gila region as defined here, with the other three ranges (Magdalena, San Mateo, and Zuni mountains) nearby. They reported that the combined population declined at a rate of almost 20% per year during this period, that all of the owl territories monitored in the two smallest ranges (Magdalena and Zuni mountains) "became vacant" by the end of the study, and that populations in the larger San Mateo Mountains and Black Range declined annually by approximately 30% and 16%, respectively.

Seamans et al. (1999) reported on short-term trends in a spotted owl population in the Tularosa Mountains, and Gutierrez et al. (2003) provided data for this population over a longer time frame. From 1993 to 2000, the population declined by approximately 6% per year (ibid. 2003). Using estimates of "realized change," they estimated that the owl population remaining in the study area in the year 2000 was only 60.8% as large as the 1993 population.

Air Combat Command (2006) monitored occupancy and reproductive rates for 83 spotted owl territories in the Gila National Forest south of Reserve from 2000 through 2005. There, both overall occupancy rates and pair occupancy rates declined during this period, possibly in response to several poor reproductive years early in that period (fig. 9). Reproduction improved in 2004 and 2005, however, with numerous young fledging in those years (fig. 9). Because populations of Mexican spotted owls appear to track reproduction with a short "lag period"

(Seamans et al. 1999; Gutiérrez et al. 2003), this suggests a possibility for increased occupancy rates in 2006 and subsequent years. Data to document that response are lacking, however.

Reasons for apparent population declines are unknown, but may involve climatic variability. Seamans, Gutiérrez, and May (2002) modeled the influence of climate on survival and reproduction of spotted owls. Both reproduction and survival were positively correlated with precipitation in the Tularosa Mountains. Precipitation during the previous monsoon season (July–Sept.) explained almost half of the temporal variability in owl reproduction, and precipitation during the previous winter explained more than half of the temporal variability in owl survival. These authors speculated that climate may influence owl vital rates indirectly by influencing prey abundance. Regardless of the underlying cause-and-effect relationships, however, their results suggest that continued drought may result in continued declines in numbers of spotted owls.

In contrast, surveys conducted in 2000 by National Forest personnel located numerous owls both in the Gila region (Gila National Forest 2000, table 1) and in nearby mountain ranges (San Mateo and Magdalena mountains, Cibola National Forest; Gila National Forest 2000, table 2) where Stacey and Peery reported precipitous declines prior to 2000. These results do not appear consistent with rapidly declining populations. We are unsure how to reconcile these conflicting data, but suggest that enough uncertainty exists to warrant continued monitoring of the owl population in the Gila region.

Biogeography and Population Genetics

Over the subspecies' range, Mexican spotted owl distribution is discontinuous, reflecting the fragmented distribution of canyonlands and forested mountains throughout the Southwest. Thus, Mexican spotted owl populations may constitute one or more metapopulations, or systems of local populations connected by dispersing individuals (Keitt, Franklin, and Urban 1995; Gutierrez and Harrison 1996; Hanski 1998). Maintaining connectivity between different populations of spotted owls thus may be important to maintaining overall viability of the subspecies. The Gila region may serve as both an important source population and an important connecting link between habitat "islands."

Keitt and others (1995; 1997) modeled landscape connectivity for spotted owls throughout the southwestern U.S. They mapped habitat islands based on land-cover maps and assessed connectivity by varying values for effective dispersal distance. They found a threshold change in landscape connectivity at a dispersal distance of about 45 km. That is, the landscape suddenly changed from a set of largely unconnected habitat islands to a set of largely connected islands if owls could effectively disperse approximately 45–50 km between clusters. Current information suggests that this is a reasonable estimate for effective dispersal distance in spotted owls (Gutiérrez, Franklin, and LaHaye 1995; Ganey et al. 1998; Willey and van Riper 2000). Their analysis further documented that numerous connections between habitat islands went through the Gila region (Keitt, Urban, and Milne 1997, fig. 3).

The same authors also evaluated relative importance of individual habitat islands to landscape connectivity by sequentially removing individual islands and reassessing connectivity in their model. They identified the Upper Gila Mountains Recovery Unit as extremely important to landscape connectivity based on both its central location and large patch size (Keitt, Urban, and Milne 1997, fig. 6). A further analysis weighted by patch area identified several small habitat islands in northern New Mexico as very important to maintaining connectivity for this owl (ibid., figs. 6 and 7). These islands are too small to serve as important source populations, but rather serve as stepping stones linking larger areas of habitat. Logic dictates that these patches remain important only if they remain connected to larger habitat islands that support source populations, and the nearest likely source population is located within the Gila region. Thus, because of both its size and location, the Gila region appears likely to play a large role in metapopulation dynamics of Mexican spotted owls, and may have importance beyond the local population.

This conclusion is further supported by current knowledge of genetic structure in this subspecies. Barrowclough et al. (2006, fig. 1b) identified three relatively distinct clades or genetic types in Mexican spotted owls. One clade was dominant in the northwestern portion of the range (southwestern Utah) and absent from the southeastern portion of the range (Sacramento Mountains, New Mexico). A second clade dominated the southeastern portion of the range but was absent from the northwestern populations. A third clade was most common in the Upper Gila Mountains Recovery Unit and southeastern Arizona, but was present throughout the range of the owl. All three clades were present in the Gila region, suggesting that populations within the Gila region facilitate gene flow across the range of the owl. Viewing their results in light of Keitt, Urban, and Milne (1997), Barrowclough et al. (2006) suggested that maintaining stepping-stone habitat fragments connecting the Upper Gila Mountains region to the rest of the population was important to maintaining population viability for Mexican spotted owls. We argue that the Gila region is particularly important within the larger Upper Gila Mountains Recovery Unit, because of both its geographic location and the relative abundance of owls there.

Prospects for the Future

Because of its relatively high abundance and geographic location, the population of Mexican spotted owls in the Gila region may be vital to maintaining viability for this threatened subspecies and in fostering its ultimate recovery. In theory, Mexican spotted owls should thrive in the Gila region, which features large expanses of montane terrain, much of it dominated by the mixed-conifer forest favored by spotted owls (Ganey and Dick 1995). The region also features geologic formations prone to forming cliffs and large outcrops containing caves and potholes, features that provide both roost and nest sites for spotted owls and suitable habitat for important prey species such as Mexican woodrats. Furthermore, the Gila region features extensive roadless areas where disturbance by land management is minimal, and where large areas of late-successional forests provide suitable habitat for spotted owls.

All of these features should interact to provide favorable conditions for this bird. Thus, the suggestion that populations of spotted owls in the Gila region may be declining (Seamans et al. 1999; Stacey and Peery 2002; Gutiérrez et al. 2003) is cause for concern, and suggests a need for continued monitoring of population status in this region.

There are other good reasons for monitoring population trends in this region. One is that this region may provide unique opportunities to evaluate relationships between spotted owls and fire. Following years of fire suppression, southwestern forests have become prone to large, stand-replacing wildfires (Gila National Forest 2005). Management intervention is often needed to restore these forests to structural conditions more in line with natural fire regimes. In many cases, initial intervention includes mechanical thinning of small trees, prescribed burning, or both treatments used in combination. The effects of such treatments on owls and their prey and habitat are not well understood. Further, mechanical thinning is not a viable option in the large roadless areas of the Gila region. Consequently, the Gila National Forest uses wildland fire management in an attempt to use naturally occurring fires, burning when climatic conditions are favorable, to reduce fuels without subjecting large areas to stand-replacing crown fires (Gila National Forest 2005). In some cases large, stand-replacing wildfires occur despite the efforts of forest managers. The large roadless areas of the Gila region, with their limited access and rugged terrain, are particularly prone to such wildfires.

Available data suggest that Mexican spotted owls are reasonably resilient with respect to even large wildfires in the short term (Bond et al. 2002; Jenness, Beier, and Ganey 2004), but long-term data on owl response to fire is generally lacking. Given current knowledge, it seems reasonable to expect that owls will also be resilient with respect to prescribed fire (e.g., Willey 1998b) and wildland fire use. Monitoring occupancy and reproduction of owl territories burned under varying conditions could provide information on how owls respond to varying fire severity and extent. Monitoring of owl response over longer time frames would also be helpful to determine whether or not short-term responses persist over these longer time frames. As a result of prescribed fires, wildland use fires, and wildfires, the Gila region features forests that represent a wide range of fire effects, in terms of both fire intensity and fire extent, and includes areas that have burned multiple times in recent history. Thus, the Gila provides unique opportunities to understand how fire affects spotted owls and their prey and habitat. Lessons learned in the Gila region regarding the effects of fire on spotted owls may be relevant throughout the broader region as fire managers strive to return southwestern forests to fuel conditions within the natural range of variability.

Other factors potentially influencing future spotted owl populations in this area include introduced avian diseases and climate change. West Nile virus has had significant impacts on populations of some birds (Peterson et al. 2004), including owls (Fitzgerald et al. 2003), and this virus has now reached New Mexico. Susceptibility of Mexican spotted owls to West Nile virus remains unknown. Similarly, avian influenza has spread throughout much of Asia, Europe, and Africa, and may spread to North America at some point. Both diseases could result in mortality or reduced fecundity in spotted owls, and these effects would likely go unnoticed in the absence of population monitoring.

Climate change also has the potential to impact spotted owls and their habitat. Climatic effects on fecundity and survival of spotted owls have been demonstrated (Seamans, Gutiérrez, and May 2002), and suggest that if drought conditions persist in the Gila region, owl populations may continue to decline. Many climate models predict increased and rapid warming in the near future (IPCC 2007). Changes predicted by these models are sufficiently large to affect the distribution of forest types occupied by spotted owls (Dale et al. 2001; Koprowski, Alanen, and Lynch 2005; Mueller et al. 2005; CIRMOUNT 2006). These changes may occur too rapidly to allow for migration of forest types. Climate change also may alter disturbance regimes, resulting in disturbances (such as wildfire and insect outbreaks) that are both more frequent and more severe than those typical of the past (Dale et al. 2001; McKenzie et al. 2004; Koprowski, Alanen, and Lynch 2005; CIRMOUNT 2006). Thus, the potential for habitat loss from climate change appears real. There may be little land managers can do to minimize such loss, but monitoring of population trends could provide an early warning if population declines occur.

In summary, the Gila region appears to be an important population center for Mexican spotted owls, and the health of the owl population there may affect the viability of the overall population of this subspecies. The Gila region at present has a wealth of suitable habitat for spotted owls, which in theory should thrive there. The large-scale fire management occurring within the Gila region also provides unique opportunities to study relationships between spotted owls and fire. Significant uncertainties for future prospects of spotted owls in this region include short-term climatic fluctuations (e.g., drought), long-term climate change and associated changes in forest types and disturbance regimes, introduction of exotic avian diseases, and possible changes in management strategies (e.g., a return to the intensive timber management implemented in Arizona and New Mexico, which factored heavily into the decision to list the owl as a Threatened Species [USDI 1993]). Monitoring of owl populations in this region could provide both information on population trends and an early warning system if negative effects of avian diseases and/or climate change operate.

Acknowledgments

We thank the numerous dedicated individuals whose investigations produced the data summarized here. K. Kindscher, R. M. King, W. R. Norris, Z. M. Peery, S. O. Williams III, and D. Zimmerman commented on earlier drafts of this paper.

Literature Cited

Air Combat Command. 2006. *Annual report: 2005 biological monitoring activities.* November 2006 draft report on file at Gila National Forest. (Cited by permission.)

Bailey, F. M. 1928. *Birds of New Mexico.* Albuquerque: New Mexico Department of Game and Fish.

Barrowclough, G. F., J. G. Groth, L. A. Mertz, and R. J. Gutiérrez. 2006. Genetic structure of Mexican spotted owl (*Strix occidentalis lucida*) populations in a fragmented landscape. *Auk* 123:1090–1102.

Bond, M. L., R. J. Gutiérrez, A. B. Franklin, W. S. LaHaye, C. A. May, and M. E. Seamans. 2002. Short-term effects of wildfires on spotted owl survival, site fidelity, and mate fidelity. *Wildlife Society Bulletin* 30:1022–28.

CIRMOUNT (Consortium for Integrated Climate Research in Western Mountains). 2006. *Mapping new terrain: Climate change and America's West.* Misc. Pub. PSW-MISC-77. Albany, CA: USDA Forest Service Pacific Southwest Research Station.

Cornely, J. E., and R. J. Baker. 1986. *Neotoma mexicana*. *Mammalian Species* 262:1–7.

Dale, V. H., L. A. Joyce, S. McNulty, R. P. Neilson, M. P. Ayres, M. D. Flannigan, P. J. Hanson, et al. 2001. Climate change and forest disturbances. *BioScience* 51:723–34.

Findley, J. S., A. H. Harris, D. E. Wilson, and C. Jones. 1975. *Mammals of New Mexico.* Albuquerque: University of New Mexico Press.

Fitzgerald, S. D., J. S. Patterson, M. Kiupel, H. A. Simmons, S. D. Grimes, C. F. Sarver, R. M. Fulton, et al. 2003. Clinical and pathologic features of West Nile Virus infection in North American owls (family Strigidae). *Avian Diseases* 47:602–10.

Ganey, J. L. 1992. Food habits of Mexican spotted owls in Arizona. *Wilson Bulletin* 104:321–26.

Ganey, J. L., and R. P. Balda. 1989. Distribution and habitat use of Mexican spotted owls in Arizona. *Condor* 91:355–61.

Ganey, J. L., and J. A. Dick. 1995. Habitat relationships of Mexican spotted owls: Current knowledge. In *Recovery plan for the Mexican spotted owl (Strix occidentalis lucida), vol II—Technical supporting information,* ed. USDI Fish and Wildlife Service, chap. 4. http://mso.fws.gov/recovery-plan.htm.

Ganey, J. L., W. M. Block, J. K. Dwyer, B. E. Strohmeyer, and J. S. Jenness. 1998. Dispersal movements and survival rates of juvenile Mexican spotted owls in northern Arizona. *Wilson Bulletin* 110:206–17.

Ganey, J. L., G. C. White, D. C. Bowden, and A. B. Franklin. 2004. Evaluating methods for monitoring populations of Mexican spotted owls: A case study. In *Sampling rare and elusive species: Concepts, designs, and techniques for estimating population parameters,* ed. W. L. Thompson, 337–85. Washington, DC: Island Press.

Gila National Forest. 2000. *Summary: Gila and Cibola National Forests Mexican spotted owl surveys. 2000 breeding season.* Unpublished report, Gila National Forest. Silver City, NM.

Gila National Forest. 2005. *Gila National Forest fire management plan.* Unpublished report, Gila National Forest, Silver City, NM.

Gutiérrez, R. J., and S. Harrison. 1996. Applying metapopulation theory to spotted owl management: A history and critique. In *Metapopulations and wildlife conservation,* ed. D. R. McCullough, 167–85 . Washington, DC: Island Press.

Gutiérrez, R. J., A. B. Franklin, and W. S. LaHaye. 1995. Spotted owl (*Strix occidentalis*). In *The Birds of North America*, No. 179, ed. A. Poole and F. Gill. Philadelphia: The Academy of Natural Sciences; Washington, DC: The American Ornithologists Union.

Gutiérrez, R. J., C. A. May, M. L. Petersburg, and M. E. Seamans. 2003. *Temporal and spatial variation in the demographic rates of two Mexican spotted owl populations.* (Final report.) Flagstaff: USDA Forest Service, Rocky Mountain Research Station.

Hanksi, I. 1998. Metapopulation dynamics. *Nature* 396:41–49.

IPCC (Intergovernmental Panel on Climate Change). 2007. *Climate change 2007: The physical science basis. Summary for policymakers.* http://www.ipcc.ch/spm2feb07.pdf (accessed February 13, 2007).

Jenness, J. S., P. Beier, and J. L. Ganey. 2004. Associations between forest fire and Mexican spotted owls. *Forest Science* 50:765–72.

Keitt, T. H., A. B. Franklin, and D. L. Urban. 1995. Landscape analysis and metapopulation structure. In *Recovery plan for the Mexican spotted owl* (Strix occidentalis lucida), *vol II—Technical supporting information,* ed. USDI Fish and Wildlife Service, chap. 3. http://mso.fws.gov/recovery-plan.htm.

Keitt, T. H., D. L. Urban, and B. T. Milne. 1997. Detecting critical scales in fragmented landscapes. *Conservation Ecology* 1(1):4. http://www.consecol.org/vol1/iss4/art4.

Koprowski, J. L., M. I. Alanen, and A. M. Lynch. 2005. Nowhere to run and nowhere to hide: Response of endemic Mt. Graham red squirrels to catastrophic forest damage. *Biological Conservation* 126:491–98.

Ligon, J. S. 1926. Habits of the spotted owl (*Syrnium occidentale*). *Auk* 43:421–29.

McKenzie, D., Z. Gedalof, D. L. Peterson, and P. Mote. 2004. Climate change, wildfire, and conservation. *Conservation Biology* 18:890–902.

Mueller, R. C., C. M. Scudder, M. E. Porter, R. T. Trotter III, C. A. Gehring, and T. G. Whitham. 2005. Differential tree mortality in response to severe drought: Evidence for long-term vegetation shifts. *Journal of Ecology* 93:1085–93.

Peery, M. Z., R. J. Gutiérrez, and M. E. Seamans. 1999. Habitat composition and configuration around Mexican spotted owl nest and roost sites in the Tularosa Mountains, New Mexico. *Journal of Wildlife Management* 63:36–43.

Peterson, A. T., N. Komar, O. Komar, A. Navarro-Sigüenza, M. R. Robbins, and E. Martínez-Meyer. 2004. West Nile Virus in the New World: Potential impacts on bird species. *Bird Conservation International* 14:215–32.

Povilitis, T. 1996. The Gila River–Sky Island Bioregion: A call for bold conservation action. *Natural Areas Journal* 16:62–66.

Reichenbacher, F. W., and R. B. Duncan. 1992. *Diet of Mexican spotted owls on National Forest System lands in Arizona and New Mexico.* Unpublished report, Albuquerque: USDA Forest Service Southwestern Region.

Seamans, M. E., and R. J. Gutiérrez. 1995. Breeding habitat ecology of the Mexican spotted owl in the Tularosa Mountains, New Mexico. *Condor* 97:944–52.

Seamans, M. E. and R. J. Gutiérrez. 1999. Diet composition and reproductive success of Mexican spotted owls. *Journal of Raptor Research* 33:143–48.

Seamans, M. E., R. J. Gutiérrez, C. A. May, and M. Z. Perry. 1999. Demography of two Mexican spotted owl populations. *Conservation Biology* 13:744–54.

Seamans, M. E., R. J. Gutiérrez, and C. A. May. 2002. Mexican spotted owl *(Strix occidentalis)* population dynamics: Influence of climatic variation on survival and reproduction. *Auk* 119:321–34.

Skaggs, R. W. 1988. *Status of the spotted owl in southern New Mexico: 1900 to 1987.* Contract No. 519-75-02, Santa Fe: New Mexico Department of Game and Fish.

Stacey, P. B., and M. Z. Peery. 2002. Population trends of the Mexican spotted owl in west-central New Mexico. Abstract. *New Mexico Ornithological Society Bulletin* 30:42.

Steele, E. S. 1927. Food of the spotted owl. *Condor* 29:123–24.

USDI Fish and Wildlife Service. 1993. Endangered and threatened wildlife and plants: Final rule to list the Mexican spotted owl as a threatened species. *Federal Register* 58:14248–71.
USDI Fish and Wildlife Service. 1995. *Recovery plan for the Mexican spotted owl* (Strix occidentalis lucida). http://mso.fws.gov/recovery-plan.htm.
Ward, J. P. Jr., and W. M. Block, 1995. Mexican spotted owl prey ecology. In *Recovery plan for the Mexican spotted owl* (Strix occidentalis lucida), *vol II—Technical supporting information,* ed. USDI Fish and Wildlife Service, chap. 5. http://mso.fws.gov/recovery-plan.htm.
Ward, J. P. Jr., A. B. Franklin, S. E. Rinkevich, and F. Clemente. 1995. Distribution and abundance of Mexican spotted owls. In *Recovery plan for the Mexican spotted owl* (Strix occidentalis lucida), *vol II—Technical supporting information,* ed. USDI Fish and Wildlife Service, chap. 1. http://mso.fws.gov/recovery-plan.htm.
Willey, D. W. 1998a. *Movements and habitat utilization by Mexican spotted owls within the canyonlands of Utah*. PhD diss., Northern Arizona University.
Willey, D. W. 1998b. *Influence of fire on Mexican spotted owls in Saguaro National Park*. Final report, Heritage Fund Program, Arizona Game and Fish Department, Phoenix, AZ.
Willey, D. W., and C. Van Riper III. 2000. First-year movements by juvenile Mexican spotted owls in the canyonlands of Utah. *Journal of Raptor Research* 34:1–7.

Table 1. Selected characteristics of 27 Mexican spotted owl nest trees and 27 randomly located trees within the nest stand in the Tularosa Mountains, New Mexico

	Nest trees		Random trees	
Variable	Mean	SD[a]	Mean	SD[a]
Age (yrs)	163.6	44.8	119.6	64.6
Tree height (m)	7.2	6.5	18.2	8.6
Dbh (cm)[b]	60.6	22.4	43.1	25.4

Source: Seamans and Gutiérrez (1995: table 3).
Note: Differences between nest and random trees were significant ($P < 0.05$) for all variables shown.
[a]Standard deviation.
[b]Diameter at breast height.

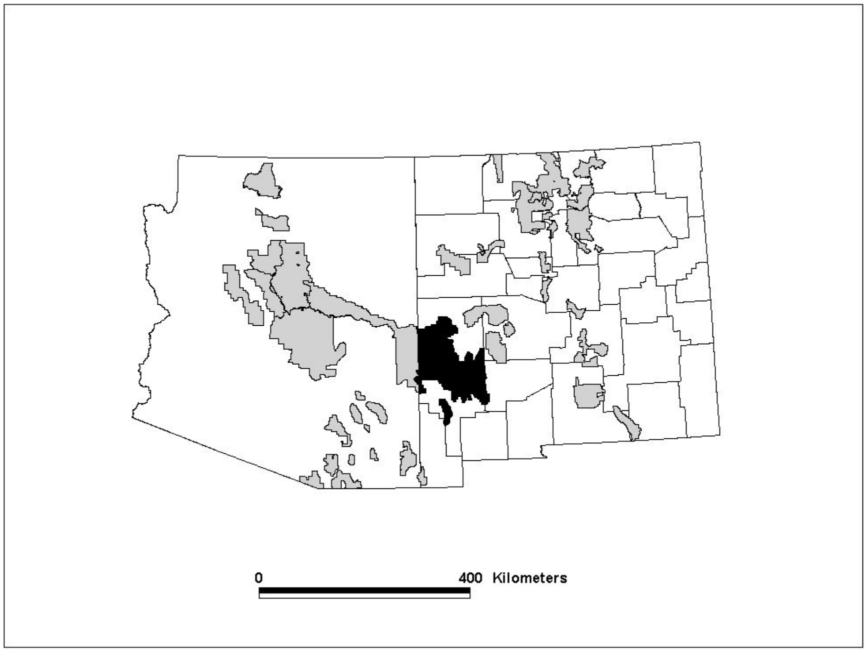

Fig. 1. Map of Arizona and New Mexico showing the location of the Gila National Forest (in black) in relation to other National Forest System lands (in gray).

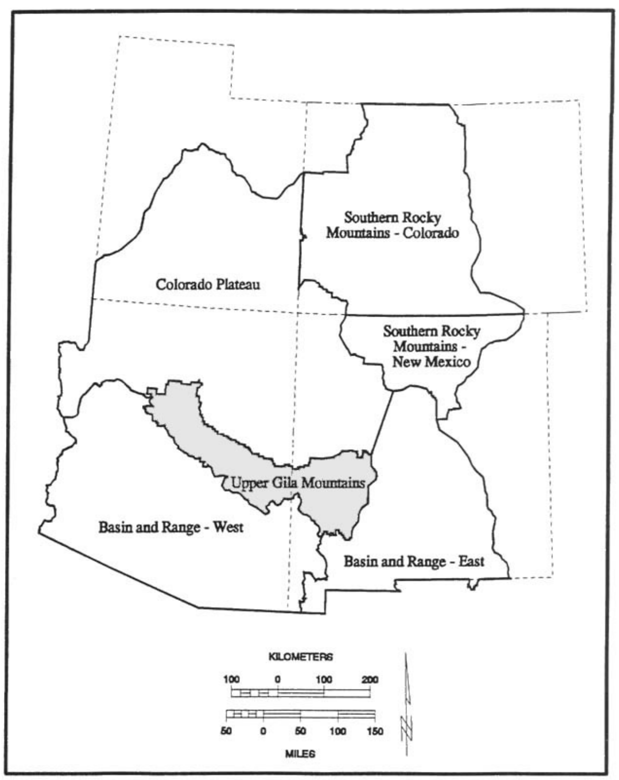

Fig. 2. Recovery Units within the United States recognized in the Mexican spotted owl recovery plan (USDI 1995). The Gila region falls within the Upper Gila Mountains Recovery Unit.

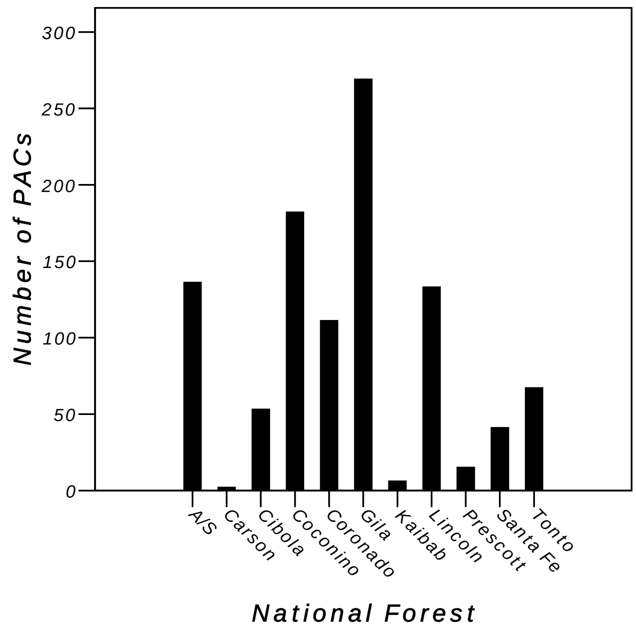

Fig. 3. Numbers of Protected Activity Centers (PACs) delineated by national forest within the Southwestern Region, USDA Forest Service. A/S = Apache-Sitgreaves National Forest. (*Source:* Unpublished data provided by S. Hedwall, US Fish and Wildlife Service, Flagstaff, AZ, Jan 2008.)

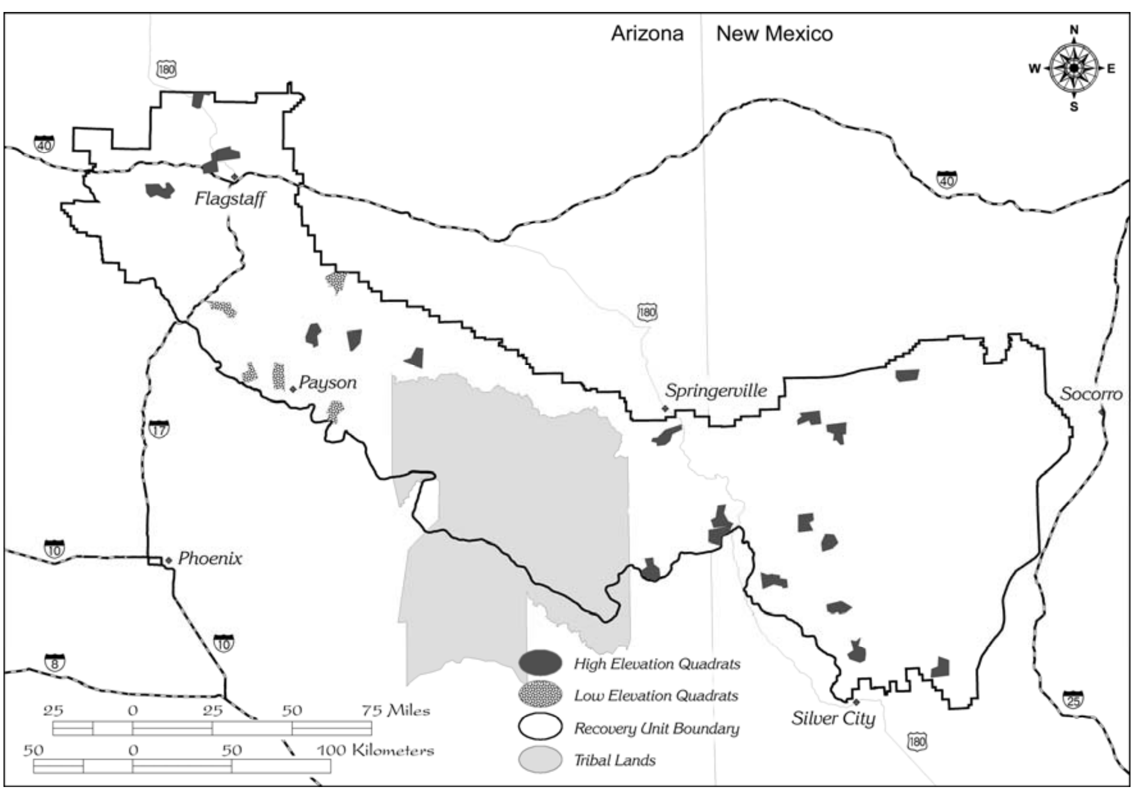

Fig. 4. Locations of 25 quadrats surveyed for Mexican spotted owls across the Upper Gila Mountains Recovery Unit in 1999. (*Source:* Ganey et al. 2004: fig. 16.2.)

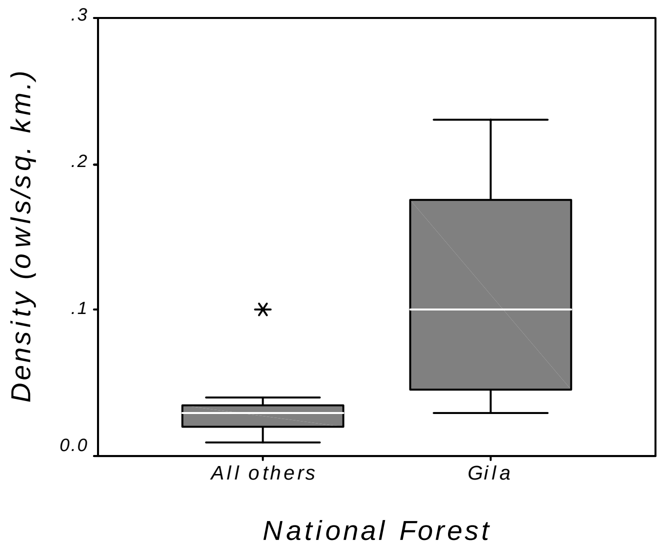

Fig. 5. Box plots of estimated density of resident Mexican spotted owls in occupied quadrats surveyed within and outside of the Gila region (n = 8 occupied quadrats in each area). The box indicates the range from the 25th to 75th percentiles, with the median shown by the line within the box. Exterior lines indicate the range in the data excluding extreme values, which are shown as asterisks. Extreme values were defined as values more than 3 box lengths outside the box.

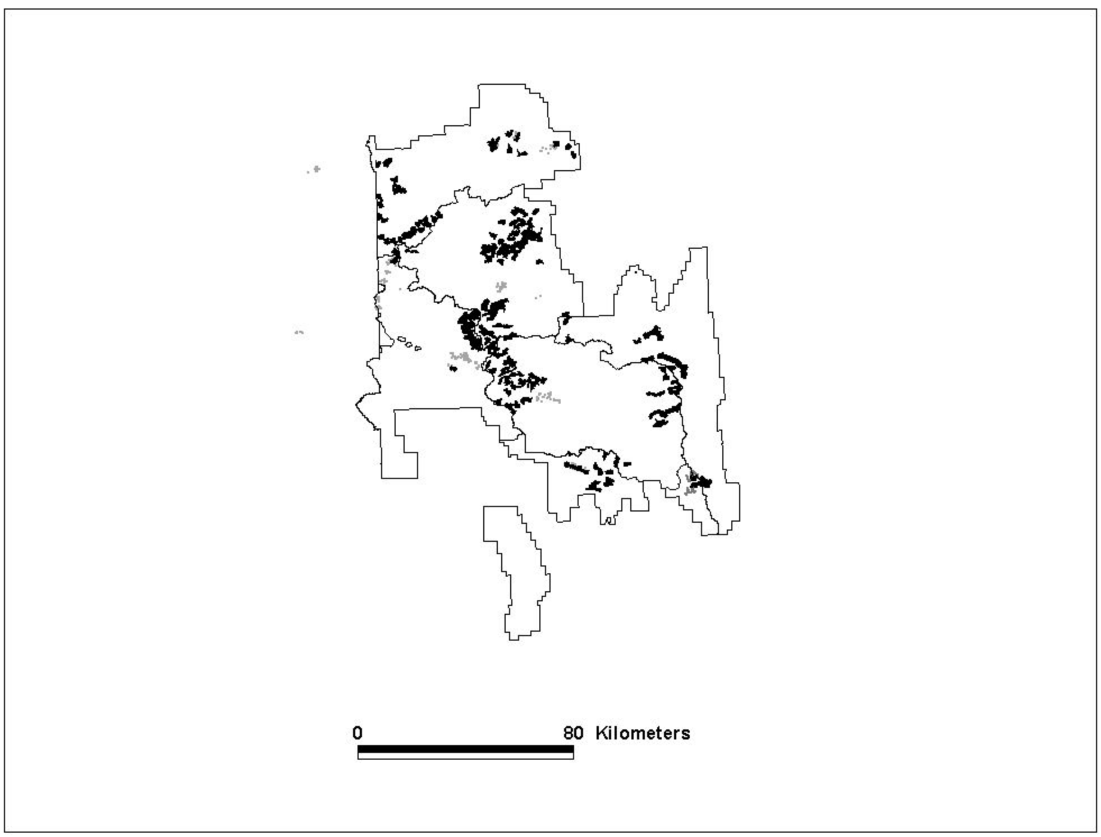

Fig. 6. Map of the Gila National Forest showing Mexican spotted owl Protected Activity Centers (PACs) in black, and locations of owls within quadrats surveyed in 1999 in gray. These data sets combined indicate that owls are well distributed throughout montane areas across the forest.

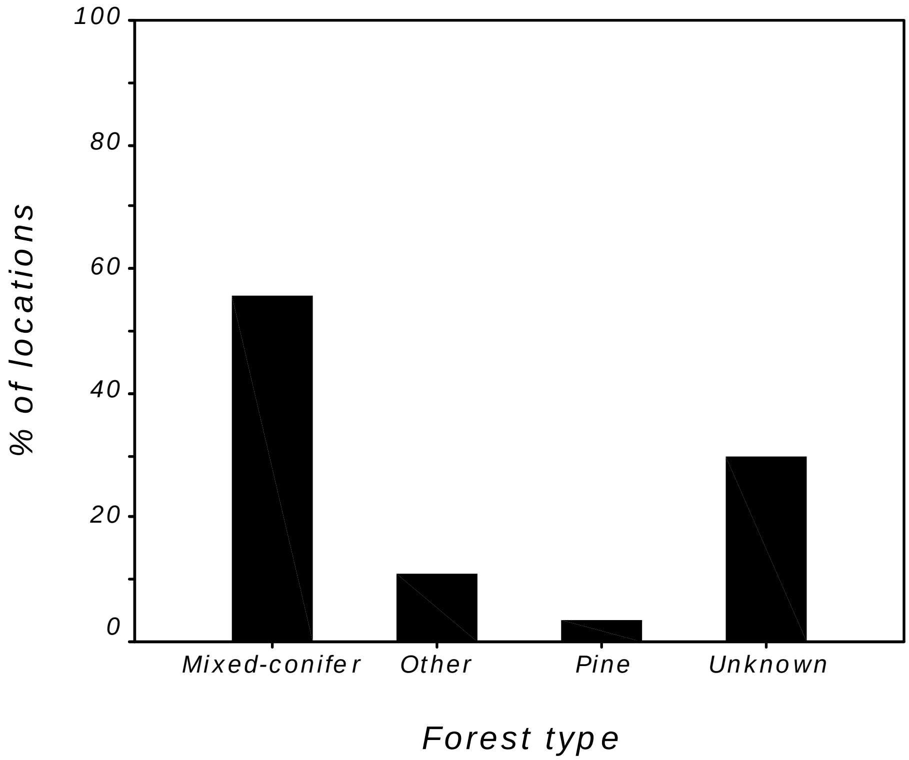

Fig. 7. Percent of Mexican spotted owl locations in various forest types in the Gila National Forest, based on a reanalysis of USDA Forest Service survey data collected 1989 to 1993 and compiled by the Mexican Spotted Owl Recovery Team in 1993 (see USDI 1995). Analysis included only visual observations of owls. *Mixed-conifer forest* was dominated by Douglas fir and/or white fir. *Pine* included both ponderosa pine and pine-oak forest types. *Other* included all other forest types, including broadleaved riparian forest types, pinyon-juniper woodlands, and spruce-fir forest. *Unknown* indicates observations where forest type was not classified.

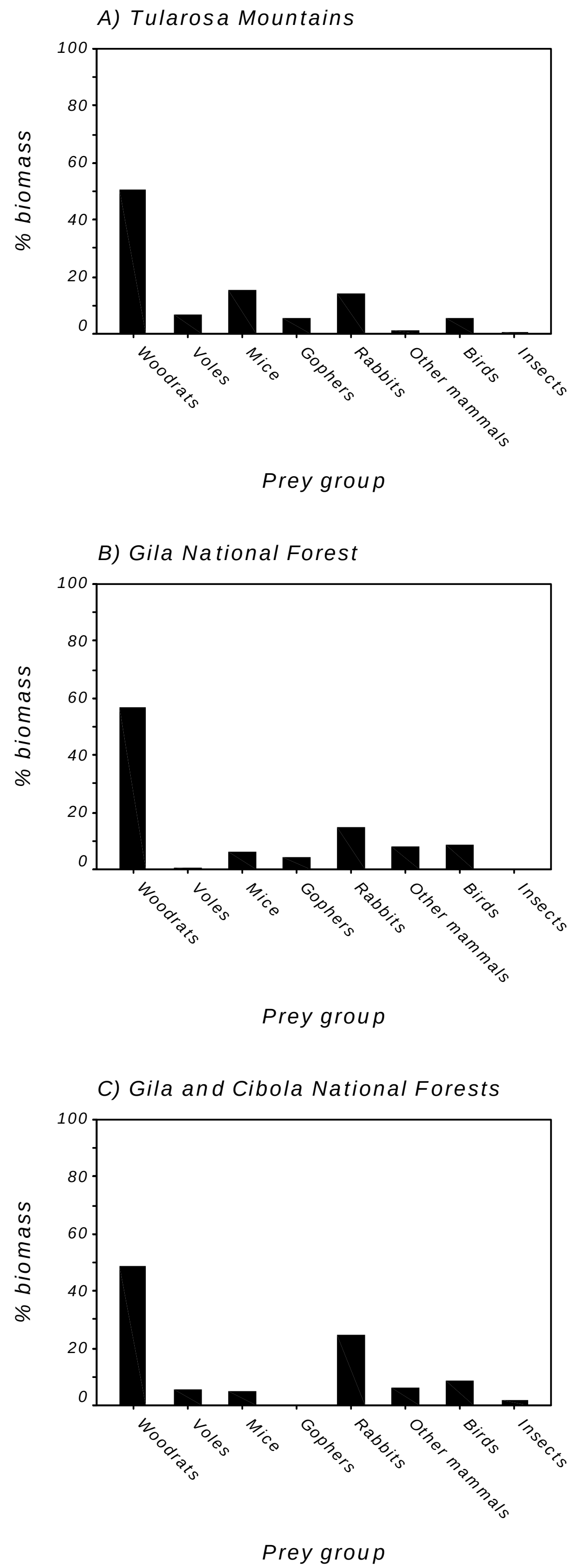

Fig. 8. Diet composition (% biomass) of Mexican spotted owls in three geographic areas within the greater Gila region. (*Sources:* [A] Tularosa Mountains, Seamans and Gutiérrez 1999; *n* = 2,162 prey items. [B] Gila National Forest, exact areas covered not specified, Reichenbacher and Duncan 1992, Appendix I; *n* = 114 prey items. [C] Gila and Cibola National Forests, exact areas covered not specified, Reichenbacher and Duncan 1992, Appendix F; *n* = 35 prey items.)

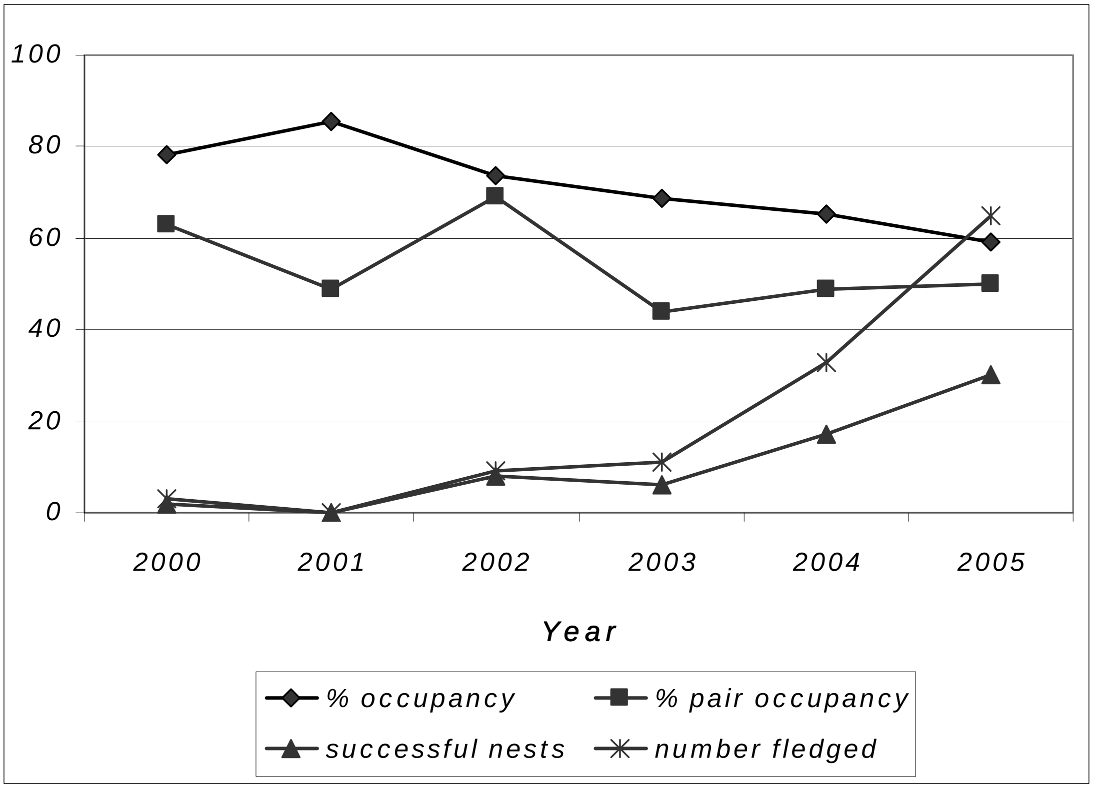

Fig. 9. Percentage of 83 Mexican spotted owl territories occupied by single owls (% occupancy) or pairs of owls (% pair occupancy), and numbers of successful nests and young fledged from those territories in the Reserve area, Gila National Forest, 2000 through 2005. Values on the *y*-axis represent percentages for occupancy variables and actual numbers for reproductive variables. (*Source:* Air Combat Command 2006.)

Vegetation and Habitat along the Gila River in Southwestern New Mexico

Kelly Kindscher

Associate Scientist, Kansas Biological Survey, University of Kansas,
2101 Constant Avenue, Lawrence, KS 66047, kindscher@ku.edu

Abstract

As part of a biodiversity study, 49 riparian sites along the Gila River in southwestern New Mexico were sampled to document the presence and abundance of many rare birds, reptiles, and amphibians and to specifically examine their vegetation and habitats, which are the topic of this paper. During the summer of 2006, a team of researchers recorded all the plant species, their percent cover, and the number of woody species from three 0.1-hectare plots at each of the 49 sites. Data from this project demonstrate that upstream vegetation (from sites in the vicinity of Gila Hot Springs) is different from vegetation downstream (from sites near the towns of Gila and Cliff and below Redrock). Upstream sites have more species/plot, less bare ground, more total plant cover and more wetland species. These data are important for providing a baseline data set for studying possible in-stream flow alterations, natural habitat changes, or climate change, which may influence both hydrological changes and vegetation.

Introduction

This project was undertaken to document the presence and abundance of many rare species and their habitats along the upper reaches of the Gila River in southwest New Mexico. One of the rarest birds, the federally endangered willow flycatcher, *Empidonax trailii*, has been documented to have the largest number of territories along this stretch of the Gila River (U.S. Fish and Wildlife Service 2002). However, the status of most other species of concern and their habitat along the Gila River is not well documented.

This paper discusses the vegetation and habitat data collected during the summer of 2006, the first year of the two-year study. Collection of these data is urgently needed to provide baseline documentation of wildlife habitat and species composition before potential changes to the river occur. Such changes include in-stream flow alteration and climatic changes. Baseline documentation can provide necessary information for management opportunities to restore and potentially improve habitat. Sound data are essential for public discourse and sound management practices. The lack of such current data documenting the biota of the Gila River is a problem that this research project can help resolve, to benefit the conservation of these bird, reptile, and amphibian species and the potential conservation and restoration of their habitat.

Forty-nine sites along the Gila River were established with Global Positioning System (GPS) coordinates so that they can be resampled in the future to determine longer-term trends and also to facilitate future data analysis that can be used to evaluate change in conservation status of these species in the event that conservation, restoration, or hydrological changes are made to these habitats.

Methods

Study Area

Fieldwork for this study of the habitats of birds, amphibians, and reptiles along the Gila River took place in Grant and Catron Counties, NM, from near the towns of Redrock, Gila, and Cliff upstream to the town of Gila Hot Springs and up the Middle and West Forks beyond the Gila Cliff Dwellings National Monument lands (fig. 1).

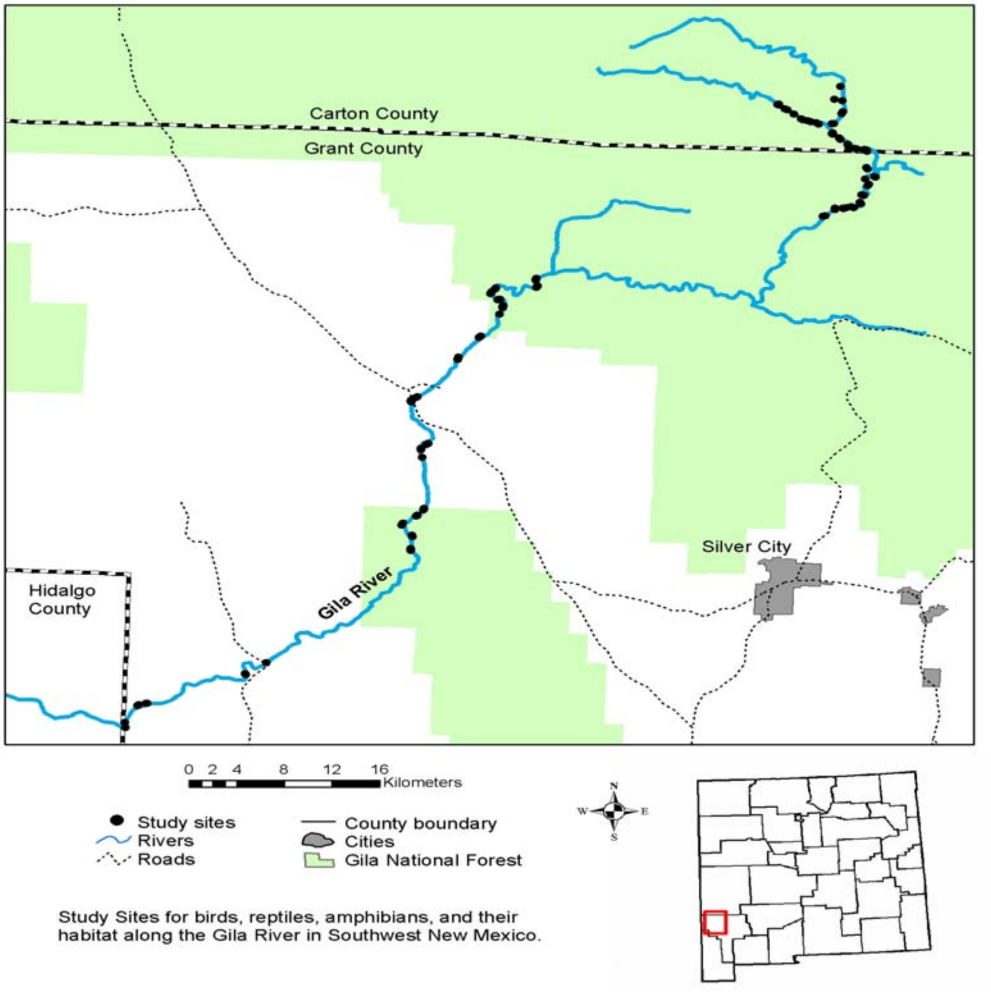

Fig. 1. Study sites along the Gila River

Methodology

Based on results from similar large-scale projects (Kindscher et al. 1998; Debinski, Kindscher, and Jakubauskas 1999; Norris and Farrar 2001; Saveraid et al. 2001), a robust methodology was established for this project in the Gila watershed. The primary focus was on two categories of sites: upstream sites (higher elevation sites from 5,000 to 6,000 feet, located nearer the town of Gila Hot Springs and the Gila Cliff Dwellings National Monument), and downstream sites (lower elevation sites from 4,000 to 5,000 feet, located nearer to the towns of Gila and Cliff and downstream to and below Redrock, NM; fig. 1). Lands in the study area are owned and managed by the federal government (Gila National Forest, Gila Cliff Dwellings National Monument, and the Bureau of Land Management), the State of New Mexico, the Nature Conservancy, and private property owners. All sites were selected within riparian areas and were separated by at least ½ mile to ensure independence.

Each site was characterized by three circular plots with an 18 m radius area (0.1 ha in size) and was sampled for all overstory and understory plant species. Cover values were determined for all plant species, and voucher specimens will be collected during the second year of fieldwork and deposited in the Dale A. Zimmerman Herbarium (SNM) at Western New Mexico University and in the Ronald L. McGregor Herbarium (KAN) at the University of Kansas.

Data were recorded in every plot for the following habitat attributes (modified from Rice, Anderson, and Ohmart 1984): the diameter at breast height (dbh) of the four largest trees, the foliage density of the ground layer (density of the foliage from the ground to 0.6 m), foliage density of the understory (1.5 m–3.0 m), the foliage density of the overstory (from 3.0 m to the canopy), the foliage height diversity, and the number of trees in the plot with dbh > 2 in.). All data were collected on a fieldwork form, copied, and entered into an Excel spreadsheet at the University of Kansas. Data were summarized by species and plots were divided into upstream and downstream locations. All species names are from the State of New Mexico checklist at the Range Science Herbarium at New Mexico State University (Allred 2007).

Results

For the 49 sites (147 plots) along the river, a total of 399 plant species were found. The riparian area contains forests dominated by Fremont's cottonwood (*Populus fremontii* S. Wats.), narrowleaf cottonwood (*Populus angustifolia* James), Goodding's willow (*Salix goodingii* Ball), and rabbitbrush (*Ericamera nauseosa* {Pallas ex Pursh} Nesom & Baird) (tables 1 and 2). In addition there are open areas of grassland and savanna and other areas of sand and gravel bars. Significant differences were found between bare ground and dominant species upstream and downstream. Upstream areas had more species (47.3 per plot) compared to downstream sites (only 32.1 species per plot). Upstream sites had less bare ground with total plant cover, including canopy overlap, of 99.8% compared to downstream sites with 62.8%. Vegetation differences were illustrated by the fact that bare ground had the highest cover class of any plant or category at downstream sites. Also, more wetland species (classified as wetland obligate species by the U.S. Fish and Wildlife Service, 2007) were found in upstream plots.

Non-native species are of concern in riparian habitats in the Southwest. Salt cedar or tamarisk (*Tamarix chinensis* Loureiro) has become a species of concern in the southwestern United States as this exotic species tends to use considerable amounts of water in riparian areas and crowds other species out. Whiteman (2006) found salt cedar along much of the Gila River and mapped its locations. The data from our Gila River project indicate that only 14 of the 72 (19%) downstream plots had tamarisk cover, with the highest percentage being only 2% of the cover of any individual plot and most other plots having no cover or only a trace. In the upstream plots (those above Turkey Creek and greater than 5,000 feet in elevation), only 4 of the 75 plots (5%) had tamarisk, also with the cover less than 2% in all plots. So overall, only 12% of the plots had tamarisk cover and the greatest percentage was 2% in any of these plots. A higher percentage of cover (but still less than 1% per plot) was found for the exotic sweet clover (*Melilotus officianalis* {L.} Pallas), which made extensive stands along middle portions of the river.

Table 1. Summary of species with greatest cover and bare ground percent cover for upstream plots taken along the Gila River in July 2006. Species cover summed from 75 plots at 25 sites, located from 3 miles below the Grapevine Campground at the Forks of the Gila (the junction of the East and West forks) upstream to along the Middle and West forks above the Gila Cliff Dwellings National Monument. All plots were between 5,000 and 6,000 feet. The symbol * designates a non-native species.

Species with Authorities and Bare Ground	**Common Name**	**Percent Cover**
Bare Ground	Bare Ground	23.9
Ericameria nauseosa (Pallas ex Pursh) Nesom & Baird	rubber rabbitbrush	8.9
Populus angustifolia James	narrowleaf cottonwood	8.5
Salix irrorata Andersson	bluestem willow	6.1
Alnus incana (L.) Moench	mountain alder	4.0
Artemisia carruthii Wood ex Carruth	Carruth's sagebrush	3.6
Acer negundo L.	boxelder	3.4
**Melilotus albus* Medik.	white sweet clover	2.7
Populus x acuminata Rydberg	lanceleaf cottonwood	2.6
Platanus wrightii S. Watson	Arizona sycamore	2.5
Populus fremontii S. Watson	Fremont cottonwood	1.6
Pinus ponderosa Lawson	ponderosa pine	1.2
Vitis arizonica Engelmann	canyon grape	1.2
Juniperus scopulorum Sarg.	Rocky Mountain juniper	1.1
Mirabilis longiflora L.	sweet four o'clock	1.0
Juniperus monosperma (Engelm.) Sarg.	oneseed juniper	1.0
Sporobolus contractus A. S. Hitchcock	spike dropseed	1.0
Brickellia floribunda Gray	Chihuahuan brickellbush	0.9

Parthenocissus vitacea (Knerr) A.S. Hitchcock	thicket creeper	0.9
Juniperus deppeana Steud.	alligator juniper	0.9
Bouteloua gracilis (Willd. ex Kunth) Lagasca ex Griffiths	blue grama	0.8

Table 2. Summary of species with the greatest cover and bare ground percent cover for downstream plots taken along the Gila River in July 2006. Species cover summed from 72 plots at 24 sites, located from the Turkey Creek confluence to below Redrock, NM. All plots were between 4,000 and 5,000 feet. The symbol * designates a non-native species.

Species with Authorities, Bare Ground and Water	**Common Name**	**Percent Cover**
Bare Ground	Bare Ground	40.4
Populus fremontii S. Watson	Fremont cottonwood	12.6
Salix gooddingii Ball	Gooddings willow	6.8
Baccharis salicifolia (Ruiz & Pavon) Persoon	mules fat	3.0
Salix exigua Nutt.	sandbar willow	2.0
Platanus wrightii S. Watson	Arizona sycamore	2.0
Ericameria nauseosa (Pallas ex Pursh) Nesom & Baird	rubber rabbitbrush	1.5
Ambrosia monogyra (Torrey & Gray ex Gray) Strother & Baldwin	burrobrush	1.5
Salix irrorata Andersson	bluestem willow	1.3
Water	Water	0.9
**Melilotus albus* Medik.	white sweet clover	0.7
Acer negundo L.	boxelder	0.5
Sporobolus contractus A. S. Hitchcock	spike dropseed	0.5
**Rumex crispus* L.	curly dock	0.4
Aristida divaricata Humboldt & Bonpland ex Willdenow	poverty threeawn	0.4
**Salsola tragus* L.	prickly Russian thistle	0.4
**Cynodon dactylon* (L.) Persoon	Bermuda grass	0.4
Prosopis glandulosa Torrey	honey mesquite	0.4
Artemisia carruthii Wood ex Carruth	Carruth's sagebrush	0.3
Amaranthus palmeri S. Watson	pigweed	0.3
Boerhavia erecta L.	erect spiderling	0.3

Discussion

The Gila River in southwest New Mexico is still a free-flowing river and is dominated by stands of native riparian species. Although there are some patches of exotic species, such as sweet clover and salt cedar, for the most part, the cover is overwhelmingly dominated by native species and is in relatively good condition. There were no rare or state or federally-listed plant species found in the plots, but this is not surprising as riparian areas typically have few rare plant species as these habitats are greatly affected by flooding disturbance.

This project's data will be archived and will be useful for conservation work, planning for restoration, and management of the river's vegetation, and will be important baseline data for any proposed actions that will change the hydrology of the river through proposed water-development projects. In addition, these data can be important for documenting and studying the habitat of rare and common species of plants, birds, and other animals, and also for the management of exotic species. Because there are differences along the river in the vegetation due to the hydrology, geology and past land-management practices, more data will be collected and the interpretations will be available for review and discussion. The final data will be available to other researchers and the public through the author's Web site: http://www.kbs.ku.edu/people/kindscher.htm

Acknowledgments

I would like to thank Quinn Long, Maggie Riggs, Hillary Loring, Bernadette Kuhn, and Sarah March for help in the field data collection and species identification, Jessica Dean and Bernadette Kuhn for data entry, Craig Freeman and

Caleb Morse for botanical identifications of specimens, and William Norris, Randy Jennings, and Roland Shook for collaborating on the project. Jack Carter and William Norris provided useful editorial comments. In addition, I would like to thank the New Mexico Department of Game and Fish for funding, and most importantly, the property owners—Gila National Forest, Gila Cliff Dwellings National Monument, the State of New Mexico, Bureau of Land Management, the Nature Conservancy, and private property owners—for giving us permission to collect these data on their respective land holdings.

Literature Cited

Allred, K. 2007. A working index of New Mexico vascular plant names. New Mexico State University Range Science Herbarium and available at: http://spectre.nmsu.edu/dept/academic.html?i=1742

Debinski, D., K. Kindscher, and M. E. Jakubauskas. 1999. A remote sensing and GIS-based model of habitats and biodiversity in the greater Yellowstone ecosystem. *International Journal of Remote Sensing* 17:3281–91.

Kindscher, K., A. Fraser, M. E. Jakubauskas, and D. Debinski. 1998. Identifying wetland meadows in Grand Teton National Park using remote sensing and average wetland values. *Wetlands Ecology and Management* 5:265–73.

Norris, W. R. and D. R. Farrar. 2001. A method for the rapid survey and natural quality evaluation of forests in the Central Hardwoods region. *Natural Areas Journal* 21:313–23.

Rice, J., B. W. Anderson, and R. D. Ohmart. 1984. Comparison of the importance of different habitat attributes to avian community organization. *Journal of Wildlife Management* 48:895–911.

Saveraid, E. H., D. M. Debinski, K. Kindscher, and M. E. Jakubauskas. 2001. A comparison of satellite data and landscape variables in predicting bird species occurrences in the Greater Yellowstone ecosystem. *Landscape Ecology* 16 (1): 71–83.

U.S. Fish and Wildlife Service. 2007. The 1988 national list of plant species that occur in wetlands. The regional list is at: http://www.fws.gov/nwi/bha/download/1988/region7.txt

U.S. Fish and Wildlife Service. 2002. Southwestern willow flycatcher recovery plan. Albuquerque, NM at: http://ecos.fws.gov/docs/recovery_plans/2002/020830c.pdf

Whiteman, K. E. (2006) Distribution of salt cedar (*Tamarix* L.) along an unregulated river in southwestern New Mexico, USA. *Journal of Arid Environments*, 64:364–68.

Over a Century of Bat Research Efforts on the Gila National Forest

Marikay A. Ramsey

Threatened and Endangered Species Program Lead, Bureau of Land Management,
(Former Southwest Region Bat Conservation Coordinator, USDA Forest Service)
Bureau of Land Management New Mexico State Office,
1474 Rodeo Rd., PO Box 27115, Santa Fe, NM 87502-0115
marikay_ramsey@blm.gov

Abstract

One of the largest national forests in the Southwest, the Gila National Forest (GNF) contains a diversity of habitat and forest types, including Chihuahuan desert scrub, pine-oak woodland, and mixed conifer forest. A variety of bat studies have been conducted in the GNF, beginning with C. Hart Merriam and Vernon Bailey in the late 1800s and continuing today. To date, over 45 biologists have conducted studies, with principal foci of research including natural history, taxonomy, and community ecology. As interests have evolved and new techniques have become available, the areas receiving the most attention have changed considerably. The most profound changes have been through advancements in technology and data analysis, which have altered the approaches taken in our research and increased the sophistication of our investigations. The studies were categorized to facilitate comparisons of the relative and changing attention given each of the focus areas over the years. Bat conservation was generally not a component of the earlier studies, but now is a focus of recent work.

Introduction

The Gila region in southwestern New Mexico provides a rich diversity of plant and animal life. The area encompasses at least six distinct biotic communities, ranging from subalpine conifer forest, to Madrean evergreen woodland, to semiarid Chihuahuan desertscrub (Brown 1982). With 1.3 million ha (3.3 million ac), the Gila National Forest (GNF) is the sixth largest national forest in the continental United States. Within the GNF are two large wilderness areas, the Gila Wilderness and the Aldo Leopold Wilderness. The Gila and San Francisco rivers, as well as their many tributaries, provide a variety of riparian habitats. Given this immense, diverse landscape, it is not surprising that over 45 biologists have researched bats in and around the GNF for more than 100 years.

This paper will first summarize who has conducted bat studies on the GNF, when and where the work was done, and the primary focus of each study. The list of researchers is not comprehensive, but includes many of those who left records of their work and covers most aspects of bat work done on the GNF over the years. The studies are then categorized by the principal areas of focus which are natural history, taxonomy, population ecology, community ecology, bioacoustics, and behavioral ecology. Within each area of focus I investigated the methods that were used, notable results, and what technological advances were employed. The advancement in technology is important in that it has altered the approach in many of the studies and increased the sophistication of the work.

U.S. Bureau of Biological Survey, 1880s–1930s

Vernon Bailey, in *Mammals of New Mexico*, summarized much of the early field work on bats that took place in southwestern NM. Bailey first worked in New Mexico under the direction of C. Hart Merriam for the Bureau of Biological Survey. This enterprise lasted over 35 years, from 1889 to 1924, and included such notable naturalists as A. K. Fisher, E. A. Goldman, C. Birdseye, and N. Hollister (see table 1). Field naturalists not officially connected with the Biological Survey but who made major contributions to knowledge of southwestern bats also included C. M. Barber. The Biological Survey was conducted in all habitats across the state, with GNF specimens collected from sites including Silver City, Luna Valley, and Diamond Creek.

Laying the Foundation, 1940s–1980s

Although bat studies continued in other parts of the state, I found little record of bat work occurring in the GNF between that of the Biological Survey and Russell E. Mumford in the late 1950s. Much of Mumford's work at this time took place in Guadalupe Canyon, near the New Mexico–Arizona–Mexico border. He and Dale A. Zimmerman, professor emeritus of biology at Western New Mexico University (WNMU), collected some noteworthy data about the bats of that area, and in fact were the first to document a yellow bat *Lasiurus ega (=xanthinus*) in New Mexico (Mumford and Zimmerman 1963). Mumford's (1963) work on the dentition of the occult myotis (*Myotis occultus)* in the GNF took place south of Luna in Catron County.

James S. Findley deserves special attention because he is singularly responsible for much of the bat research that has ultimately taken place in the state. Findley arrived at the University of New Mexico (UNM) in 1955 and served as professor of biology, the curator of mammals and the director of the Museum of Southwestern Biology, and the chairman of the biology department. Many of the biologists in table 1 were students of Findley's, including C. Jones, A. Harris, H. Black, W. Gannon, R. Jennings and M. Ramsey. Findley's contributions to the knowledge of GNF and New Mexico bats included natural history, taxonomy, and community ecology. The most long-standing contributions made by Findley were in coauthoring *Mammals of New Mexico* (1975), and authoring *The Natural History of New Mexican Mammals* (1987) and *Bats: A Community Perspective* (1993). Findley and his graduate students contributed a great deal to our understanding of bats across the Southwest and beyond.

The research conducted during the 1960s and 1970s continued much of Findley's work and truly set the trend for the future. This group includes many of Findley's graduate students such as Clyde Jones, Arthur Harris, and Hal Black. One of Jones's (Findley and Jones 1961) contributions was the first records of three bat species in the GNF and New Mexico: Allen's lappet-browed bat (*Idionycteris phyllotis*), spotted bat (*Euderma maculatum*), and western red bat (*Lasiurus blossevillii*). Jones (1965, 1966) also made the first forays into population and community ecology by studying population changes in bats across seasons and years and by looking for the factors that influence the distribution and activity periods of bats. Harris was one of the first to look into issues of classifying the often confusing southwestern *Myotis* species using morphological characters (Harris and Findley 1962; Harris 1974). The impact of the bat research accomplished by this cohort of researchers is still influencing the work being conducted today.

In 1969, Roger W. Barbour and Wayne H. Davis made an important contribution to bat research by publishing *Bats of America*. This was the first widely available reference to provide a key to identifying the bats of the United States, with summaries of information on their life histories. Using experience gained in the GNF, Barbour and Davis provided a discussion of the known distribution of Allen's lappet-browed bat (*I. phyllotis*), which had first been captured in the Southwest in 1955. In subsequent publications (1970), they contributed to the ongoing discussion regarding the systematic relationships between the little brown bat (*Myotis lucifugus*) and the occult myotis (*M. occultus*).

Another important name in southwestern bat research is Bruce J. Hayward, professor emeritus of biology at WNMU. Hayward focused much of his early bat work in Arizona, including research on Allen's lappet-browed bat (*I. phyllotis*) (Hayward and Johnson 1961) and flight speeds in western bats (Hayward and Davis 1964). Hayward contributed three influential publications regarding the natural history of the cave bat (*M. velifer*) (1970), the western long-nosed bat (*Leptonycteris sanborni* [= *curasoae*]) (1971), and the western Pipistrelle (*Pipistrellus hesperus*) (Hayward and Cross 1979). In 1972, Hayward and student Duston L. Hunt Jr. lived many a biologist's dream by conducting a summer-long vertebrate study of portions of the Gila Wilderness. They surveyed in seven habitat types and captured 13 bat species using mist nets. Their notable finds included long-legged myotis (*M. evotis*) and southwestern myotis (*M. auriculus*) in sympatry (sharing the same localities and resources at the same time and place), and differential habitat use by California myotis (*M. californicus)* and small-footed myotis (*M. ciliolabrum)*. Hayward continued to make contributions to the knowledge of bats in the GNF until his retirement in the mid-1990s (Hayward 1994, 1995).

The 1980s were a slow time for bat research in the GNF; I was able to find only a single paper, authored by Troy Best (1988), which included GNF bat specimens. Best looked at morphological variation in spotted bats (*E. maculatum*), and found significant sexual dimorphism and interpopulation heterogeneity in certain characters. A second paper, authored by David W. Reducker, Terry L. Yates, and Ira F. Greenbaum (1983), used specimens from the San Mateo Mountains, immediately east of the GNF, to investigate the systematics and evolutionary affinities of southwestern long-eared *Myotis* using morphological, karyotypic, and starch-gel electrophoretic techniques. Many of the researchers who worked in the GNF also worked in the San Mateo Mountains due to their proximity.

The Modern Era, 1990s to Present

The 1990s began with the continuing influence of Findley in the exploration (1993) by Luis G. Herrera-Montalvo, Theodore H. Fleming, and Findley of the dietary implications of the carbon composition of the pallid bat (*Antrozous* *pallidus*), an insectivorous bat that also regularly visits bat-adapted cacti and agaves in the Sonoran and Chihuahuan deserts.

Renn Tumlison (1993) used GNF specimens to look for correlations between morphological variation and geography in Allen's lappet-browed bat (*I. phyllotis*). Based on his analyses, he concluded that the species separates into two subspecies, *I. phyllotis phyllotis*, (Mexico, New Mexico, most of Arizona) and *I. phyllotis hualapaiensis* (northwestern Arizona, Utah, and Nevada).

In the mid-1990s, Findley student William L. Gannon, associate curator of the Museum of Southwestern Biology, initiated a bat survey of New Mexico funded in part by Share with Wildlife, New Mexico Department of Game and Fish. As part of those survey efforts, Gannon and his crew surveyed seven sites over two years on the Reserve Ranger District (Gannon 1994, 1996) within the GNF. They captured eight species and collected fecal samples and voucher specimens. Gannon used an acoustic bat-detection system called AnaBat to monitor bat activity and create recordings and sonograms for a bat acoustic library at UNM. In 1998, Gannon entered into the controversy surrounding the long-eared myotis (*M. evotis*) and the southwestern myotis (*M. auriculus*) by documenting syntopy (co-occurrence) in several localites across New Mexico and Arizona. In 2001, Gannon et al. explored two other morphologically confusing species, the California myotis (*M. californicus*) and the small-footed myotis (*M. ciliolabrum*). Gannon and others had determined in 1999 that the ultrasonic calls of these two species were distinctive, with the small-footed myotis having a lower-frequency call. Having detected sonic differences between the two species, Gannon looked for morphological characters that would distinguish them when in hand. They concluded that the external ear morphology is distinctive, with *M. ciliolabrum* having slightly larger ears (O'Farrell, Miller, and Gannon 1999).

In 2006, Gannon and Gabor R. Racz used ecomorphology to evaluate ecological relationships between the long-eared myotis (*M. evotis*) and the southwestern myotis (*M. auriculus*), two very similar species that are sometimes sympatric. They used traditional and geometric morphometrics to look for character displacement, and determined that there is morphological character displacement between sympatric populations of the two species, with *M. evotis* more specialized to feed on hard-bodied prey. Gannon has also contributed to multiple papers on echolocation and has made major contributions toward a better understanding of bat acoustics and bat acoustic systems.

Randy D. Jennings and Marikay A. Ramsey are two more Findley-influenced biologists who conducted bat work in the GNF starting in the mid-1990s. Upon Hayward's retirement, Jennings succeeded him as WNMU professor of biology, and regularly takes his students on educational mist-netting field trips across the GNF. Jennings assisted Ramsey in a bat survey of the Black Range, Mimbres, and Mogollon mountains (1996) where they measured diversity and attempted to assess the status of several former species of concern (U.S. Fish and Wildlife Category 2 Candidates). They netted at eight sites, capturing over 300 bats representing 17 species. Diversity appeared to be related to structural differences in vegetation and water sources, with the highest diversity at vegetatively uncluttered sites with open surface water. Ramsey, Jennings, and former Hayward student Lori Weber looked at winter bat activity at two sites in the Big Burro Mountains. Twelve nights of mist netting and acoustic sampling yielded eleven nights of bat activity, including 38 bat captures representing nine species. Ramsey and Weber also conducted mammal surveys, which included bats, of the Beaverhead Ecosystem Management Unit on the Black Range Ranger District (Ramsey et al. 1998) of the Gila. In 2001, Ramsey conducted agave and nectar-feeding bat surveys in the south end of the Big Burro Mountains, erecting hummingbird feeder arrays (32 feeders) in the middle of Palmer's agave (*Agave palmeri*) stands. Use of these agaves by nectar bats was not documented. Ramsey also has conducted abandoned mine surveys for bats in national forests across the Southwest.

Owen F. Williams, another former Hayward student, conducted a faunal analysis of the Las Animas Creek in 1996. He captured and photographically documented the western red bat (*L. blossevillii*)—the first to be captured in Sierra County.

A discussion of bat work in the GNF would be remiss if it didn't include abandoned mine surveys. Abandoned mines can provide the same habitat characteristics that caves offer, but don't have the same longevity. Underground mine surveys have provided a great deal of information about bat roosts, but can be extremely hazardous to conduct. Since the early 1990s, J. Scott Altenbach, recently retired professor of biology at UNM, has worked with the New Mexico Abandoned Mine Lands (NMAML) program across the state, surveying abandoned mines prior to closure. Altenbach, his former graduate student Rick Sherwin, and Randall Armijo and Homer Milford from the NMAML program, have surveyed mines across the GNF, including large areas in the Big Burro Mountains and in the Kingston Mining District. The abandoned mine work conducted by Altenbach and Sherwin has made huge contributions to the understanding of how bats use mines and has demonstrated the enormous complexity of this relationship (Altenbach 2007a, 2007b).

Ernest W. Valdez et al. (1999) used protein electrophoresis to compare the little brown myotis (*M. lucifugus carissima*) and the occult myotis (*M. occultus*). Their research added to a long-term debate regarding whether these were two distinct species or whether *M. occultus* was a subspecies of *M. lucifugus*. Over one hundred specimens, including several from the GNF, were used to determine that there were high similarities among all samples, resulting in the conclusion that the two nominal taxa were a single species, *M. lucifugus*.

In 2001, Travis Perry and crew conducted an inventory of bat species on the Ladder Ranch and adjacent public lands east of the Black Range. They used mist nets to capture bats and radio telemetry to attempt to locate maternity roosts of big brown bats (*Eptesicus fuscus*) and fringe-tailed myotis (*M. thysanodes*). A total of nine roosts were located, six in rock crevices, two in tree cavities, and one in a barn (Perry and Gunnell 2001).

Lyle Lewis has mist-netted for bats across the GNF since his arrival in New Mexico in 2000. Lewis and fellow biologists surveyed the Turkey Creek, Willow Creek, and Iron Creek portions of the Gila Wilderness in 2005 with the purpose of documenting the presence of Allen's lappet-browed bat (*I. phyllotis*) and the relative abundance of other captured bats. They used mist nets and AnaBat detectors to sample nine sites. Out of 394 bats captured, representing 12 species, were a total of five female *I. phyllotis* at two sites. Acoustic sampling revealed calls which "presumably were made by either spotted bats (*E. maculatum*) or Allen's lappet-browed bats (*I. phyllotis*)"; however, because call characteristics overlap a great deal, they were unable to differentiate between the two. Lewis concluded that old-growth habitats such as are found in the Gila Wilderness are very important for the conservation of this species in New Mexico (Lewis and Norris 2006).

In 2002, Antoinette Piaggio and others added to the study of the systematic relationship between the little brown bat (*M. lucifugus carissima*) and the occult myotis (*M. occultus*) by sequencing the mitochondrial cytochrome-b and cytochrome oxidase II genes of specimens previously used in allozyme studies. The results disagree with Valdez et al. 1999, by suggesting that *M. occultus* is a distinct species, and represents an evolutionarily distinct monophyletic lineage.

Paul Cryan followed the 1964 work of Findley and Jones on seasonal movements of the hoary bat (*L. cinereus*) by looking at the seasonal distribution of four migratory tree bats (silver-haired bat [*Lasionycteris noctivagans*], hoary bat [*L. cinereus*], western red bat [*L. blossevillii*], and eastern red bat [*L. borealis*]) in North America. Using museum occurrence records from 127 mammal collections (including some specimens from the GNF), he mapped the monthly distribution of these four species. Cryan concluded (2003) that distribution of the sexes in the summer differed at a continental scale for *L. noctivagans* and *L. cinereus*, while *L. blossevillii* and *L. borealis* distributions differed at smaller scales. Reasons for different distributions of the sexes were unclear, but may involve competition for resources, different energy or thermoregulation needs, or other reproductive or social factors.

In 2004 and 2005, Dan Taylor conducted experiments to test bats' responses to low water levels in livestock troughs. He used four study sites across the Southwest, including one in the Black Range of the GNF. Taylor manipulated the water level in the troughs and monitored bat activity when the troughs were full and when the water level had been drawn down by 30.5 cm (12 in). Using a Sony night-vision video camera equipped with supplemental infrared light, he counted successful bat passes (when bats obtained a drink of water), and unsuccessful passes (no drink). He concluded that when water levels in livestock troughs dropped by 30.5 cm (12 in) or more, it took significantly more passes for bats to successfully drink. Through Bat Conservation International, Taylor is working to raise awareness about the importance of livestock waters to wildlife, and has recently completed a manual on developing wildlife-friendly waters (Taylor and Tuttle 2007).

The long list of researchers who have contributed to knowledge of the bat fauna of the GNF would be incomplete without Keith Geluso. From 2003 to 2005, Geluso examined activity of bats outside their winter roosts at 27 sites across southern and central New Mexico, including seven sites on the GNF. He captured 794 bats representing 12 species from November to March. Several species regularly took food and water during the winter; however, for most species, individuals captured in March averaged 20% lighter in body mass than individuals of the same species captured in November (Geluso 2005). In 2006 he assessed the recurrence of the spotted bat (*E. maculatum*) and Allen's lappet-browed bat (*I. phyllotis*) at multiple sites across the state, including 13 sites in the GNF. Using mist nets, spotlights, and audible calls, Geluso documented spotted bats at 69% of historical sites (11 of 16 sites across the state), and documented *Euderma* at 4 new sites (including 7 of the 13 sites on the GNF). He also documented Allen's bat at 100% of historical sites (7 of 7 sites across New Mexico), and documented the species at 2 new sites (including 8 of the 13 sites on the GNF). When comparing netting effort and relative proportions of individuals captured in the 1960s, Geluso concluded that there were relatively equal numbers of individuals per unit of effort, thereby suggesting that populations of both species were stable across the state.

Focus Areas

Table 1. Year(s), primary researcher(s), localities worked, and the primary focus of over 100 years of bat work conducted in the Gila region

Year(s)	Primary Researchers	Localities Worked	Natural History	Taxonomy	Community Ecology	Sensory Ecology	Behavioral Ecology	Population Ecology
1889–1924	C. Hart Merriam	Gila-wide	X					
1889–1931	V. Bailey	Gila-wide	X					
1894	A. K. Fisher	Silver City	X					
1900	C. M. Barber	Mule Creek	X					
1908	E. A. Goldman	Gila Valley	X					
1908	C. Birdseye	Luna Valley	X					
1909	N. Hollister	Gila-wide	X					
1957	R. Mumford	south of Luna						
1960–1993	J. Findley	Taylor Creek, Wall Lake, Willow Creek, Mogollon Mtns., Cottonwood Canyon, State Fish Hatchery (SFH)-Glenwood, Luna, Aragon	X	X	X			X
1961–1972	C. Jones	Taylor Creek, Wall Lake, Willow Creek, Mogollon Mtns., Cottonwood Canyon, SFH-Glenwood, Luna	X	X	X			X
1962–1974	A. Harris	Taylor Creek, Black Range, SFH-Glenwood		X				
1970	R. Barbour and W. Davis	Willow Creek, Iron Mesa Lake		X				
1961–1995	B. Hayward (and D. Hunt)	Gila Center, Little Creek, White Creek, Prior & Apache Cabins, McKenna, Woodland, Snow, Half Moon & Little Turkey Parks, Lilly, Mars & Miller Springs, Gilita, Iron, Manzanita, Mogollon, Sycamore & Turkey Creeks, Jordan, Rawmeat & Turbo Canyons, W. Fork Corral, Hummingbird Saddle, Mogollon Baldy, The Meadows, Kemp Place, Trotter Place	X					
1961–1995	B. Hayward	Signal Peak, Trout Creek Tank, Sapillo Creek, Meadow Creek,	X					

		Tadpole Ridge, Saddle Rock Tank, Gold Gulch, Jack's Peak, Sawmill Tank, Mule Creek, Cooney Place, Pine Cienega Creek, Tennessee Creek						
1972	R. Suttkus	Willow Creek, SFH-Glenwood			X			
1972	H. Black	Unspecified area of Gila					X	
1988	T. Best	Willow Creek area, Woodland Park, Lake Roberts						X
1993	L. Herrera, T. Fleming, & J. Findley	Catron County					X	
1993	R. Tumlison	Unspecified area of Gila		X				
1994–2006	W. Gannon (with R. Sherwin, T. DeCarvalho, M. O'Farrell, & G. Racz)	Eagle Peak, Devil's Park, Adam Hogue Lake, Bearwallow Tank, S. Fork Negrito, Sheep Spring, Willow Creek, Taylor Creek, Saddle Rock, Bar 6 Canyon, Macho Canyon Spring	X	X		X		
1994–present	R. Jennings	Big Dry Creek, Negrito Creek, Bill Lewis Cienega, Saddle Rock			X			
1996–present	M. Ramsey (and L. Weber, K. Worley, & J. Garcia)	Big Dry Creek, Sacatone Creek, Negrito Creek, Bill Lewis Cienega, Mimbres River, Gallinas Canyon, East Canyon, Indian Creek, Saddle Rock, Doagy Spring, Indian Peaks, Bull Pass, Beaver Creek, Meadow Creek, Signal Peak, Black Hawk, Hoo Doo Canyon, Middle Fork Gila, Gila Center, Chloride Creek, Gold Hill, Las Animas Creek, Gila River Bird Area, Burnt Cabin Cienega	X		X			
1996	O. Williams	Las Animas Creek	X					
1997–present	S. Altenbach (with R. Sherwin & R. Armijo)	Gold Hill, Big Burro Mtns., Kingston area	X					
1999	E. Valdez, J. Choate, M. Bogan & T. Yates	Quaking Aspen Creek, Bearwallow Tank, Sheep Springs, Meadow Creek		X				
2000–present	L. Lewis (with E. Pierce, W. Rainey,	Iron Creek Lake, Iron Creek, Iron Creek Mesa Pond, Clayton Mesa Pond, Turkey Feather	X		X	X		

	& S. Norris)	Pass, Cooper Creek, Middle Fork Gila, Trotter Meadow, Bill Lewis Cienega, Chloride Creek, Las Animas Creek, Trout Creek, Burnt Cabin Cienega						
2001	T. Perry & K. Gunnell	Las Animas Creek, Davis Well, Hermosa townsite, Palomas Creek, Upper and Lower Seco Creeks	X					
2002	A. Piaggio, E. Valdez, M. Bogan, & B. Spicer	Grant County, Catron County		X				
2003	P. Cryan	Gila-wide						X
2006	D. Taylor	Bald Hill, Chloride Canyon				X	X	
2006	K. Geluso	Willow Creek area, Burnt Cabin Cienega, SFH-Glenwood, Taylor Creek, Saddle Rock, Gwynn Tank, Lake Roberts, Lichty Farm, Gila River, Gila River Bird Area, Black Canyon, Burnt Cabin Flat, Cooney Canyon/Mimbres River, Railroad Canyon			X		X	

In the following discussion, the above thirteen decades of work are categorized into groups according to the focus of each study (tables 2–7). Within each group, studies are arranged chronologically, and some papers fall into more than one category. Advances in methods and technology are then highlighted for each group, and notable results are reviewed.

Natural History

Table 2. Biologists conducting research on the natural history of bats in the Gila National Forest

Researcher(s)	Year(s) of Research	Methods/Technology
V. Bailey and BBS crew	1894–1931	Shotgun, hand capture
R. Mumford	1957–1963	Mist nets
J. S. Findley	1960–1993	Mist nets
C. Jones	1961–1972	Mist nets
R. Barbour & W. Davis	1969–1970	Mist nets
B. J. Hayward	1961–1995	Mist nets
W. Gannon	1994–2006	Mist nets, AnaBat detectors
R. D. Jennings	1994–present	Mist nets
J. S. Altenbach	1995–present	Method for vertical mine shaft surveys
M. Ramsey	1996–present	Mist nets, AnaBat detectors
O. Williams	1996	Mist nets
L. Lewis	2000–present	Mist nets, bat detectors
T. Perry	2001–present	Mist nets, bat detectors, radio telemetry
K. Geluso	2003–present	Mist nets, bat detectors
D. Taylor	2006	Bat detector, infrared video, night-vision goggles

Advances in Methods and Technology: The primary method of capture for Merriam, Bailey and the Biological Survey crew was a shotgun, and Bailey even regretted that shooting was not allowed within city limits. Bats were also captured by hand, with hand nets and trip lines, but none produced large numbers. Mist nets were used to capture bats as early as 1932, and they remain the most commonly used device for capturing bats. Ultrasonic detector systems began receiving attention as a tool for assessing general bat activity in the early-to-mid-1980s. They gained popularity throughout the 1990s when the possibility of species identification became apparent. Gannon used AnaBat detectors in 1994 to monitor bat activity and create recordings and sonograms. In later years, and with the use of the extensive UNM bat call library, Gannon and other experienced researchers used bat detectors to identify bats to species. Altenbach developed a relatively safe method of abandoned mine shaft evaluation. In evaluating over 2,000 mines across the West, he has demonstrated not only that bats use shafts but that the incidence of use is higher than in horizontal workings. Radio telemetry has been used to track bats since the late 1960s, but, through the 1980s, radio transmitters were too large to be used on most North American bat species. Recent advances in radio telemetry include the small size of radio transmitters (<1 g), and the longer battery life of the transmitters which can now last several weeks. Night-vision devices such as night-vision goggles and infrared video cameras allow a researcher to observe and/or photograph bats at roosts and known foraging sites. Video cameras provide for tape playback, through which accurate roost or exit counts can be made.

Notable Results: In 1931 Bailey wrote of only 18 bat species and two bat families known from New Mexico, the common bats (Vespertilionidae) and free-tailed bats (Molossidae). Jones's 1961 paper added the first records of 2 more bat species, Allen's lappet-browed bat (*I. phyllotis*) and the red bat (*L. borealis* [=*blossevillii*]), to the state, which brought the total count to 20. In 1975, when Findley et al. wrote *Mammals of New Mexico*, 25 bat species were documented for the state, a number that remained unchanged through *The Natural History of New Mexican Mammals* in 1987. The current state count is three bat families, consisting of 29 bat species (Geluso et al. 2005).

Conservation was not yet on the minds of the early naturalists, but Bailey did mention "the usefulness of bats in that they destroyed insect pests." The need for conservation was first mentioned in Barbour and Davis's *Bats of America* (1969), where they stated that the definitive causes of two decades of bat population declines were unknown, but possible factors included disturbance by man, insecticide poisoning, disease or disease control, and overcollecting. Conservation recommendations became a standard part of published articles and management reports in the 1980s and 1990s.

Taxonomy/Systematics

Table 3. Biologists conducting research on the taxonomy/systematics of bats in the Gila National Forest

Primary Researcher(s)	Year of Research	Methods
J.S. Findley	1960	Morphological characters—*M. evotis* & *auriculus*
A. H. Harris & J. S. Findley	1962	Morphological characters—*M. lucifugus* & *yumanensis*
R. E. Mumford	1963	Morphological characters—*M. occultus*
J. S. Findley & C. Jones	1967	Morphological characters with statistical analyses—*M. fortidens*, *lucifugus, & occultus*
A. H. Harris	1974	Morphological characters with multivariate discriminate analysis—*M. yumanensis & lucifugus*
D. W. Reducker et al.	1983	Morphological characters using morphological, karyotypic, & starch-gel electrophoretic techniques—*M. auriculus*, *evotis, milleri & thysanodes*
R. Tumlison	1993	Morphological characters using univariate & multivariate techniques—*I. phyllotis*
E. W. Valdez et al.	1999	Morphological characters using protein electrophoretic techniques—*M. occultus*
W. L. Gannon et al.	2001	Morphological characters & echolocation calls—*M. californicus & ciliolabrum*
A. J. Piaggio et al.	2002	Sequenced two mitochondrial genes—*M. occultus & lucifugus*
W. L. Gannon & G. R. Racz	2006	Morphological characters using traditional & geometric morphometric techniques—*M. auriculus & evotis*

Advances in Methods and Technology: Almost all of the taxonomic studies using bats from the GNF have involved species from the genus *Myotis*. Nine species of *Myotis* occur in New Mexico, and many of them are easily confused. In 1960, Findley looked at long-eared *Myotis* of the Southwest and Mexico. Comparing the morphology of museum specimens, Findley concluded that subspecies *auriculus* and *apache* were morphologically more similar to the eastern species *M. keenii (=septentrionalis)* than to *M. evotis*. He suggested that both be regarded as subspecies of *M. keenii (=septentrionalis)*. Later analysis by Reducker, Yates, and Greenbaum (1983), using traditional morphology, karyotypic and starch-gel electrophoresis, and cladistic analysis, determined that *M. evotis*, *M. auriculus*, and *M. milleri* were distinct species. In 2006, Gannon used traditional and geometric morphometrics to look for character displacement in *M. evotis* and *M. auriculus* jaw measurements. He found morphological character displacement between the two species when sympatric, with *M. evotis* being more specialized to feed on hard-bodied prey like beetles.

Another two species of taxonomic interest are *M. lucifugus* and *M. occultus*. A great deal of discussion has ensued over the years regarding whether *M. occultus* was a stand-alone species or whether it was a subspecies of *M. lucifugus*. In 1999 Valdez et al. used protein electrophoresis on museum specimens and determined that there was little to no genetic differentiation in 20 loci studied and that therefore the two taxa represented a single species. Three years later, Piaggio et al. examined two mitochondrial genes from some of the same specimens sampled by Valdez et al. Their results suggest that *M. occultus* represents an evolutionarily distinct lineage and is separated from *M. lucifugus* enough to be considered a separate species.

Notable Results: Contributions from Findley (1960), Reducker, Yates, and Greenbaum (1983), Gannon (1998), and Gannon and Racz (2006) have helped determine the systematic relationships of southwestern long-eared *Myotis,* especially *M. evotis* and *M. auriculus*, and shed light on sympatric species and character displacement. Research conducted by Mumford (1963), Findley and Jones (1967), Valdez et al. (1999), and Piaggio et al. (2002) have clarified the systematic relationships of *M. occultus* and *M. lucifugus*, with the current understanding that all bats captured in New Mexico and originally determined to be *M. lucifugus* are actually *M. occultus*.

Community Ecology

Table 4. Biologists conducting research on the community ecology of bats in the Gila National Forest

Primary Researcher(s)	Year(s) of Research	Methods and Results
C. Jones	1958–1963	Mist nets & shotgun in 3 habitat types; 19 species, 1,595 bats
C. Jones	1957–1965	Mist nets at 5 sites; 19 species, 1,257 bats
C. Jones & R. Suttkus	1957–1968	Mist nets at 3 sites; 19 species, 1,004 bats
R. Jennings	1994–present	Mist nets at 4 sites, multiple species & bats
M. Ramsey & R. Jennings	1996–1997	Mist nets at 8 sites; 17 species, 301 bats. Conservation recommendations.
L. Lewis & S. Norris	2005	Mist nets at 9 sites—12 species, 394 bats. Bat detectors—totaling 22 detector nights. Emphasis on *I. phyllotis*

Advances in Methods and Technology: From 1958 to 1963, Jones sampled bats across three biotic communities and categorized the bat fauna into six lowland and 13 highland forms. He also summarized seasonal distribution and activity periods. In 1966, using eight years of data, he observed that there were annual fluctuations in numbers and species captured. He found correlations between seasonal shifts in numbers and precipitation, and wondered if heavy collecting at some sites had skewed capture numbers. Jones and Suttkus (1972) analyzed 11 years of mist-netting data, measuring relative abundance of bats and annual fluctuations. They saw considerable variation in species numbers collected within a year and throughout the study. They also recognized the biases in sampling with mist nets. Lewis and Norris (2006) captured 394 bats representing 12 species at nine sites, and found sexual segregation by habitat and/or elevation for several species. Geluso (2006) found spotted bats (*E. maculatum*) and Allen's lappet-browed bats (*I. phyllotis*) at most historical locations. When comparing netting effort and relative proportions of captured individuals in the 1960s to his data, he concluded that there were relatively equal numbers of individuals per unit of effort across decades.

Notable Results: In 1965, Jones began to elucidate the distribution of southwestern bats across biotic communities, and summarized seasonal distribution. He later (1966) explored the seasonal and annual fluctuations in bat populations and considered the effects of heavy sampling. He determined that seasonal shifts in populations were correlated to differences in monthly precipitation. Jones and Suttkus (1972) determined that numbers of species and individuals were correlated with ecological ranges of the bats and human disturbance. They considered the impacts of extensive collecting at specific sites and the possibility that collecting had contributed to lower bat numbers.

Bioacoustics

Table 5. Biologists conducting research on the bioacoustics of bats in the Gila National Forest

Primary Researcher(s)	Year(s) of Research	Methods & Results
W. L. Gannon	1994–1995	AnaBat at 7 sites—monitor activity & record calls for UNM Call Library
M. O'Farrell et al.	1994–1995	AnaBat at 59 sites in Southwest (37 sites in NM)—establish vocal signatures to be used when identifying free-flying bats
L. Lewis & S. Norris	2005	AnaBat at 9 sites for a total of 22 detector nights to detect *Idionycteris phyllotis*
D. Taylor	2006	Peterssen time expansion detector at 4 sites in Southwest to help determine species identifications

Advances in Methods and Technology: The development of bat detectors and ultrasonic call analysis techniques has revolutionized bat research. Bat detectors can detect species that are not typically captured in mist nets and can be used in areas where conventional methods cannot be deployed. Gannon (1994, 1996) used the AnaBat detector system to monitor bat activity and record species-specific calls and sonograms. O'Farrell, Miller, and Gannon (1999) developed a method of identifying bats to species by qualitatively using certain call structures, such as maximum and minimum frequencies and morphological aspects of calls. They also encouraged active call collection, in order to provide a contextual basis for species identification. Lewis and Norris (2006) determined that acoustic calls of *I. phyllotis* were very similar to those of *E. maculatum* (beginning above 20 kHz, and dropping to 6–11 kHz), and concluded that it is not possible to definitively separate spotted bat and Allen's bat calls. Taylor and Tuttle (2007) used a Peterssen bat detector to aid in identifying species. The Peterssen is a time-expansion detector, which is similar to making a high-speed tape recording and then playing it back at a lower speed. These detectors use digital techniques to store all characteristics of the signals. Because each signal is stretched out in time, it is possible to hear details of the sound not audible with other methods.

Notable Results: Contributions from Gannon (1994, 1996), and O'Farrell, Miller, and Gannon (1999) have helped develop standardized methods for the recording, archiving, and analysis of chiropteran echolocation calls.

Behavioral Ecology

Table 6. Biologists conducting research on the behavioral ecology of bats in the Gila National Forest

Primary Researcher(s)	Year(s) of Research	Methods
H. Black	1972	Examined museum specimens to determine frequency of occurrence of moths in *Eptesicus fuscus* diets compared to *Lasiurus cinereus*
L. G. Herrera et al.	1991	Used carbon stable-isotope techniques to examine carbon composition in diet of *Antrozous pallidus*
D. Taylor	2005	Used video camera and night vision goggles to determine bat response to low water levels at livestock troughs
K. Geluso	2003–2005	Mist netted bats to examine winter activity outside roosts

Advances in Methods and Technology: In 1972, Black used a vacuum dessicator to determine the density of moth scales in digestive tracts and fecal pellets of big brown bats (*E. fuscus*) and hoary bats (*L. cinereus*). He found a greater utilization of moths by hoary bats, even though both species are sympatric and are active during the same hours. Herrera-Montalvo, Fleming, and Findley (1993) used carbon stable-isotope analysis to determine if southwestern pallid bats (*A. pallidus*) would contain substantial amounts of Crassulacean Acid Metabolism (CAM) carbon from their association with flowering cacti and agaves. They determined that carbon composition of pallids varied geographically, with no simple association with the geographic distribution of bat-pollinated cacti and agaves. Taylor and Tuttle (2007) tested bats' responses to low water in livestock troughs. Using an infrared video camera and a bat detector, he recorded the number of successful and unsuccessful passes.

Notable Results: Geluso (2005) observed bats regularly drinking and documented several species feeding on insects in winter. Most common species fed regularly; however, certain species such as pallid bats (*A. pallidus*) did not forage until March. Taylor and Tuttle (2007) found that as water levels drop, bats may reach a threshold where a tank is effectively eliminated as a place to drink for many bat species.

Population Ecology

Table 7. Biologists conducting research on the population ecology of bats in the Gila National Forest

Primary Researcher(s)	Year(s) of Research	Methods & Results
J. S. Findley & C. Jones	1960–1964	Examined museum specimens & literature records of *L. cinereus*
J. S. Findley	1965	Mist-netted *Euderma* with comments on relative abundance and habitat use
T. L. Best	1988	Examined museum specimens finding 10 of 16 characters exhibiting geographic variation among *Euderma* populations
P. M. Cryan	2003	Examined museum specimens of tree bats (*Lasiurus* and *Lasionycteris*) to determine seasonal distribution

Advances in Methods and Technology: Using museum specimens and intensive mist-netting, Findley and Jones (1964) looked at the sexual segregation in hoary bats (*L. cinereus*), and noted that females reach peak numbers in May but are absent in most other months. A year later, Findley and Jones (1965) made observations on the relative abundance of spotted bats (*E. maculatum*), suggesting that in the Southwest, they were a bat of ponderosa pine during their breeding season. Best (1988) found significant geographic variation among four regional populations of spotted bats (*E. maculatum*), possibly indicating that there is little exchange of individuals among populations. When looking at the seasonal distribution of hoary bats (*L. cinereus*) and other similar "tree bats," Cryan (2003) found a broad area of sympatry between western and eastern red bats (*L. blossevillii* and *borealis*) and clarified patterns of seasonal distribution for all species studied.

Notable Results: Contributions from Findley and Jones (1964) and Cryan (2003) have helped clarify details regarding seasonal movements in several North American tree bats. Research conducted by Findley and Jones (1965) and Best (1988) have contributed to the knowledge of the spotted bat (*E. maculatum*), a sometimes elusive species.

Future Perspectives

Since Vernon Bailey's *Mammals of New Mexico* was published in 1931, there have been many technological, analytical, and empirical advances in bat research. Much of the progress has been a result of new developments in electronic equipment and information technology, as well as research based on models and testable hypotheses. The ability to test hypotheses has been enhanced by the development of more sophisticated analytical procedures and more accessible computer hardware and software. An important lesson from over a century of work is that not all discoveries have been made. With the addition of 4 bat species to the 25 that were documented as occurring in New Mexico in Findley et al.'s 1975 *Mammals of New Mexico*, it is clear that more can be learned.

With a greater understanding of the ecological roles of southwestern bats, there is a concurrent need to understand the consequences of forest management on bats. Many bats are closely associated with various components of forest structure; therefore, forest activities such as felling of trees and snags, prescribed fire, vegetation manipulation/control, and road building may strongly influence bats. Looking at forest management at a landscape scale, we need to understand the cumulative effects of management activities across the Southwest. Given the scale at which bats roost, forage, and travel, it is likely that changes in landscape characteristics heavily influence bat populations (Hayes and Loeb 2007). Bat conservation will also require that we continue to gain an understanding of the ecological requirements of bats in order to develop appropriate conservation and management plans. There is a critical need to continue to assemble information on the basic biology of bats, as well as to improve methods of estimating bat numbers and monitoring bat populations over time. Specific information on species and sites may help avoid controversies about the status of species that can and do arise as a result of decisions based on incomplete information.

Literature Cited

Altenbach, J. S. 2007a. Abandoned mine surveys for bats: Kingston Mining District, Sierra Co, NM. Unpublished report. Gila National Forest. Truth or Consequences, NM.

———. 2007b. Abandoned mine surveys for bats: Gold Hill Mine Reclamation Project, Grant Co, NM. Unpublished report. NM Mines and Minerals Division. Albuquerque, NM.

Bailey, V. 1931. Mammals of New Mexico. *North American Fauna* 54:1–412.

Barbour, R. W., and W. H. Davis. 1970. The status of *Myotis occultus*. *Journal of Mammalogy* 51:150–51.

———. 1969. *Bats of America*. Lexington, KY: University of Kentucky.

Best, T. L. 1988. Morphological variation in the spotted bat *Euderma maculatum*. *The American Midland Naturalist* 119 (2): 244–52.

Black, H. L. 1972. Differential exploitation of moths by the bats *Eptesicus fuscus* and *Lasiurus cinereus*. *Journal of Mammalogy* 53 (3): 598–601.

Brown, D. E. 1982. Biotic communities of the American Southwest—United States and Mexico. *Desert Plants* 4 (1–4): 1–342.

Cryan, P. M. 2003. Seasonal distribution of migratory tree bats (*Lasiurus* and *Lasionycteris*). *Journal of Mammalogy* 84 (2): 579–93.

Findley, J. S. 1993. *Bats: A community perspective*. Cambridge, UK: Cambridge University Press.

———. 1987. *The natural history of New Mexican mammals*. Albuquerque, NM: University of New Mexico Press.

———. 1960. Identity of the long-eared *Myotis* of the Southwest and Mexico. *Journal of Mammalogy* 41 (1): 16–20.

Findley, J. S., A. H. Harris, D. E. Wilson, and C. Jones. 1975. *Mammals of New Mexico*. Albuquerque, NM: University of New Mexico Press.

Findley, J. S., and C. Jones. 1967. Taxonomic relationships of bats of the species *Myotis fortidens*, *M. lucifugus*, and *M. occultus*. *Journal of Mammalogy* 48:429–44.

———. 1965. Comments on spotted bats. *Journal of Mammalogy* 46 (4): 679–80.

———. 1964. Seasonal distribution of the hoary bat. *Journal of Mammalogy* 45 (3): 461–70.

———. 1961. A new United States record of the Mexican big-eared bat. *Journal of Mammalogy* 4:97.

Gannon, W. L. 1998. Syntopy between two species of long-eared bats (*Myotis evotis and Myotis auriculus*). *Southwestern Naturalist* 43 (3): 394–96.

———. 1996. 1995 bat survey. Final report to Gila National Forest, Reserve Ranger District, Reserve, NM.

———. 1994. 1994 bat survey. Final report to Gila National Forest, Reserve Ranger District, Reserve, NM.

Gannon, W. L., and G. R. Racz. 2006. Character displacement and ecomorphological analysis of two long-eared *Myotis* (*M. auriculus* and *M. evotis*). *Journal of Mammalogy* 87 (1): 171–79.

Gannon, W. L., R. E. Sherwin, T. N. deCarvalho, and M. J. O'Farrell. 2001. Pinnae and echolocation call differences between *Myotis californicus* and *M. ciliolabrum*. *Acta Chiropterologica* 3 (1): 77–91.

Geluso, K. 2006. Recurrence of the spotted bat (*Euderma maculatum*) and Allen's big-eared bat (*Idionycteris phyllotis*) in New Mexico. Unpublished report. New Mexico Department of Game and Fish, Santa Fe, NM.

———. 2005. Winter activity of bats outside their roosts in New Mexico. Unpublished report. New Mexico Department of Game and Fish, Santa Fe, NM.

Geluso, K., T. R. Mollhagen, J. M. Tigner, and M. A. Bogan. 2005. Westward expansion of the eastern pipistrelle (Pipistrellus subflavus) in the United States, including new records from New Mexico, South Dakota, and Texas. *Western North American Naturalist* 65 (3): 405–9.

Harris, A. H. 1974. *Myotis yumanensis* in interior southwestern North America, with comments on *Myotis lucifugus*. *Journal of Mammalogy* 55 (3): 589–607.
Harris, A. H., and J. S. Findley. 1962. Status of *Myotis lucifugus phasma* and comments on variation in *Myotis yumanensis*. *Journal of Mammalogy* 43 (2): 192–99.
Hayes, J. P., and S. C. Loeb. 2007. The influences of forest management on bats in North America. In *Bats in Forests—Conservation and Management*, ed. M. J. Lacki, J. P. Hayes, and A. Kurta. Baltimore: The Johns Hopkins University Press.
Hayward, B. J. 1995. Field notes on a biotic survey of the Big Burros and Big Lue Mountains. Unpublished report. Gila National Forest. Silver City, NM.
———. 1994. Field notes on a mammal survey of the Pinos Altos Mountains and Sapillo Creek drainage complex. Unpublished report. Gila National Forest. Silver City, NM.
———. 1971. The natural history of the western long-nosed bat *Leptonycteris sanborni (=curasoae). Western New Mexico University Research in Science* 1 (2): 75–123.
———. 1970. The natural history of the cave bat *Myotis velifer. Western New Mexico University Research in Science* 1 (1): 1–74.
Hayward, B. J., and S. P. Cross. 1979. *The natural history of Pipistrellus hesperus* (Chiroptera: Vespertilionidae). Western New Mexico University, Office of Research No. 3.
Hayward, B. J., and R. Davis. 1964. Flight speeds in western bats. *Journal of Mammalogy* 45:236–42.
Hayward, B. J., and D. Hunt Jr. 1972. Vertebrate study of the Wilderness Ranger District, Gila National Forest, NM. Unpublished report. Gila National Forest. Silver City, NM.
Hayward, B. J., and R. Johnson. 1961. Notes on *Plecotus phyllotis* from Arizona. *Journal of Mammalogy* 42:402.
Herrera-Montalvo, L. G., T. H. Fleming, and J. S. Findley. 1993. Geographic variation in carbon composition of the pallid bat, *Antrozous pallidus*, and its dietary implications. *Journal of Mammalogy* 74 (3): 601–6.
Jones, C. 1966. Changes in populations of some western bats. *The American Midland Naturalist* 76 (2): 522–28.
———. 1965. Ecological distribution and activity periods of bats of the Mogollon Mountains area of New Mexico and adjacent Arizona. *Tulane Studies in Zoology* 12 (4): 93–100.
———. 1961. Additional records of bats in New Mexico. *Journal of Mammalogy* 42 (4): 538–39.
Jones, C., and R. D. Suttkus. 1972. Notes on netting bats for eleven years in western New Mexico. *The Southwestern Naturalist* 16 (3–4): 261–66.
Lewis, L., and S. Norris. 2006. Allen's lappet-eared bat (*Idionycteris phyllotis*) surveys in the Gila Wilderness. Unpublished report. New Mexico Department of Game and Fish. Santa Fe, NM.
Mumford, R. E. 1963. Unusual dentition in *Myotis occultus*. *Journal of Mammalogy* 44 (2): 275.
Mumford, R. E. and D. A. Zimmerman. 1963. The southern yellow bat in New Mexico. *Journal of Mammalogy* 44 (3): 417–18.
O'Farrell, M. J., B. W. Miller, and W. L. Gannon. 1999. Qualitative identification of free-flying bats using the Anabat detector. *Journal of Mammalogy* 80 (1): 11–23.
Perry, T. W., and K. Gunnell. 2001. Bat diversity and maternity roost survey of the Ladder Ranch, New Mexico. Unpublished report. Turner Foundation, Inc. Atlanta, GA.
Piaggio, A. J., E. W. Valdez, M. A. Bogan, and G. S. Spicer. 2002. Systematics of *Myotis occultus* (Chiroptera: Vespertilionidae) inferred from sequences of two mitochondrial genes. *Journal of Mammalogy* 83 (2): 386–95.
Ramsey, M. A., and R. D. Jennings. 1996. Bat survey of the Black Range, Mimbres and Mogollon mountains. Unpublished report. New Mexico Department of Game and Fish. Santa Fe, NM.
Ramsey, M. A., L. J. Weber, and R. D. Jennings. 1997. Winter and spring bat activity in the Gila National Forest. Unpublished report. Gila National Forest. Silver City, NM.
Ramsey, M. A., L. J. Weber, K. Worley, and J. Garcia. 1998. Bat survey of the Beaverhead Ecosystem Management Unit, Black Range Ranger District, Gila National Forest. Unpublished report. Gila National Forest. Silver City, NM.
Reducker, D. W., T. L. Yates, and I. F. Greenbaum. 1983. Evolutionary affinities among southwestern long-eared *Myotis* (Chiroptera: Vespertilionidae). *Journal of Mammalogy* 64 (4): 666–77.
Taylor, D. A., and M. Tuttle. 2007. *Water for wildlife: a handbook for ranchers and range managers*. Austin, TX: Bat Conservation International.
Tumlison, R. 1993. Geographic variation in the lappet-eared bat, *Idionycteris phyllotis*, with descriptions of subspecies. *Journal of Mammalogy* 74 (2): 412–21.

Valdez, E.W., J. R. Choate, M. A. Bogan, and T. L. Yates. 1999. Taxonomic status of *Myotis occultus. Journal of Mammalogy* 80 (2): 545–52.
Williams, O. F. 1996. A preliminary report on the fauna of Las Animas Creek. Unpublished report. Gila National Forest. Silver City, NM.

Where the River Meets the Ditch: Effects on Riparian Regeneration of Floodplain Geomorphology, Floods, and Surface Flow Diversion in the Cliff–Gila Valley, New Mexico

Ellen S. Soles

Department of Geography, Northern Arizona University
Ellen.Soles@nau.edu

ABSTRACT
Historic accounts of the Gila River near the Cliff–Gila Valley of southwestern New Mexico portray a clear, rushing stream between thickly vegetated banks. When this study began, in 1999, the river was wide, shallow, and braided among cobble floodplains largely devoid of vegetation. The original study from which this paper is derived examined how interactions between natural causes and human activities created present-day conditions in the Cliff–Gila Valley, and the implications of those conditions for potential regeneration of the riparian system. A number of data sources were employed to examine temporal correspondence among human-imposed factors, floods, and resulting river condition between 1880 and 2000. Flood histories, anecdotal accounts of change in the riparian corridor, historic aerial photography, and data from floodplain morphology surveys conducted in 1999 and 2000 were evaluated to reconstruct the river's hydrologic and geomorphic history. To predict potential patterns of riparian regeneration on floodplains, eight piezometers were installed near the river channel to obtain biweekly data on relative elevations of groundwater and Gila River surface water during the study period. Variance between the river's natural base flow regime and base flow remaining after irrigation diversions was examined for the period 1969 through 2001. Evaluation of relative groundwater levels in conjunction with the historic air photos reveals complex interactions between anthropogenic and natural features of the valley's hydrologic system. Vegetation regrowth on the active channel upstream of the diversions has occurred more rapidly than downstream of them, where riparian regeneration generally occurs earliest in abandoned channels and backwaters removed from the currently active channel. Integration of the different data sets strongly suggests that small to moderate flood events are a vital component of riparian vigor in the system.

INTRODUCTION

In southwestern New Mexico, the Gila River and its riparian floodplains occupy only a minute percentage of the landscape. Yet, like similar systems throughout this semiarid region, they provide a disproportionate amount of essential vegetative cover and forage for hundreds of species (Apple 1985). Complex biologic, geomorphic, and hydrologic interactions are created and sustained by these systems, whose resilience depends both on stream surface flows and on the alluvial groundwater systems to which they are connected (Leenhouts, Stromberg, and Scott 2006). Their consequent ecological diversity is well recognized (Auble, Friedman, and Scott 1994; Brady, Patton, and Paxson 1985; Bren 1993; Lamb and Lord 1992).

The region's human occupants have also been sustained, for millennia, by these riparian zones. Historic settlers of the late 19th century were no exception. They concentrated in small alluvial valleys like those that characterize the Gila's upper watershed. The Cliff–Gila Valley is typical: Less than 2 miles wide and 15 miles long, it supported agriculture on only a modest scale, but the river's perennial flow provided a steady water supply for crops. Immigrants settled in the valley and constructed irrigation works by 1880.

Thirty years earlier, Emory had described the Gila River just downstream of the valley as "narrow, covered with large round pebbles. The growth of trees [cottonwood, sycamore, mesquite] and weeds was very luxuriant . . ." (Emory 1848). In the Cliff–Gila Valley, the river made a very different impression when this study began in 1998. Its channel was wide, flanked by tall cutbanks of sand and silt, or by broad cobble floodplains nearly devoid of all but sparse upland vegetation like broomweed and rabbit brush. Levee remnants formed five-foot-high cobble and gravel berms against many stretches of the river. Occasional clumps of younger cottonwoods and willows (*Populus fremontii* and *Salix spp.*) were evident, but aged, enormous cottonwoods that perched on terraces six to ten feet above the river overwhelmingly dominated the riparian tree community.

This paper presents results from two aspects of a study, completed in 2003, that reconstructed the valley's hydrologic, geomorphic, and land use history after 1880 to evaluate the relative effects of human modifications and flooding on existing and potential conditions in the valley's riparian zone. Two basic questions motivated the study. How had natural events and human activities interacted to create the existing conditions in the Cliff–Gila Valley? And how did existing water use practices—particularly diversions of surface flow for irrigation—affect potential regeneration of the riparian community?

In semiarid regions, changes in hydrology caused by surface-water diversion or groundwater pumping can produce shifts in riparian stand structure, species composition, and vigor (Nilssen and Berggren 2000; Stromberg and Patten 1990; Stromberg, Tiller, and Richter 1996). A substantial volume of work has examined the relationship between instream flow characteristics and ecosystem condition (Richter et al. 1997; Rosenberg, McCully, and Pringle 2000; Tharme 2003). Riparian species of the southwestern U.S. are typically adapted to the erratic hydrographs of its rivers, and many are dependent on groundwater during periods of drought (Amlin and Rood 2002; Jolly 1996; Patten 1998). In these systems, the interactions between shallow alluvial groundwater and river surface flow that occur in the river's hyporheic zone are vital to riparian recruitment, survival, and vigor. Diversions for agriculture in the Cliff–Gila Valley are modest, but during dry seasons may capture the Gila's entire baseflow of about 40 cubic feet per second (cfs). The effects on surface water are obvious; the consequences for floodplain groundwater levels and therefore for seedling survival and riparian regeneration, less so. The research for this study illuminated the importance of interactions between floodplain geomorphology and the river's flood regime in ameliorating diversion impacts on the riparian system.

PHYSICAL GEOGRAPHY

The three forks of the upper Gila River form in the high elevations of the Mogollon and Black mountains, around 10,000 feet, to flow through a rugged landscape designated as the nation's first Wilderness (Tellman, Yarde, and Wallace 1997). The forks join to form the main-stem Gila River near the Gila Cliff Dwellings National Monument. Mostly canyon-bound, the river crosses another 20 miles of Wilderness and Gila National Forest lands before making an abrupt turn at the USGS "Gila at Gila" gaging station a few miles upstream of the tiny towns of Gila and Cliff (fig. 1). A nearly continuous record of discharge has been collected at or near this site since 1928. Below the gaging station, the river travels for about 14 miles through the somewhat broader alluvial zone of the Cliff–Gila Valley before entering the long, constricted reach that carries it nearly to the Arizona border.

The valley's elevation is roughly 4600 feet. The river's watershed here encompasses about 1900 mi^2 (U.S. Geological Survey 2003). Watershed vegetation is comprised of mixed conifer, Ponderosa pine, pinyon–juniper, and grass/chaparral types (USDA Forest Service 1968). A complex geology characterizes the watershed, much of which occupies the transition between the Colorado Plateau and Basin and Range structures (Clemons, Christiansen, and James 1980; Trauger 1972). Volcanic flows and sedimentary deposits of Tertiary–Quaternary age underlie or form outcrops throughout the Cliff–Gila Valley area, and exposed Tertiary deposits of Gila conglomerate, a relatively impermeable rock layer, are particularly evident. Some fine-grained lake deposits of late Tertiary age are present, especially around the Duck Creek valley. The ancestral Gila River cut through these deposits. During later Quaternary time, its valley partially filled with alluvium, which today forms the highest benches above the river's floodplain. More recent alluvial fill in the valley bottom, of Pleistocene to Holocene origin, ranges in depth from 20 to 100 feet (Trauger 1972; USDA Soil Conservation Service 1954; U.S. Geological Survey 1923). The dense underlying deposits tend to support small perched aquifers in the alluvial fill and to accelerate groundwater movement across valley-facing hill slopes.

Annual average precipitation at higher elevations of the watershed is about 16 inches, and at Cliff, about 14 inches. It arrives in a generally bimodal pattern, in which the months of April through June tend to be driest, and July through September wettest (USDA Soil Conservation Service 1954; Western Regional Climate Center 2003). However, precipitation is extremely variable, ranging from about 6 inches to 26 inches per year in the period between 1940 and 2000. The Gila's flow regime is likewise highly variable, both intra- and interannually. Large-scale, frequent flooding prevailed during the last decades of the 20th century, particularly by comparison with prior years. Eight floods of >10,000 cfs, including the two largest floods of record, occurred during the 25 years from 1972 to 1997—four times as many as in the preceding 40 years. Table 1 shows the number and relative frequencies of varying flood magnitudes during two periods, 1929–1969 and 1970–1996.

Table 1. Selected mean daily flood magnitudes and frequency of occurrence at Gila gagesite, 1929–1969 and 1970–1996

Flood magnitude (cfs)	1929–1969		1970–1996	
	Number	Frequency	Number	Frequency
1000–2500	124	0.3 years	199	0.1 years
2000–8000	28	1.5 years	70	0.4 years
> 5000	3	13.7 years	20	1.4 years

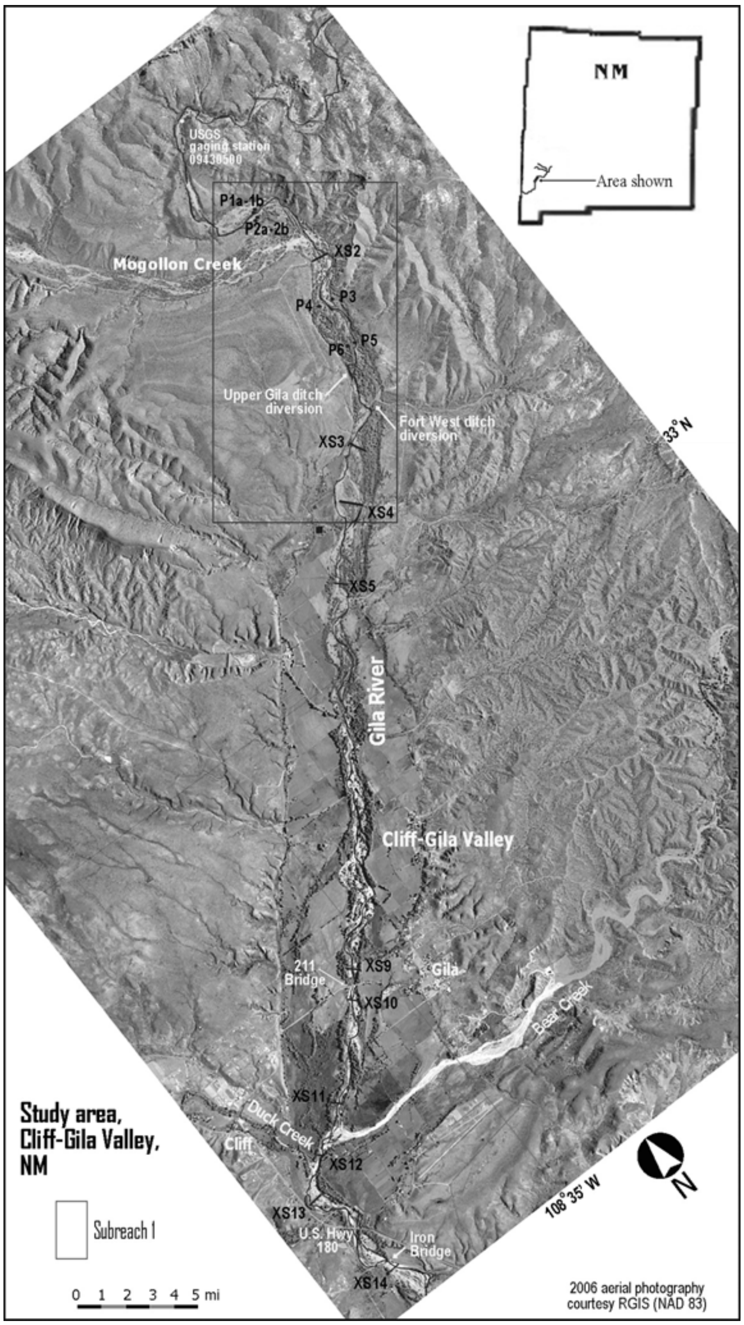

Fig. 1. Aerial photography (2006) of the study area in the Cliff–Gila Valley, New Mexico. Field data were collected from 1999 through 2001 at the sites shown.

The geomorphic effects of large floods in semiarid alluvial valleys are extremely complex. Among other factors, duration of flooding, relative magnitudes of main-stem and tributary flooding, and patterns of existing vegetation can strongly influence patterns of erosion and deposition within the main-stem channel (Baker 1988; Beven 1981; Bourke and Pickup 1999; Bull 1988; Graf 1988; Kennedy 1999; Simon and Darby 1999). In addition, the magnitude of geomorphic change within the river corridor is sometimes less closely related to the absolute magnitude of a particular flood than to the relationship between mean annual discharge and maximum peak discharge for a given watershed (Kochel 1988). In spite of the frequency of major flooding after 1972, each was, statistically speaking, a relatively rare event. As a consequence, the variance between discharge during each flood and average annual discharge was much more extreme than would be the case in a more humid, less variable system. The geomorphic results of the floods in the Cliff–Gila Valley were substantial.

HISTORIC AND SOCIAL GEOGRAPHY

The region's rugged and remote nature are reflected in the relatively late dates at which modern settlement occurred. Mormon settlers brought farming to the valley around 1870, and a local farmer opened the first grocery in Cliff around 1890 to serve the supply wagons that traveled between Silver City and the silver mines to the northwest at Mogollon (Calvin 1946, 114). The grocer also ran the region's only ferry across the Gila River, enabling travelers to cross the river during higher flows. The first bridge across the river wasn't built until 1915, when Iron Bridge, just south of Cliff, was constructed (*Mogollon Mines* 1916).

Gravity-fed irrigation ditches in the Cliff–Gila Valley were constructed before 1880 (interview, March 2000). By 1927, residents were irrigating 2900 acres to produce "corn, alfalfa, garden truck, melons, and deciduous fruits" (Black 1927, 9). USDI Bureau of Reclamation reported in 1930 about 3500 acres of valley "bottom lands" under irrigation. Most were at the upstream end of the valley, as areas farther downstream were "unfavorably affected by the meandering river channel which makes maintenance of diversions difficult and the contracted valley outlet [around the Duck Creek confluence] which causes frequent flooding of the lower lands" (USDI Bureau of Reclamation 1930). During the 1930s and 1940s, major land owners frequently leased lands to tenant farmers or sharecroppers (interview, February 2001). Residents recall that corn and beans were major crops through at least the 1940s (interviews April 2000 and February 2001), although today alfalfa and pasturage are predominant in valley fields.

Substantial changes on the river and its riparian corridor were imposed during the 20th century. In addition to farming and grazing operations, extensive channelization work began in the mid-1940s and by 1965 had significantly modified the river's planform, or pattern, and its floodplain. Flood damage to levees in 1978 inspired additional construction the following year. Twelve local arroyos, including all but one of the major tributary drainages in the valley, were dammed for sediment control by 1964. Maintenance of diversion berms and other structures for the valley's three major gravity-fed irrigation ditches is ongoing.

Water Use

The largest land and water rights owner in the Cliff–Gila Valley is the Phelps Dodge Corporation (PD). Operating as Pacific Western Land Company, the corporation bought land—and the attached water rights, many of which hold priority dates as early as any in the valley—from valley landowners beginning in the late 1950s (interview, April 2000). Around 1970, PD built a low diversion dam and pumping station on the river to supply water to their mining operation at Tyrone, about 30 miles southeast of Gila. The diversion is located near the downstream end of the valley, below the Highway 180 bridge (fig. 1). One consequence of this location is that streamflow that may have otherwise been diverted for irrigation farther upstream remains in the river channel during its course through the valley.

Nonetheless, complete dewatering of parts of the river in the valley sometimes occurs during dry seasons. The diversions for the Fort West and Upper Gila ditches are located near the valley's head (fig. 1). Total surface flow diversion into these ditches averages about 60 cfs during the summer irrigation months. During very dry periods, however, river discharge can fall to around 30 cfs, and all of this is diverted into the two ditches.

While some valley irrigators may supplement their ditch supply with shallow groundwater wells (Wilson and Lucero 1998), river discharge levels generally control irrigation capacity during dry seasons. No major storage works have been constructed on the Gila River upstream of the Arizona border, despite repeated proposals to do so. In fact, the USGS gaging station site just upstream of the Cliff–Gila Valley has often been revisited as a potential dam or diversion site (fig. 1). It was suggested as a power production site as early as 1916, and ten years later as a major storage facility for irrigation (Black 1927). Dam construction was reproposed after an Army Corps of Engineers irrigation and flood control study of the Gila River in 1938 (Clark 1987). In 1968, after a Supreme Court ruling that finalized New Mexico's claim to the river at an annual average of 18,000 acre-feet (A-F), dam construction at the gaging station site was authorized as part of the Colorado River Basin Project Act (Reisner 1986). The proposed Hooker Dam (named for a local resident who had historically farmed the terraces near the site) would have created an impoundment large enough to back up into the Gila Wilderness, with effects on habitat for endangered species. This fact and the project's questionable economic feasibility led to the eventual demise of the proposal (Fradkin 1968).

The most recent incarnation of the Gila River water capture proposals is outlined in the Arizona Water Settlement Act and accompanying Consumptive Use Forbearance Agreement, or CUFA. The terms of the CUFA allow New Mexico to divert up to 140,000 additional A-F every 10 years in the Gila basin. The state would be eligible for up to $128 million in federal funding if it "develops additional Gila Basin water as provided in the CUFA" (New Mexico Office of the State Engineer/Interstate Stream Commission 2006). Slightly more than half this amount could be used for nondiversion water measures. Regional stakeholders are involved in discussions to develop a set of proposed diversion and/or nondiversion alternatives for environmental and economic analysis.

STUDY METHODS

Flooding and Geomorphic History

A variety of data were collected for the study (for additional detail on all methods, see Soles 2003). They included anecdotal accounts of historic floods and river condition from newspaper archives and other sources, as well as interviews with local residents. These were cross-referenced to archival records and maps dating back to about 1880. Digital orthophotoquads (U.S. Geological Survey 1999) were used to georeference five sets of historic aerial photography (1935, 1950, 1965, 1974, 1980). Photo scales ranged from 1:18,000 to 1:40,000; all photos were scanned at 600 dpi. On each photo, 150 to 350 ground control points, predominantly near the river corridor, were identified and marked to georeference the photos. Georeferencing was by a linear rubber sheeting procedure to allow for the substantial topographic variation depicted in each image (ERDAS 2001). Root mean square error was less than 8 meters for all control points. The georeferenced photos comprising each year's coverage were joined to provide a semicontrolled mosaic of the study reach. All mosaics were retained as raster layers. The air photo mosaics formed the basis for digitized vector layers. The river planform, riparian floodplain vegetation, and unvegetated floodplain surfaces were digitized from each set of photos.

Field data collection included depth to groundwater measured in piezometers, topographic cross-section surveys, and extensive field reconnaissance of the study reach. Data collection sites are shown in figure 1. Ten channel cross sections established by Natural Resource Conservation Service staff were extended by 200 feet to 500 feet to include all floodplain and abandoned channel surfaces. These were surveyed in 1999 and again in 2000 by laser level. Riparian vegetation type and age class and surface sediment deposits were also mapped at each cross section. Years in which the active river channel occupied the now-abandoned channels evident at each cross section were dated by georeferencing cross-section endpoints to the historic air photos.

Cross-section survey data were analyzed in WINXSPro v. 2.0 (USDA Forest Service 1998). For estimates of Manning's *n* values**,** Arcement and Schneider's (1984) methods were applied to Cowan's (1956) equation. Separate roughness coefficients were calculated for the active channel, adjacent floodplains, and terrace/overflow channel areas at each cross section. Field notes and photographs aided in selecting elevations and widths at which Manning's *n* was determined to change, for example, where floodplain vegetation density changed substantially. Rating curves for the three cross sections nearest the USGS gaging station just upstream of the valley were developed to generate estimates of the discharge required to overtop abandoned channels. Calculated discharge and mean depths were checked against measured discharge values to refine the rating curves. The only significant flow event during the study period, a 2800-cfs flood, occurred on August 6, 1999. Calculated stage heights for 2800-cfs flows were checked against surveyed elevations of debris left by the flood.

Groundwater Data Collection and Analysis

The effects of irrigation diversions on potential future condition were assessed by (1) analysis of diversion effects on river baseflow, and (2) evaluation of groundwater and surface water interactions relative to existing topography.

Data from four USGS gaging stations were used to evaluate diversion effects: Gila at Gila (09430500), Mogollon Creek (09430600), and those on the Fort West and Upper Gila ditches. Shallow groundwater and surface flow interactions upstream of the diversions were monitored and evaluated using data from three sets of piezometers and staff gages installed between the USGS gaging station and the diversion farthest upstream. Each of these methods is described in more detail below.

Low flow variation. Comparison of the river's natural flow regime with flow immediately below the first two major irrigation diversions in the Cliff–Gila Valley was conducted by IHA analysis (IHA 2001) of data for the years 1969–2001 to detect any significant variation in flow regime under diversion conditions. As the shortest period covered by available gage records was 33 years, this provided the limiting time frame for evaluating impacts to the river's hydrologic regime (Richter et al. 1997). Four of the hydrologic parameters affected by the diversions—mean duration of low flow pulses, annual means of 30- or 90-day low flows, and base flow discharge—were identified. All four parameters are considered potentially "ecologically significant" for riparian seedling survival (Poff et al. 1997; Richter 1999; Richter and Richter 2000). IHA software calculated differences in central tendency between natural and altered conditions, established confidence limits for these differences, and reported significance values for each.

The IHA analysis used mean daily discharge values from the Mogollon Creek, Gila River, Upper Gila Ditch, and Fort West Ditch gages. Only mean daily discharge values >15 cfs at the Mogollon Creek gage were included, to adjust for the creek's ephemeral nature at its confluence with the river. Discharge measurements (Buchanan and Somers 1969) were made at two locations in order to correlate actual discharge downstream of the Mogollon Creek confluence to that recorded at the Gila gage upstream. Reported mean discharge at the Gila gagesite and measured discharge at cross section 2 (XS 2) are shown in table 2. The results suggest that under seasonally dry conditions, Mogollon Creek contributes little to Gila base flows. Results were checked by fitting discharge measured at XS 2 to mean discharge recorded at the gaging station during the preceding 2-h period (r^2 of 0.97). The resulting regression was then used to check the validity of excluding all Mogollon flows of < 15 cfs from consideration for IHA analysis. In the equation below, *Qxs2* = discharge at XS 2; *gage Q* = discharge at Gila gagesite.

$$Qxs2 = (1.04953 \text{ gage } Q) - 9.0922; \; r^2 = 0.97$$

Table 2. Measured Gila River discharge during the study period

Date	Gage Q (cfs)	Qxs2 (cfs)
3/12/99	63.3	54.4
5/13/99	44.0	33.9
6/27/99	30.3	27.6
7/21/99	59.3	45.2
9/29/99	105.5	105.3
4/4/00	57.3	54.3
7/31/00	45.0	40.5

Gage Q = 2-h mean of discharge at Gila gagesite beginning 2 h before time of discharge measurement at XS 2. Qxs2 = discharge measured at XS 2.

This equation was applied to all Gila gagesite daily means for the months of April through October (designated as "summer" months for the IHA study) for the IHA period, 1969–2001. The results were compared against daily sums of mean discharge from the Gila gage and discharge >15 cfs from the Mogollon gage (*Qgm*). Variance between summed and calculated estimates ranged from 1% to 3%, and for flow of less than 200 cfs—most pertinent to seedling survival—*Qgm* generally overstates total discharge downstream of the Gila–Mogollon confluence. Including all Mogollon flows > 15 cfs helped to avoid overstating possible groundwater depletion effects on riparian communities below the diversions.

Daily diversions as measured at the ditch gage sites over the 33-year period were subtracted from *Qgm* in order to estimate daily mean discharge values (*Qnet*) for the river below the diversions. (Note that *Qnet* most accurately represents net river flow regime immediately below the diversions. Farther downstream, ditch and field seep and irrigation tailwater returns increase the volume of water in the river channel.) IHA (2001) analysis compared *Qgm* and *Qnet* for significant variation in flow regime.

Piezometers. Variance in alluvial groundwater elevation changes relative to changing river stage could suggest variability in substrate density between sites, or the existence of preferential subsurface flow paths, i.e., abandoned river channels currently buried beneath the floodplain. To monitor groundwater elevation shifts relative to water surface levels in the active Gila River channel, a total of eight 1¼″ piezometers were installed at three sites in July 1999, using techniques and materials outlined in The Nature Conservancy's (TNC's) *Hydrologic Monitoring Manual* (1996). All piezometers are located within Subreach 1; their locations are shown in figure 1. At each site, piezometers bracket the active channel. Final piezometer depths ranged from 12–18 feet below ground surface. All piezometers are located upstream of irrigation diversions in the Gila Valley; property ownership considerations precluded the installation of additional piezometers farther downstream. Staff gages were installed in and above the active channel at each piezometer site to monitor river stage from approximately 0.5 feet to 6.6 feet. The lip of each piezometer, ground surface, staff gages, and reference points were surveyed by level, rectified to a common datum elevation. Detailed instructions for piezometer and staff gage measurements were supplied to local TNC/Upper Gila Watershed Alliance personnel who made semimonthly visits to the sites. Piezometers were bailed or purged to remove accumulated sediment about once every four months. Two staff gages were lost to flood and one to vandals, resulting in a few missing data points for river water surface elevations. The staff gages were replaced and the sites were resurveyed.

RESULTS

Groundwater Elevations Analysis

Low flow comparison, unimpacted and impacted. Analysis of streamflow under natural (*Qgm*) and diverted (*Qnet*) conditions revealed significant variance in the river's low flow regime below the Upper Gila and Fort West diversion points. For the period from 1969–2001, *Qgm* was never zero, while *Qnet* resulted in zero flow during 3% of days during the irrigation season, April through October. The diversions resulted in a hundredfold increase in the number of < 20-cfs streamflow days, and more than doubled the number of < 50-cfs streamflow days.

IHA (2001) was used to calculate streamflow "targets" based on 25th- or 75th-percentile calculations of unimpacted streamflow for selected parameters. (The percentiles replace a statistical calculation of one standard deviation from the mean for strongly skewed and variable hydrologic data.) For this study, 7-, 30-, and 90-day minimum flows (averaged annual minima during the respective number of days) were chosen for analysis. In no years did *Qnet* streamflow exceed the 90-day minimum streamflow target of about 44 cfs. It reached the targeted 30-day minimum, about 29 cfs, only in 1991 and 1993, and the 7-day minimum target of 23 cfs only in 1991.

Surface and groundwater relations. To relate changing river stage to groundwater elevations at piezometer sites, the variance between each river stage and piezometer depth reading (n = 31 to 33) was calculated. Variances were graphed against (1) time and (2) distance from channel edge. Even under the generally uniform surface conditions at the piezometer sites, relative changes in Gila River water elevations and groundwater elevations varied substantially. Figure 2 shows the variance on each measurement date, July 1999–January 2001 (days 180 through 760 on the graphs). The zero line on each graph indicates equal groundwater and surface water elevation.

Floodplain groundwater levels appear, on the whole, to reflect changing river stage. Piezometer water elevations were usually lower than river surface elevation, showing this reach to be generally effluent to the floodplain. However, localized groundwater flow in the opposite direction, floodplain to river, also occurs. For example, near the Gila's confluence with Mogollon Creek, shallow standing water along the east river bank was consistently colder during summer months than the water in the channel thalweg. This was true even when the east bank had been in steady sunshine for five to six hours (personal observations, 1999–2000). Groundwater movement at this spot was toward rather than away from the river.

Interactions between ground and surface waters are complex (Maddock et al. 1995). Groundwater flow rate and direction are strongly influenced by the relative permeability of substrate (Hawkins and Stephens 1983), at times causing groundwater to move along a path more parallel with the river than perpendicular to it. Other variables—density of streamside vegetation, for example—can also affect the interaction between ground and surface water. The apparent anomalies noted above suggest greater water uptake by vegetation at some sites than others, and/or differences in substrate permeability between the river and piezometers at the different sites. These possibilities

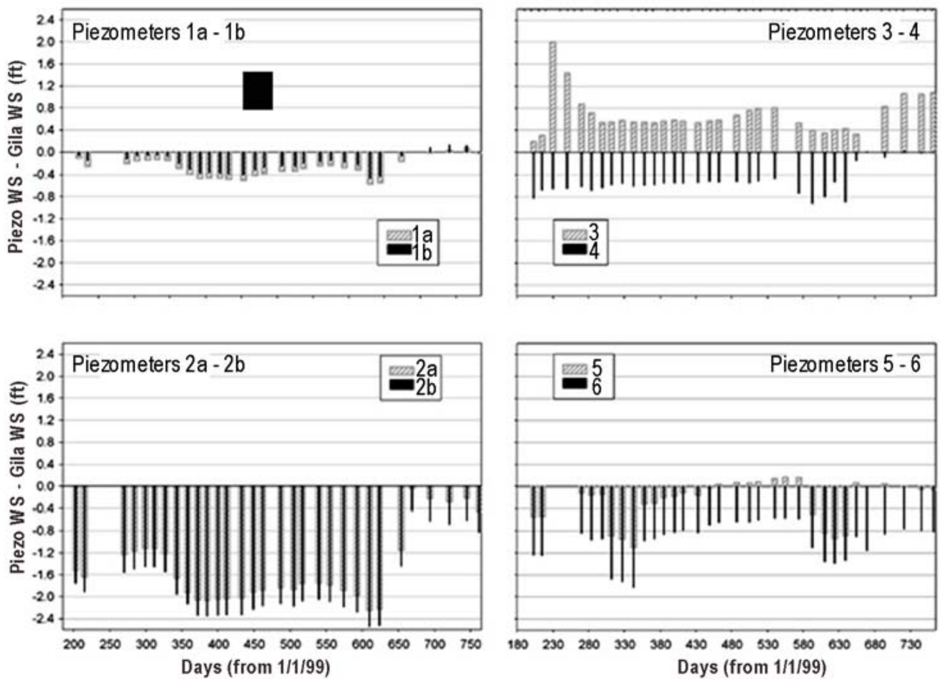

Fig. 2. Relative water elevations in the Gila River and eight piezometers from semimonthly measurements, July 1999 through January 2001.

were examined. Box-and-whisker plots depicting piezometer distance from the active channel and variances between measured groundwater and Gila River surface elevations were constructed and are shown in figure 3. Each box-and-whisker set represents data from one piezometer, and its length indicates the amount of variability between changes in river surface and groundwater elevation at that location. Greater length therefore represents lessened or slower groundwater response to changing river stage. The 25th- and 75th-percentile measured variations are outlined by each box, and the whiskers show 10th and 90th percentiles. Squares above and below each box are 5th- and 95th-percentile variation.

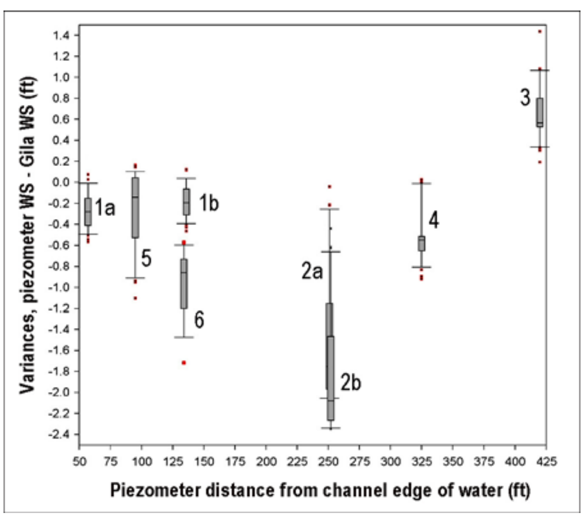

Fig. 3. Box-and-whisker plots of variance between measured piezometer water elevations and Gila River surface elevation by piezometer distance from river edge of water, for the period July 1999 through January 2001.

The plots show that variance between changing river stage and groundwater elevation is little related to distance from active flow. For example, variance was highest in P2a and P2b, located about 250 feet from the active channel edge, and much less in P4, about 325 feet from the river. P4 is located beside an overflow channel that traverses a wide cobble floodplain to intersect the active channel. P2a and P2b are in deep sand in an abandoned river channel parallel to active flow. The aerial photos show this as the active channel in 1974. Variance is also relatively high in P5 and P6, both placed closer to the river than any other piezometer except P1a. P5 is situated on a high sand terrace near the diversion split. The terrace was farmed until sometime between 1965 and 1974, and an irrigation ditch between the field and the hills to the east was evident until at least 1965. The ditch diversion point was about ½ mile upstream. Subsurface flow traveling downstream along the abandoned ditch would follow a much straighter, and therefore shorter, course than the river itself, while substrate permeability would largely determine the velocity of flow. P6, across the river, is situated in what was in 1965 the active river bed. Active flow meanders sharply toward the old channel before turning back to the east.

P3 is farthest from the active channel. Groundwater in the piezometer was consistently elevated above the river surface, and showed among the least variation from surface water elevation. It was placed in a sand terrace 20 feet east of an overflow channel that was once the upstream end of the ditch near P5. At least a few inches of water were present in this channel during every site visit, and it supports a luxuriant growth of reed, forbs, and young cottonwood. The piezometer site is very close to the old diversion point, and this is probably reflected in the lack of variance between changing river stage and groundwater elevation within the piezometer. Water entering the abandoned ditch flows about the same distance downstream to P3 as it does to the river staff gage where measurements were taken. If seepage from the river does enter the floodplain perpendicular to active flow at the staff gage, its effects on groundwater elevation at P3 would be quite muted by comparison.

Cross-Section Survey Interpretation

During low flow periods, the river typically occupies a single channel through the Cliff–Gila Valley. But swales and depressions marking the courses of abandoned or overflow channels create an extensive mosaic across its floodplain. The aerial photographs clearly show the development of this complex pattern of bars, backwaters, and overflow channels, and they also appear on the cross-section surveys. Figure 4 shows the active and overflow channels in Subreach 1 that were digitized from the air photos taken in 1935, 1980, and 1996. The channel planforms during intervening years are excluded for clarity, but the air photos show that the river occupies a single channel only in the 1965 photos, when levee construction was complete but high-intensity flooding was yet to follow.

At cross sections throughout the study reach (fig. 1), the active channel thalweg is typically incised below and shifted laterally from its historic channels. The general pattern is of lowering in the channel elevation over time. Surface deposits in the abandoned channels are often composed of sand and fine gravels; coarser materials form the active channel. Some of the fine-grained surface sediments found in the abandoned channels and on their banks would have been deposited by floods that occurred between 1980 and 1996, particularly where dense vegetation was present.

The cross sections included in Subreach 1 (XS 2 through XS 4) are representative of changes in channel morphology and planform throughout the study area. The lower end of this reach, immediately downstream of the Upper Gila and Fort West diversion points, is among those most affected by baseflow reduction. Conversely, other variables that could strongly influence channel condition are little present in this reach. Cattle grazing in riparian areas is nearly nonexistent and no roads cross the channel; although bulldozers were occasionally used to maintain irrigation berms, their impact was much less than that observed at locations downstream. Cross sections 3 and 4 are within the reach that was channelized between 1950 and 1984; cross section 2 is above it.

Topography mapped at XS 2 and XS 4 is shown in figure 5 (XS 3 is excluded for space considerations). The cross sections are viewed facing downstream. Dates when the active channel occupied currently abandoned channels, digitized from the georeferenced air photos, are identified on the drawings. Other data superimposed on the cross-section plots include the elevations of flood debris and cottonwood seedlings found after the August 1999 flood, calculated water surface elevations for the estimated flood discharge of 2800 cfs, descriptions of surficial sediments, and locations of existing riparian vegetation.

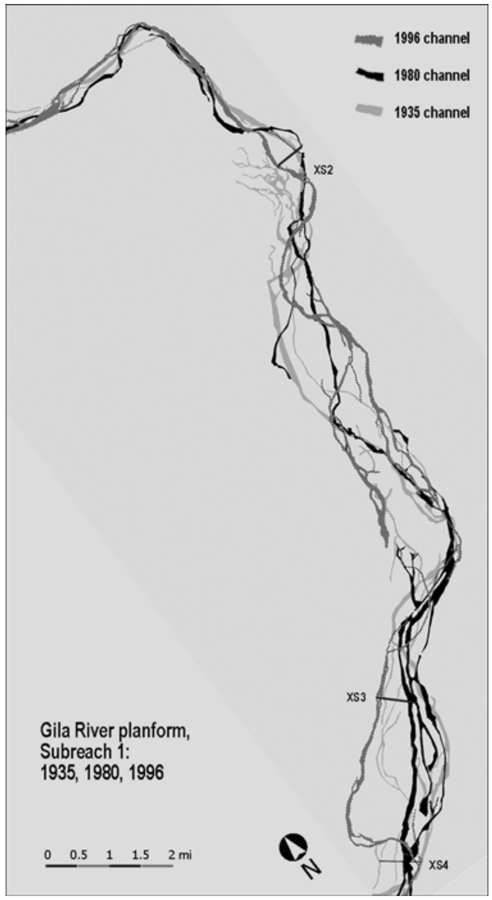

Fig. 4. Gila River planform in the Cliff–Gila Valley, mapped from aerial photography taken in 1935, 1980, and 1996. The area shown, Subreach 1, is delineated in figure 1.

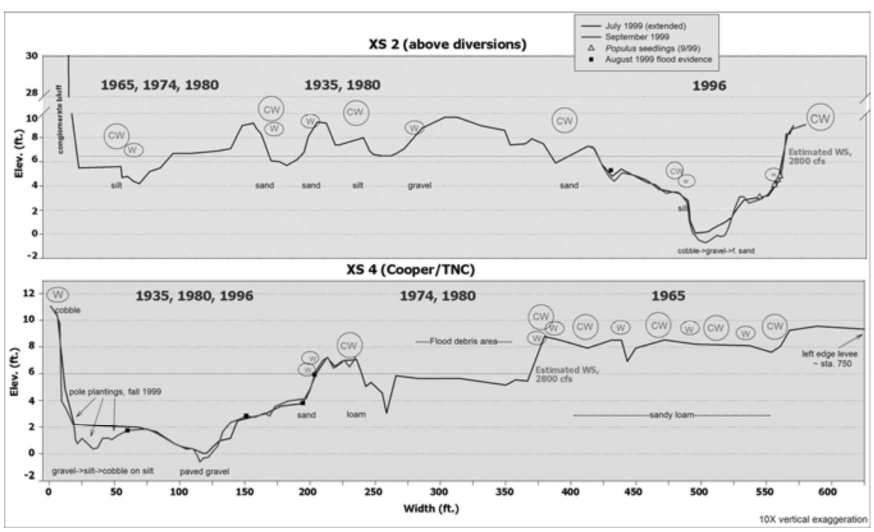

Fig. 5. Channel and floodplain morphology at XS 2 and XS 4, surveyed in 1999. Other features mapped are surface sediments, riparian vegetation, and dates when the active river channel occupied currently abandoned channel features. CW = cottonwood stand; W = willow stand. Size of oval indicates the relative size of trees in each stand. WS = water surface.

At XS 2, the Gila River channel in 1965 was located on the far left floodplain, against the base of a Gila conglomerate cliff. In 1978, one of the largest floods on record left the river braided at this location. The 1980 photos show it occupying both the 1965 and historic 1935 channel. The densest vegetation on the cross section, composed of midsized willows and cottonwoods, now grows around these old channels. By 1996, the river had shifted laterally far right to its current position, where the thalweg is five to six feet below the historic channels. No levee construction has taken place around XS 2, but high bars throughout the reach are unvegetated and composed of coarse gravel and cobble. When the study began, a dense, narrow band of small cottonwood and sycamore trees lined the left bank; only clover grew on a low cobble bar on the right side of the channel. Thick stands of cottonwood, willow, and baccharis were present along overflow channels throughout the area.

Repeated efforts to channelize the river near XS 3 (graph omitted) were made between about 1950 and 1980. By 1984, the river had permanently breached the levee constructed on its right bank. Gravel and cobble are now exposed along the active channel banks and the channel thalweg is about five feet lower than its 1974–1980 counterpart. Little vegetation grows along the channel, except for willow poles planted by the landowner. A conspicuous network of abandoned channels, which probably marks borrow areas for levee construction as well as the river's historically braided channel in this reach, occupies the broad floodplain left of the current active channel. A thick gallery of cottonwood and willow, growing in deep sand, lines the far left side of the floodplain 600 to 800 feet from the river.

Lateral and downward channel migration at XS 4 (fig. 5) has placed the active channel about 500 feet left of its 1965 location and about 8 feet lower. Loamy sand covers the area and a dense gallery of 50-foot cottonwoods grows there. The 1974 channel, now buried in heavy flood debris, is shifted left and down about two feet. In 1980 the river occupied both this channel and the current channel before cutting farther left during later floods. The active channel displaced a levee constructed along the left floodplain, leaving a near-vertical cutbank of unconsolidated silt and sand as the river's left bank. Both active channel banks were barren of vegetation when the study began. Willow and baccharis grew on a sandy terrace 100 feet right of the river.

Flood evidence. The Gila gaging station recorded a small flood of about 2800 cfs in August 1999. This discharge has a calculated recurrence interval of about two years. In September 1999, flood effects were documented in the field and analyzed via WinXSPro (1998). Comparative survey data from before and after the August 1999 flood were analyzed for changes in channel morphology and bed material. The elevations of flood debris and of riparian tree seedlings, ranging in height from three inches to about one foot, were mapped (fig. 5). Flood debris evidence was used in refining stage–discharge curves with WinXSPro (USDA Forest Service 1998) constructed for the three cross sections in Subreach 1. For instance, at XS 2 the highest flood debris was found in the thick stands of young cottonwood and sycamore crowding the left bank. The trees retained flood debris nearly 2 feet above the ground, but were not otherwise disturbed. They apparently resisted "flood training," or being laid down by high flows, due to both their density and trunk diameter. Therefore, the flood debris found in these and similar stands of trees was a good marker for flood stage.

At XS 2, nearest the gaging station, WinXSPro calculated discharge of only 1300 cfs for the stage height at which the highest flood debris was found. However, what had been a shallow second channel on river left, just upstream of XS 2, appeared both considerably deeper and steeper in September than on previous visits. Dense nonwoody vegetation growing to a height of more than 5 feet on the bar left of this channel had been completely flattened, indicating that it was inundated during the flood. This channel had captured some portion of the floodwaters, diverting it from the main channel before it reached XS 2. *Populus* seedlings were found at XS 2 shoreward of a small bar on the right side of the active channel; no seedlings had been evident during a site visit in July 1999. Similar patterns were noted at cross sections farther downstream.

WinXSPro also calculated stage heights greater than flood evidence found along the active channel at XS 3. Evidence of flow was found in an abandoned channel left of the cross section. Some portion of flow was also diverted into the Fort West ditch and its overflow ditch upstream of XS 3 and XS 4. However, the overflow ditch returns water to the main river channel just upstream of XS 4. At the cross section, floodwaters were confined within the active channel because of the river's planform between XS 3 and XS 4. The abrupt turn it makes below XS 3 (fig. 4) was one of the more pronounced changes in planform that followed the large floods of the 1980s–1990s. It put the river on a path parallel with XS 4 until its sharp turn to the south just upstream of the cross section. This flow pattern and a vertical right bank in this reach prohibited this relatively small flood from overtopping floodplains and overflow channels at XS 4. The flood debris elevations mapped at XS 4 matched the 2800-cfs stage height calculated by WinXSPro.

In October 2000, a smaller flood occurred in the Cliff–Gila Valley. The Gila gagesite recorded flow as about 1100 cfs. Abandoned channels through the study reach were again overtopped, and lightweight flood debris was deposited among the nonwoody vegetation growing in them (personal observation, October 2000).

DISCUSSION

Hyporheic flow zones, where surface waters and shallow groundwaters mix, are vital components of alluvial systems like that in the Cliff–Gila Valley. Hyporheic flow occurs at varying spatial and temporal scales. For example, at the small streambed scale, water enters the streambed (i.e., the alluvial aquifer) at the downstream end of pools and moves through the streambed sediments to re-emerge at a downstream riffle (Vaux 1968; White, Elzinga, and Hendricks 1987). At larger scales, complex geomorphic features like those in the Gila River system—mid-channel bars, backwater zones, and the floodplain network of abandoned and overflow channels—interact strongly with hyporheic flows (Stanford, Ward, and Ellis 1994). Water often enters the alluvial aquifer at the upstream end of bar or floodplain features, and flows laterally through the alluvium before remixing with surface water at the lower end (Stanford and Ward 1993). However, sediment composition and permeability, including substrate in abandoned or buried channel forms, significantly affects the rate and direction of groundwater movement (Poole and Berman 2001; Whiting 1998). Shallow groundwater movement through preferential flow pathways within buried channels may reemerge in backwaters and side channels (Stanford and Ward 1992). At these scales, valley morphology and sediment characteristics are the primary drivers of hyporheic flow direction and speed.

The combined effects of flooding and channelization works in the Cliff–Gila Valley transformed the river's planform between 1935 and 1996. Air photos from the first date show a complex system of multiple channels through the valley. Such channel braiding in alluvial valleys like those in the Gila River system can represent one of many geomorphic phases for the river as it adjusts to varying levels of precipitation, runoff, and tributary or main-stem sediment inputs (Ashmore 1991; Carson 1984; Ferguson 1993; Fujita 1989). Watershed-scale impacts resulting in loss of native ground cover—e.g., drought or intensive grazing—may also contribute. Whatever the cause for the river's complex system of multiple channels in 1935, by 1965 levees constructed through the center of the valley bottom constrained the river in a single channel. The near-continuous lines of levees were designed to constrain discharge of up to ~10,000 cfs, virtually eliminating the possibility that moderate floods would access the wider valley floodplain. However, in 1978, a flood of >35,000 cfs damaged or destroyed most of the levees. Many were rebuilt the following year and were again heavily damaged by floods in 1983–1984. (No significant repairs were made after these events.)

By 1980, riparian vegetation had been removed by mechanical means or scoured during floods, leaving broad expanses of the valley floor barren. The remaining riparian trees were generally found on irrigation ditches or were large, old cottonwoods on high terraces near the extreme edge of the floodplain. The 1980 air photos showed that the loss of vegetative cover again revealed the floodplain network of active and overflow channels, including the combined effects of flooding and levee construction.

Even twenty years later, in 1999, riparian regeneration along the active channel margin downstream of the diversions was extremely spotty. These banks remained generally devoid of native riparian species. This was the case even where other effects like cattle grazing were absent. Above the diversions, however, stands of young cottonwood, sycamore, and willow had appeared along many of the river's active channel banks. The contrast suggested that water availability in the active channel exercised control over seedling survival, implicating the irrigation diversions in reduced recruitment of such species.

Seed dispersal by native southwestern riparian species, including cottonwood, occurs during the spring months (Patten 1998). Cottonwood seeds are viable for only one to eight weeks. Seedling roots may grow up to 6 mm per day (Fenner, Brady, and Patton 1984), and Mahoney and Rood (1991) observed the highest rates of root growth when the water table declined by less than two inches (4 cm) per day. Seedling establishment and survival, therefore, is typically dependent on periods of moderately high streamflow during the spring months, and relatively slow recession of groundwater levels to allow roots to maintain connectivity with the water table (Fenner, Brady, and Patton 1985; Glinsky 1977; Kondolf et al. 1987; Siegel and Brock 1990; Smith et al. 1998).

Piezometer data collected for the study showed that during low flow periods, the river generally loses water to the shallow floodplain aquifer rather than the reverse. Therefore, decreasing the river's base flow and its wetted bank perimeter can result in lower alluvial water tables. The low-flow IHA analyses confirmed that significant impacts to the river's base flow regime are imposed by the diversions during the months of April–October. Comparison of diverted and undiverted flow conditions between 1969 and 2001 showed that diverted flow reached the "targeted" 30-day minimum discharge (the 25th percentile of full baseflow) during only two years—1991 and 1993. Extended periods of moderate runoff during those two years kept even diverted streamflow levels within the target range. Therefore, it was during those years that any riparian seedlings established during spring seed dispersal were most likely to have survived.

Comparative analysis of the 1980 and 1996 air photos showed that riparian regeneration was occurring at some locations downstream of the diversions. Field observations in March and September 2000 located stringers of young cottonwood (ca. 30 feet tall, diameters of 4–6 inches) below XS 4. These trees were growing in or next to overflow channels up to 300 feet from the active channel. The surfaces are elevated six to eight feet above the active channel thalweg. However, where these channels diverge from the active channel upstream, they are typically only slightly elevated above the active channel. As the evidence from the August 1999 flood also showed, many are easily overtopped during even small floods. A June 1987 color infrared (CIR) air photo shows a thoroughly scoured floodplain in this reach, with a nearly complete absence of woody vegetation. (CIR photography is particularly suited to revealing areas of high moisture, like the leaves of riparian vegetation.) In a somewhat informal exercise, 12 cottonwood trees growing near four overflow channels downstream of XS 4 were cored. The cores were sanded and mounted in order to make counts of the annual growth rings. Distinguishing cottonwood growth rings is often difficult, and the counts varied from 6 to 10 years. The mean was 7.4 years. The combined evidence from the IHA analysis, CIR photo, and tree rings strongly suggests that these trees were established in 1991 or 1993.

The effects of channelization work and lateral channel movement during the 1978 and 1984 floods left many stretches of the river incised through vertical cutbanks in the valley. Vertical banks can decrease seedling survival by reducing the chances for seeds to lodge in a place "protected from removal by subsequent disturbance" (Scott, Friedman, and Auble 1996, 328). It is likely that at the same time that the young cottonwoods found in overflow sites downstream of the diversions began growing, other seedlings took root along the active channel. Major floods (> 14,000 cfs) occurred in 1993, 1994, and 1997. Seedlings on the active channel would have been highly exposed to scouring during these floods. Because floodwater velocities are reduced in the overflow channels, seedlings there are protected from such effects. Abandoned channels have therefore been identified as ideal "nursery sites" for riparian reestablishment by other authors (e.g., Asplund and Gooch 1988; Braatne, Rood, and Heilman 1996; Brady, Patton, and Paxson 1985).

Stromberg (1993) and others (e.g., Shafroth, Stromberg, and Patten 2000) note the additional importance of substrate availability on riparian regeneration: establishment in fine-grained sediments like sand or silt greatly enhances the possibility of survival. As a very general rule in the valley, floodplain and low terrace elevation above the Gila River channel is strongly related to substrate grain size. Throughout the valley, elevated terraces and cutbanks adjacent to the low floodplain are generally composed of sand, sandy loam, and silt. The most active bar and floodplain surfaces usually contain a high percentage of coarse gravel and cobble. At the overflow channel regeneration sites downstream of XS 4 described earlier, all young trees were found growing in sandy loam. At the surveyed cross sections, fine-grained substrate was also most likely to be found in and around the abandoned channel features (fig. 5), because the reduced water velocities in these channels allow finer sediments transported in floodwaters to drop from suspension. Deposition of these finer-grained materials is part of an important feedback mechanism that enhances not only seedling establishment potential, but longer-term survival rates. Soil or substrate texture strongly determines the capillary fringe extent, i.e., the height to which moisture from the water table rises to become available to the shallow roots of woody and herbaceous species (Smith et al. 1998). Mahoney and Rood (1992) found drought stress response in hybrid *Populus* strongly associated with substrate texture: increasing coarseness resulted in greater declines in several plant health indicators. Since the regional climatic regime generally provides little direct precipitation during the months of April through June, the capillary action of soil moisture drawn upward from alluvial storage is important for plant survival, vigor, and mortality rates (Shafroth, Stromberg, and Patten 2000).

The patterns of riparian vegetation recovery below the diversion points for the Upper Gila and Fort West ditches reflect the importance of interactions among floodplain and channel morphology, substrate permeability, and the alluvial recharge effects of small and moderate floods. The significance of flooding to riparian recruitment and vigor in these systems is well recognized (e.g., Leenhouts, Stromberg, and Scott 2006; Newman, Vivoni, and Groffman 2006). Often, however, flood effects are considered in terms of "overbank" flooding —when water overtops banks along the active channel to spread out on the floodplain. Floodplain groundwater recharge in the Cliff–Gila Valley, particularly from small to moderate flood events, occurs under somewhat different circumstances. Through much of the valley, channel incision and lateral cutting along the main channel preclude overbanking during these events. Rather, floodwaters often enter overflow channels diverging from the main channel. Many of these are easily overtopped by even small floods. Water moving down each channel locally recharges the channel bottom and surrounding floodplain soils. With sufficient discharge and duration, groundwater recharge can occur across broad areas of the floodplain through the extensive network created by these channels. Because, over time, moderate floods are those most likely to occur with the greatest frequency, their contribution to alluvial groundwater recharge and riparian vigor is correspondingly vital.

Acknowledgments

It is impossible to list here everyone who helped make completion of the work possible, but I remain grateful to them all. The original study benefited greatly from the input of my advisors at NAU, Drs. Lenn Berlin, Lee Dexter, and Tina Kennedy. Special thanks to Jeanmarie Haney for her careful review of this paper, and to The Nature Conservancy of New Mexico for financial support.

References

Interviews

Birch, JoDee and Robby. Gila, NM, April 10, 2000.
Clark, Robert. Deming, NM, February 11, 2001; by phone, February 26, 2001.
Cooper, Tom. Gila, NM, April 12, 2000; February 11, 2001.
Hooker, Donald. Gila, NM, February 9, 2001.
Hunt, Duston. Gila, NM, February 10, 2001.
Jackson, George. Gila, NM, April 10, 2000; February 10, 2001.
Kartchner, Lois Ann. Gila, NM, April 1, 2000.
Munoz, Eugene. Riverside, NM, April 11, 2000.
Norris, Dave. Gila, NM, February 11, 2001.
Ogilvie, Dave. By phone, July 1999; Silver City, NM, February 11, 2001.
Polanco, Julio and Lorenza. Gila, NM, February 10, 2001.
Stailey, Linda. By phone, March 18, 2000; Gila, NM, April 5, 2000.
Woodrow, Jerry and Otho. Gila, NM, April 10, 2000.

Cited Works

Amlin, N. M., and S. B. Rood. 2002. Comparative tolerances of riparian willows and cottonwoods to water-table decline. *Wetlands* 22:338–46.

Apple, L. L. 1985. Riparian habitat restoration and beavers. In *Riparian ecosystems and their management: Reconciling conflicting uses.* USDA Forest Service General Tech. Report RM-120. Fort Collins, CO: Rocky Mountain Forest and Range Experiment Station.

Arcement, G. J. Jr., and V. R. Schneider. 1984. FHWA-TS-84-204. McLean, VA: Federal Highway Administration.

Ashmore, P. E. 1991. How do gravel-bed rivers braid? *Canadian Journal of Earth Sciences* 28:326–41.

Asplund, K. A., and M. T. Gooch. 1988. Geomorphology and the distributional ecology of Fremont cottonwood (*Populus fremontii*) in a desert riparian canyon. *Desert Plants* 9:17–27.

Auble, G. T., J. M. Friedman, and M. L. Scott. 1994. Relating riparian vegetation to present and future streamflows. *Ecological Applications* 4:544–54.

Baker, V. R. 1988. Flood erosion. In *Flood Geomorphology*, ed. V. R. Baker, R. C. Kochel, and P. C. Patton, 81–95. New York: Wiley & Sons.

Beven, K. J. 1981. The effect of ordering on the geomorphic effectiveness of hydrological events. International Association of Scientific Hydrology Publication 132, 510–26.
Black, R. F. 1927. Gila River investigation: Report on the possibilities of irrigation and electrical power development in Grant County, New Mexico. Unpublished report for the State Engineer, New Mexico.
Bourke, M. C., and G. Pickup. 1999. Fluvial form variability in arid central Australia. In *Varieties of fluvial form,* ed. A.J. Miller and A. Gupta, 249–71. Chichester, UK: John Wiley & Sons.
Braatne, J. H., S. B. Rood, and P. E. Heilman. 1996. Life history, ecology, and conservation of riparian cottonwoods in North America. In *Biology of Populus and its implications for management and conservation,* ed. R. F. Stettler, H. D. Bradshaw Jr., P. E. Heilman, and T. M. Hinckley, 57–85. Ottawa: NRC Research Press.
Brady, W., D. R. Patton, and J. Paxson. 1985. *The development of southwestern riparian gallery forests.* USDA Forest Service General Tech. Rep. RM-120. Fort Collins, CO: Rocky Mountain Forest and Range Experiment Station.
Bren, L. J. 1993. Riparian zone, stream and floodplain issues: A review. *Journal of Hydrology* 150:277–99.
Buchanan, T. J., and W. P. Somers. 1969. *Discharge measurements at gaging stations*. Book 3, chapter A8 in *Techniques of Water-Resources Investigations of the United States Geological Survey.* Washington, DC: U.S. Government Printing Office.
Bull, W. B. 1988. Floods: Degradation and aggradation. In *Flood geomorphology*, ed. R. Baker, R. C. Kochel, and P. C. Patton, 157–65. New York: Wiley & Sons.
Calvin, R. 1946. *River of the sun: Stories of the storied Gila.* Albuquerque: University of New Mexico Press.
Carson, M. A. 1984. The meandering–braided river threshold: A reappraisal. *Journal of Hydrology* 73:315–34.
Clark, I. G. 1987. *Water in New Mexico: A history of its management and use*. Albuquerque: University of New Mexico Press.
Clemons, R. E., P. W. Christiansen, and H. L. James. 1980. *Scenic trips to the geologic past no. 10: Southwestern New Mexico.* Socorro, NM: New Mexico Bureau of Mines & Mineral Resources.
Cowan, W. L. 1956. Estimating hydraulic roughness coefficients. *Agricultural Engineering* 37:473–75.
Emory, W. H. 1848. *Notes of a military reconnaissance*. Ed. R. Calvin. Albuquerque: University of New Mexico Press.
ERDAS, Inc. 2001. *Imagine* [v. 8.5; GIS software.] Atlanta, GA.
Fenner, P., W. W. Brady, and D. R. Patton. 1984. Observations on seeds and seedlings of Fremont cottonwood. *Desert Plants* 6:55–58.
———. 1985. Effects of regulated water flows on regeneration of Fremont cottonwood. *Journal of Range Management* 38:135–38.
Ferguson, R. I. 1993. Understanding braiding processes in gravel-bed rivers: Progress and unsolved problems. In *Braided Rivers,* ed. J. L. Best and C. S. Bristow, 73–87. London: The Geological Society.
Fradkin, P. L. 1968. *A river no more: The Colorado River and the West.* Tucson, AZ: University of Arizona Press.
Fujita, Y. 1989. Bar and channel formation in braided streams. In *River Meandering,* ed. S. Ikeda and G. Parker, 417–62. Washington, DC: American Geophysical Union.
Glinsky, R. L. 1977. Regeneration and distribution of sycamore and cottonwood trees along Sonoita Creek, Santa Cruz County, Arizona, 116–23.
Graf, W. L. 1988. Definition of flood plains along arid-region rivers. In *Flood Geomorphology,* ed. V. R. Baker, R. C. Kochel, and P. C. Patton, 231–42). New York: Wiley & Sons.
Hawkins, D. B., and D. B. Stephens. 1983. Ground-water modeling in a southwestern alluvial basin. *Ground Water* 21:733–40.
IHA. *See* Smythe Scientific Software and The Nature Conservancy.
Jolly, I. D. 1996. The effects of river management on the hydrology and hydroecology of arid and semi-arid floodplains. In *Floodplain processes,* ed. M. G. Anderson, D. Walling, and P. Bates, 577–610. Chichester, UK: John Wiley & Sons.
Kennedy, B. A. 1999. Flow and sedimentation at tributary river mouths: A comparison with mesotidal estuaries. In *Varieties of fluvial form,* ed. A.J. Miller & A. Gupta, 411–26. Chichester, UK: John Wiley & Sons.
Kochel, R. C. 1988. Geomorphic impact of large floods: Review and new perspectives on magnitude and frequency. In *Flood Geomorphology,* ed. V. R. Baker, R. C. Kochel, and P. C. Patton, 169–87. New York: Wiley & Sons.
Kondolf, G. M., J. W. Webb, M. J. Sale, and T. Felando. 1987. Basic hydrologic studies for assessing impacts of flow diversions on riparian vegetation: Examples from streams of the eastern Sierra Nevada, California, USA. *Environmental Management* 11:757–69.

Lamb, B. L., and E. Lord. 1992. Legal mechanisms for protecting riparian resource values. *Water Resources Research* 28:965–77.
Leenhouts, J.M., J.C. Stromberg, and R.L. Scott, eds. 2006. *Hydrologic requirements of and consumptive ground-water use by riparian vegetation along the San Pedro River, Arizona.* US Geological Survey Scientific Investigations Report 2005–5163.
Lewin, J. 1996. Floodplain construction and erosion. In *River flows and channel forms,* ed. G. Petts and P. Calow, 203–20. Oxford, UK: Blackwell Science, Ltd.
Maddock, I. P., G. E. Petts, E. C. Evans, and M. T. Greenwood. 1995. Assessing river–aquifer interactions within the hyporheic zone. In *Geomorphology and groundwater,* ed. A.G. Brown, 53–74. Chichester, UK: John Wiley & Sons.
Mahoney, J. M., and S. B. Rood. 1991. A device for studying the influence of declining water table on poplar growth and survival. *Tree Physiology* 8:305–14.
Mahoney, J. M., and S. B. Rood. 1992. Response of a hybrid poplar to water table decline in different substrates. *Forest Ecology and Management* 54:141–56.
Mogollon mines. 1916. Vol. 7 in *The New Bridge Over the Gila River*. Mogollon, NM.
New Mexico Office of the State Engineer/Interstate Stream Commission. 2006. *Briefing on upper Gila River settlement decision process—July 2006.* http://www.ose.state.nm.us/isc_colorado_gila_sanfran_committee_info.html (accessed October 4, 2006).
Newman, B. D., E. R. Vivoni, and A. R. Groffman. 2006. Surface water–groundwater interactions in semiarid drainages of the American southwest. *Hydrological Processes* 20:3371–94.
Nilssen, C., and K. Berggen. 2000. Alterations of riparian ecosystems caused by river regulation. *Bioscience* 50:783–92.
Patten, D. T. 1998. Riparian ecosystems of semi-arid North America: Diversity and human impacts. *Wetlands* 18:498–512.
Poff, N. L., J. D. Allan, M. B. Bain, J. R. Karr, K. L. Prestegaard, B. D. Richter, R. E. Sparks, and J. C. Stromberg. 1997. The natural flow regime: A paradigm for river conservation and restoration. *BioScience* 47:769–84.
Poole, G. C., and C. H. Berman. 2001. An ecological perspective on in-stream temperature: Natural heat dynamics and mechanisms of human–caused thermal degradation. *Environmental Management* 27:787–802.
Reisner, M. 1986. *Cadillac Desert.* New York: Penguin Books.
Richter, B. D. January 1999. Characterizing hydrologic regimes in ecologically meaningful terms. In *Stream Notes.* Fort Collins, CO: Stream Systems Technology Center, Rocky Mountain Research Station.
Richter, B. D., J. V. Baumgartner, R. Wigington, and D. P. Braun. 1997. How much water does a river need? *Freshwater Biology* 37:231–49.
Richter, B. D., and H. E. Richter. 2000. Prescribing flood regimes to sustain riparian ecosystems along meandering rivers. *Conservation Biology* 14:1467–78.
Rosenberg, D.M., P. McCully, and C. M. Pringle. 2000. Global-scale environmental effects of hydrological alterations—Introduction. *BioScience* 50:746–51.
Scott, M. L., J. M. Friedman, and G. T. Auble. 1996. Fluvial processes and the establishment of bottomland trees. *Geomorphology* 14:327–39.
Shafroth, P. B., J. C. Stromberg, and D. T. Patten. 2000. Woody riparian vegetation response to different alluvial water table regimes. *Western North American Naturalist* 60:66–76.
Siegel, R. S., and J. H. Brock. 1990. Germination requirements of key southwestern woody riparian species. *Desert Plants* 10:3–33.
Simon, A., and S. Darby. 1999. The nature and significance of incised river channels. In *Incised river channels: Processes, forms, engineering and management,* ed. S. E. Darby & A. Simon, 3–18. Chichester, UK: John Wiley & Sons.
Smith, S. D., D. A. Devitt, A. Sala, J. R. Cleverly, and D. E. Busch. 1998. Water relations of riparian plants from warm desert regions. *Wetlands* 18:687–96.
Smythe Scientific Software and The Nature Conservancy. 2001. *Indicators of Hydrologic Alteration*. (IHA v. 5.0.0; statistical software).
Soles, E. S. 2003. *Where the river meets the ditch: Human and natural impacts on the Gila River, New Mexico, 1880–2000.* Master's thesis, Northern Arizona University, 2003.

Stanford, J. A., and J. V. Ward. 1992. Management of aquatic resources in large catchments: recognizing interactions between ecosystem connectivity and environmental disturbance. In *Watershed management: Balancing sustainability and environmental change,* ed. R. J. Naiman, 91–124. New York: Springer-Verlag.

———. 1993. An ecosystem perspective of alluvial rivers: Connectivity and the hyporheic corridor. *Journal of the North American Benthological Society* 12:48–60.

Stanford, J. A., J. V. Ward, and B.K. Ellis. 1994. Ecology of the alluvial aquifers of the Flathead River, Montana. In *Groundwater ecology,* ed. J. Gibert, D. L. Danielopol, and J. A. Stanford, 367–90. San Diego: Academic Press.

Stromberg, J. C. 1993. Instream flow models for mixed deciduous riparian vegetation within a semiarid region. *Regulated Rivers: Research & Management* 8:225–35.

Stromberg, J. C., and D. T. Patten. 1990. Riparian vegetation instream flow requirements: A case study from a diverted stream in the eastern Sierra Nevada, California, USA. *Environmental Management* 14:185–94.

Stromberg, J.C., R. Tiller, and B. Richter. 1996. Effects of groundwater decline on riparian vegetation of semi-arid regions—The San Pedro River, Arizona. *Ecological Applications* 6:113–31.

Tellman, B., R. Yarde, and M. G. Wallace. 1997. *Arizona's changing rivers: How people have affected the rivers.* Tucson, AZ: University of Arizona Water Resources Research Center.

Tharme, R.E. 2003. A global perspective on environmental flow assessment—Emerging trends in the development and application of environmental flow methodologies for rivers. *River Research and Applications* 19:397–441.

The Nature Conservancy. 1996. *Hydrologic monitoring manual* (version 4.0). Arlington, VA: The Nature Conservancy.

Trauger, F. D. 1972. *Water resources and general geology of Grant County, New Mexico*. (Hydrologic Report 2). Albuquerque: University of New Mexico Press.

USDA Forest Service. [1968?] *Multiple use impact survey report, Hooker dam and reservoir project, Gila National Forest.* Unpublished report.

USDA Forest Service. 1998. *WinXSPRO* (v. 2.0; hydraulic analysis software). Fort Collins, CO: USDA Forest Service.

USDA Soil Conservation Service. 1954. *Program for runoff and waterflow retardation and soil erosion prevention.* Unpublished report; revised June 1954.

USDI Bureau of Reclamation. 1930. *Report on upper Gila River investigations of 1929–1930, in pursuance of act of Congress approved May 25, 1928.* Unpublished report. Denver, CO.

U.S. Geological Survey. 1923. *The lower Gila region, Arizona.* U.S. Geological Survey Water-Supply Paper 498. Washington, DC: U.S. Government Printing Office.

U.S. Geological Survey. 1999. *Canteen Canyon, New Mexico 7.5'.* (1:24,000 scale digital orthophotoquad from 1996 aerial photography.)

U.S. Geological Survey. 1999. *Cliff, New Mexico 7.5'.* (1:24,000 scale digital orthophotoquad from 1996 aerial photography.)

U.S. Geological Survey. 2003. *Surface water data for New Mexico.* http://waterdata.usgs.gov/nm/nwis/sw (accessed November 2, 2002).

Vaux, W. G. 1968. Intragravel flow and interchange of water in a streambed. *Fishery Bulletin* 66:479–89.

Western Regional Climate Center. 2003. http://www.wrcc.dri.edu/cgi-bin (accessed March 21, 2003).

White, D. S., C. H. Elzinga, and S. P. Hendricks. 1987. Temperature patterns within the hyporheic zone of a northern Michigan river. *Journal of the North American Benthological Society* 6:85–91.

Whiting, P. J. July 1998. Bank storage and its influence on streamflow. In *Stream Notes.* Fort Collins, CO: Stream Systems Technology Center, Rocky Mountain Research Station.

Wilson, B. C., and A. A. Lucero. 1998. *Irrigated agriculture water use and acreage in New Mexico counties and river basins, 1993–1995*. Technical Report 50. Santa Fe, NM: New Mexico Office of the State Engineer.

Abstracts

Effects of Pulse Events at Different Spatial Scales on Arid Land and Alpine Stream and River Ecosystems

V. Acuña,[1,2] C.N. Dahm,[1] K. Tockner,[2] P. Reichert,[2] and U. Uehlinger[2]
[1]Department of Biology, University of New Mexico, vicenc@sevilleta.unm.edu
[2]Swiss Federal Institute of Aquatic Science and Technology, Switzerland

The primary objective of this project is to investigate the effect of spatial and temporal scales on ecosystem stability to pulsed flow events. Stream metabolism (primarily gross primary production and ecosystem respiration) is used to evaluate ecosystem stability. Despite several disturbance studies in streams, information is still lacking concerning how floods affect entire river systems. The spatial scale effect is assessed at two climatically contrasting systems, the Upper Gila catchment (NM and the Thur catchment (Switzerland) in order to attain more robust conclusions. Extended goals and preliminary results from the Upper Gila are presented in this session.

Historical Overview of Gila Trout Conservation

James E. Brooks[1] and David L. Propst[2]
[1]U.S. Fish and Wildlife Service—New Mexico Fisheries Resource Office, 3800 Commons Ave. NE, Albuquerque, NM 87109, jim_brooks@fws.gov
[2]New Mexico Department of Game and Fish, Conservation Services Division, Santa Fe, NM 87504, dpropst@state.nm.us

Gila trout *Oncorhynchus gilae* conservation in southwestern NM began in the early 1920s with captive propagation, limited stockings, and placement of stream habitat improvement structures in the 1930s. Beginning in 1970, artificial barrier construction, use of piscicide to remove non-native trout species, discontinuation of non-native salmonid stockings in Gila Wilderness waters, and transplantations of wild Gila trout were primary conservation actions for Gila trout. The initial recovery plan for Gila trout was produced in 1979 and subsequently revised in 1984, 1993 and 2003. Gila trout were originally listed as "endangered" with implementation of the Endangered Species Act in 1973. Primary factors addressed in current recovery strategies center on protection and replication of relictual populations. Gila trout were downlisted from endangered to threatened species status in July 2006, including a special rule to allow limited take by angling. Continuing primary threats to conservation of this species are non-native salmonids and post-wildfire impacts to stream habitats.

Natural Watershed Restoration

Van Clothier
Watershed Restoration, Box 2721, Silver City, NM 88062, (505) 388-5296, streamdynamics@aznex.net

Induced Meandering uses the power of floodwaters to heal degraded stream channels with their own energy and sediment. Before and after photos of watercourses will show dynamic changes during the healing process. The natural processes that govern stream channel stability will be demonstrated, showing examples of projects that have failed or succeeded based on the design's ability to transport sediment without aggrading or degrading the channel. The crucial role of native riparian vegetation in stabilizing streambanks and floodplains to modulate floods and droughts by optimizing groundwater recharge and stream base flow conditions cannot be underestimated.

Mimbres Zoology: Animals, Composite Creatures, and Human–Animal Transformations

Leslie Cohen
Museum of Indian Arts and Culture/Laboratory of Anthropology, Santa Fe, NM, (505) 476-1261

Since at least Darwin, the sciences we practice have not been associated with religious beliefs. However, prehistoric people viewed things differently; their material and spiritual worlds were one. Observation combined with myths and religious beliefs to explain how the world worked. Archaeologists' access to prehistoric views of animals is limited to surviving images and three-dimensional artifacts. From AD 800 to 1150, the Mimbres of the Gila region created vivid paintings of animals on their pottery. This complex zoological imagery of identifiable species, creatures composed of blended species, and human–animal transformations will be explored.

Post-Wildfire Effects on Gila Trout (Oncorhynchus *Giliae*) Populations and Habitat

Stephanie M. Coleman,[1] Colleen Caldwell,[2] and Jim Brooks[3]
[1]New Mexico State University and U.S. Fish and Wildlife Service
[2]New Mexico State University, New Mexico Fish and Wildlife Research Unit, P.O. Box 30003, Dept. 4901, Las Cruces, NM 88003-0003
[3]U.S. Fish and Wildlife Service—New Mexico Fisheries Resource Office, 3800 Commons Ave. NE, Albuquerque, NM 87109

Endangered Gila trout in NM have been affected by recent wildfires in the Gila and Aldo Leopold Wilderness. The extent of the relationship between fire severity and its effect on aquatic systems is not fully understood, creating conflict between wilderness fire management and endangered species management. This project will focus on that relationship by studying Gila trout streams exposed to varied levels of wildfire and characterizing post-fire effects. Correlating a range of fire-severity effects to an array of observable stream variables will increase our understanding of fire as a disturbance and as an important part of ecosystem dynamics. Sampling in 2005 showed no Gila trout in low-burn areas, while unburned areas showed multiple sizes classes and reproductive effort. Major habitat types consisted of riffles and runs with gravel and cobble substrate. Pools are uncommon in any of the burn areas. Siltation of fine sediment was evident after summer rains.

A Collaborative Method for Assessing Environmental Flows on the Upper Gila River: Justification and Need

Jeanmarie Haney
The Nature Conservancy, 1510 E. Fort Lowell Rd., Tucson, AZ 85719, jhaney@tnc.org

The hydrology of the upper Gila River is described, and results are presented from preliminary assessment of potential flow alteration if diversion were implemented per the provisions of the New Mexico Consumptive Use and Forbearance Agreement, ratified as part of the Arizona Water Settlements Act. Analysis indicates that flow alteration would consist chiefly of reduced low flows, occurrence of zero flow days, and reduced frequency of small floods. Ecological impacts may consist of direct impacts to native fish as well as other aquatic species and direct and indirect impacts to riparian vegetation and associated wildlife. A collaborative, science-based, environmental flows approach is recommended for analyzing NM's diversion options.

Twenty Year Temporal and Spatial Burn Severity Patterns in the Gila Wilderness, NM

Zachary A. Holden,[1] Penny Morgan,[1] and Matthew G. Rollins[2]
[1]Department of Forest Resources, University of Idaho, Moscow, ID 83843
[2]Rocky Mountain Research Station Fire Sciences Lab, Missoula, MT 59808

Little is known about landscape patterns of burn severity. Hundreds of fires have burned in the Gila Aldo Leopold Wilderness Complex, NM (GALWC) since the Wildland Fire Use program was implemented there in 1975, providing a unique opportunity to evaluate spatial and temporal patterns of naturally burning fires. We used pre- and post-fire Landsat TM imagery to create differenced Normalized Burn Ratio (dNBR) images of 114 non-grassland fires greater than 40 hectares from 1984–2004 in the GALWC. 120 field plots collected in 2004 were used to define thresholds between low, moderate, and severe post-fire ecological

effects. We used Bayesian analysis to compare the observed versus expected distribution of burn-severity classes with respect to biophysical setting (aspect, elevation, and potential vegetation type). Preliminary analyses show that severe fire patches tend to occur more often on north-facing slopes, in mesic forest types, and at higher elevations. Fire extent and severe extent have increased during the 20-year period of this analysis. Trends toward increasingly large and severe fires are strongly correlated with corresponding trends in intra-annual precipitation variability (total number of days without rain and maximum rain-free interval). Our results suggest that short-term, localized climate variability rather than climate warming may be contributing to increased extent and severity of recent fires in the Gila NF.

Thirty Years of Wildland Fire Use: Effects of Repeated Fires on Ponderosa Pine Forest Stand Structure in the Gila Wilderness, NM

Zachary A. Holden,[1] Penny Morgan,[1] Matthew G. Rollins,[2] and Alisa R. Keyser[2]
[1]Department of Forest Resources, University of Idaho, Moscow, ID 83843
[2]Rocky Mountain Research Station Fire Sciences Lab, Missoula, MT 59808

Land-use change and fire exclusion have severely altered many southwestern ponderosa pine forests. Fire is an important component of forest restoration, but little is known about the effects of repeated wildland fires on forest structure. Ponderosa pine forest stand structure was measured in the Gila Wilderness in unburned, once-burned, and multiply burned areas. Areas that had burned in the mid-century and then again under WFU were also compared. We observed significant differences in the number of small-diameter trees between unburned areas and areas burned multiple times in both areas, but no significant differences in numbers of large-diameter trees. Areas that burned mid-century had significantly different tree size-class distributions than all other treatments, suggesting that the timing of fires in the last century has been critical to the development of current stand structures. In the Gila Wilderness, densities of large (>47.5 cm) snags were measured using line intercept sampling in once-, twice-, and thrice-burned areas. Mean snag densities were significantly higher in once-burned areas but did not differ between twice- and thrice-burned areas, suggesting that repeated wildland fires may leave many large snags standing.

Gila River Herpetofauna: A Historical Perspective of Current Diversity

Randy D. Jennings[1] and Charles W. Painter[2]
[1]Department of Natural Sciences, Western New Mexico University, Silver City, NM 88062
[2]New Mexico Department of Game and Fish, Santa Fe, NM

Despite the rich regional diversity of reptiles and amphibians, dedicated studies of the herpetofauna of the Gila River Valley are few. The most important early collection of amphibians and reptiles in the region was that of Emory and the U.S.–Mexican Boundary Survey (ca. 1845). These specimens were deposited in the Smithsonian Institution where they were studied by Baird, Girard, and Kennicott. The resultant works by Baird included descriptions of many new species. Cope (United States National Museum) named more species and documented geographical distributions. Law (Museum of Vertebrate Zoology, University of California–Berkeley) conducted additional studies in Grant and Catron counties in the early 1900s.

During the 20th century, herpetologists from several major natural history institutions contributed to the understanding of the herpetofauna of southwestern NM, including Cole (American Museum of Natural History), Degenhardt (Museum of Southwestern Biology–University of New Mexico [MSB–UNM]), Dixon (Texas Cooperative Wildlife Collection), Painter (MSB-UNM), and Wright (Los Angeles County Museum). Biologists from other disciplines have also contributed to that understanding including Findley and Jones (MSB–UNM), and Hayward and Hunt (Western New Mexico University). Regional studies on specific groups of amphibians and reptiles have been conducted more recently by Cole (*Aspidoscelis*), Jennings (*Rana*), and Fitzgerald (*Thamnophis*). This information has been compiled by Degenhardt et al. (1996).

Seventy-three species of amphibians and reptiles have been documented from the Gila River drainage in NM. Many are known from a small number of specimens, while others are widespread and common along the river. Some species may be extinct within the drainage, while others represent introduced, non-native, and often invasive species. New species to the herpetofauna have been documented as recently as August 2006.

Summer Broad-Scale Movement of Rio Grande Suckers in Perennial Interrupted Streams on the Ladder Ranch, NM

Carter G. Kruse,[1] Heather Johnson,[1] and Steve Dobrott[2]
[1]Turner Enterprises, Inc., 1123 Research Dr., Bozeman, MT 59718, carter.kruse@retranches.com
[2]Ladder Ranch, HCR 31, Box 95, Caballo, NM 87931

Rio Grande suckers (*Catostomus plebeius*) are a species in decline across their native range in NM and CO; however, not much is known about their basic ecology. The Ladder Ranch, in Sierra County, NM, contains several populations of Rio Grande suckers. In summer 2003 and 2004 we tagged with passive integrated transponder (PIT) a total of 425 adult Rio Grande suckers to better understand broad-scale movement patterns. Subsequent sampling events resulted in 327 recaptures of 216 tagged fish. A high percentage (49%) of tagged fish were not recaptured, even though study sections were relatively closed (to movement). Many tagged fish moved very little over the course of the study, but in one section the overall average distance moved by individuals exceeded 500 m, with movements greater than 2 km documented. Rio Grande suckers appear to be a moderately to very mobile species when compared to other stream fishes of similar sizes.

The Status of Allen's Lappet-Eared Bats in NM

Lyle Lewis
U.S. Fish and Wildlife Service, New Mexico Ecological Services Field Office, 2105 Osuna Rd. NE, Albquerque, NM 87113, lyle_lewis@fws.gov

Very little is known about the life history of the Allen's lappet-eared bat (*Idionycteris phyllotis*) in NM. Limited information suggests their roosting requirements are very specialized. Between 1957 and 1975, although not abundant, Allen's lappet-eared bats were fairly consistently captured at some survey sites by bat researchers in NM. Over the last 30 years, they have been captured less frequently. An analysis of historical occurrence records, limited roosting information, and comprehensive surveys since 2000 suggests that viable populations of Allen's lappet-eared bats may now be limited to NM's wilderness areas.

An Analysis of Restoration Need and Opportunity of Fire-Adapted Ecosystems of the Gila National Forest, NM

M. Reese Lolley,[1] Patrick McCarthy,[2] Anne Bradley,[2] Cecilia McNicoll,[3] Joseph S. Encinas,[3] Jerry A. Monzingo,[3] Carolyn Koury,[3] Gabriel Partido,[3] and Marc Levesque[4]
[1]The Nature Conservancy, Washington Field Office, South Central Program, 1001 W. Yakima Ave., Ste. 325, Yakima, WA 98902, (509) 248-6697, rlolley@tnc.org
[2]The Nature Conservancy, New Mexico Field Office, 212 E. Marcy St., Ste. 200, Santa Fe, NM 87501, (505) 988-1542
[3]USDA Forest Service, Gila National Forest, 3005 E. Camino Del Bosque, Silver City, NM 88061, (505) 388-8201
[4]Acadia West LLC, P.O. Box 1412, Silver City, NM 88062-1412, (505) 313-7104

A central priority of the Southwest Region, USDA Forest Service is to restore the ecological functionality of forests and grasslands, with primary emphasis on fire adapted ecosystems. The Gila National Forest and The Nature Conservancy completed a coarse-scale analysis that identifies and prioritizes restoration need and opportunity across the Gila landscape. We summarized literature of twelve broad vegetative classes, characterized their current and pre-European disturbance regimes, calculated the relative ecological departure from current and modeled reference conditions, ranked restorability, summarized restoration challenges, opportunities and constraints, and developed strategic recommendations. The Gila landscape has changed dramatically over the last 130 years in response to land-use patterns and resulting changes in disturbance regimes. A landscape perspective as well as differentiating differences of individual ecosystem restoration needs and opportunities will be essential to successfully reversing negative ecological trends.

Restoration of Fire-Adapted Landscapes in Gila Country

Cecilia McNicoll,[1] Wendel Hann,[2] Joe Encinas,[2] and Marc Levesque[3]
[1] C Bar C Natural Resource Consulting, Silver City, NM
[2] USDA Forest Service, Silver City, NM
[3] Acadia West, Silver City, NM

An assessment of Gila Country is in progress to provide information for prioritization and design of Forest Service and Bureau of Land Management fuel and vegetation management projects. During 2005 an assessment was conducted to prioritize areas based on hazard to Wildland Urban Interface (WUI), Mexican spotted owls (MSO), Gila trout, and other resource values. Fire Regime Condition Class (FRCC) was mapped across the Gila National Forest to provide one of the data inputs for developing this prioritization. FRCC is a three-class (low—1, moderate—2, high—3) system for determining departure from the natural fire and vegetation regime, and provides an indication of the sustainability of fire-adapted ecosystems. The Signal Peak area just north of Silver City, covering about 360,000 acres, was identified as one of the higher priority areas for an assessment to evaluate treatment scenarios that would reduce fire behavior hazard to WUI and MSO habitats, and improve condition of fire-adapted ecosystems.

Results indicated that almost one third of the total area had potential for severe fire behavior with most of the WUI encompassed within. Almost two thirds of the total area was in moderate to high FRCC departure (condition classes 2 and 3) with most of the MSO encompassed. Subsequent evaluation indicated that some type of potential treatment to reduce fire behavior hazard and improve condition could be applied to about 25% of the area. Model predictions indicate that fire behavior hazard could be reduced by approximately 35%, while FRCC was improved across about 25% of the area. WUI areas were prioritized based predominantly on fire behavior hazard, with Signal Peak Lookout, Black Mtn Electronic Site, Lockneys, and Devils Garden areas north of Pinos Altos indicating the highest hazard. MSO habitat areas were evaluated in a similar manner, but with equal weight on fire behavior hazard and FRCC, with Black Peak, Redstone 1, Cherry Creek, Little Cherry Creek, and McMillen indicating a need for priority.

Brief Review of the Geology of the Cliff-Gila Area

David Menzie
Geologist, New Mexico Environment Department—Surface Water Quality Bureau, 910 E. 32nd St., Silver City, NM 88061, (505) 388-0599

The rate-limiting process for landscape change at the spatial scale below that of a physiographic province is river incision, a complex process influenced by base-level change, climate, hydrology, and local tectonics. A key observation central to understanding NM's landscapes and geomorphology is that with few exceptions, rivers statewide are actively incising, exposing surficial deposits and allowing geologists to reconstruct landscape change (Pazzaglia and Hawley 2004).

The Cliff-Gila Basin of NM is an alluviated trough of upper Cenozoic basin fill of the Gila Group with lesser amounts of basaltic volcanics and recent alluvium. The sedimentary clastic rocks filling the basin mostly originate from erosion of the vast pile of volcanic rocks in the uplifted Mogollon Mountains adjacent to the Cliff-Gila Basin and thus some of the origin of the Cliff-Gila Basin begins in the Mogollon Mountains. The Mogollon Mountains are a major geologic and structural element of southwestern NM and are the result of constructional volcanism and volcano-tectonic processes in middle Tertiary time, modified and complicated by Basin and Range deformation in late Tertiary time (Ratté and Gaskill 1975).

Geologic mapping in the Cliff-Gila Basin documents aggradation and formation of an integrated upper Gila fluvial system in Pliocene to early Pleistocene time (Trauger 1972 and Leopoldt 1981). For the Gila Conglomerate, most geologists have made a clear distinction between (1) upper, poorly consolidated basin-fill deposits, with thicknesses in the 330 to 990 ft range, and (2) lower conglomeratic units that are locally as much as 3,280 ft thick. The lower, partly indurated zone is commonly designated the Gila Conglomerate even though some of this older basin-fill is made up of sandstones and mudstones.

A Decade of Native Fish Research on the Upper Gila River in Southwest NM

Dennis Miller[1] and John N. Rinne[2]
[1]Department of Natural Sciences, Western New Mexico University, Silver City, NM 88062, millerd@wnmu.edu
[2]Rocky Mountain Research Station, USDA Forest Service, 2500 S. Pineknoll Dr., Flagstaff, AZ

A summary will be presented on a recently compiled database of fish and associated physical data collected on the Gila River. Described will be 57 sites, including 21 annually sampled sites, stretching from the three forks near the Gila Cliff Dwellings to the AZ border. The size and breadth of the database will be described, as well as the possible use for management of native fishes on the Gila and its tributaries in NM and AZ. Future research and use of the database will be discussed, including merging with a database from the Verde River in AZ.

SFRA Native Plant Restoration of the San Francisco River Watershed Riparian Forests and Uplands

Lou Naue and Allison Alterman
San Francisco River Association, PO Box 250, Glenwood, NM 88039, (505) 539-2032, sfra@gilanet.com

The San Francisco River Association (SFRA) is a non-profit watershed restoration entity, focusing on the San Francisco River watershed. Through collaboration with agencies for public land management, private landowners, and the San Francisco Soil and Water Conservation District, our team of in-house and contract restorationists have achieved numerous on-the-ground projects using many innovative techniques. Ethical wild-harvesting of native seed, propagation in our nursery and return of endemic genetic material to site-specific communities are among the innovations. Planting for species diversity, streambank stabilization, and wildlife habitat, we have propagated several native plant species that are not available at any commercial nursery in the state. We compile complete botanical species lists of every project area and are working on a comprehensive riparian and upland species list for the watershed. This monsoon season provided the opportunity to add many species to our lists. Planting to restore and improve diversity in the riparian forests, we plant native trees, shrubs, and many flower and grass seeds.
SFRA plants thousands of poles of various endemic willow species for bank stabilization, beaver habitat, and protection of inland planting groups of many young riparian hardwood species and shrubs.

The Stream Reach Concept: Prehistoric Agriculture in Southwestern Riverine Environments

Fred L. Nials and David A. Gregory
Center for Desert Archaeology, Tucson, AZ

Agriculture may have begun in the arid/semi-arid Southwest *ca*. 4000 BP, and it appears that irrigation may have accompanied the introduction of maize. The earliest-known agricultural sites often occur in alluvial locations favoring persistent emergent stream segments and irrigation. These locations bound naturally defined stream reaches. Stream reaches tend to respond in specific and predictable ways to specific climate and river regimes and their potential for irrigation agriculture may be characterized, allowing analysis of human response to these environmental variables. The stream reach concept also serves as an explanatory model for prehistoric agricultural practices and distribution of irrigation-agriculture populations.

Mexican Wolf Blue Range Reintroduction Project Update

John Oakleaf, Dan Stark, Shawn Farry, and Saleen Richter
New Mexico Department of Game and Fish, Mexican Wolf Field Team Leader, Conservation Services Division, Datil, NM, (505) 690-0496

The prime objective of the Mexican Wolf Blue Range Reintroduction Project that started in 1998 is: “To conserve and ensure the survival of *Canis lupus baileyi* by maintaining a captive breeding program and re-establishing a viable, self-sustaining population of at least 100 Mexican wolves in the middle to high elevations of a 5000-square-mile area within the Mexican wolf’s historic range.” The first release of wolves occurred in March of 1998 and has continued each year since. In the history of the project there have been 105 wolves released 165 times, through 88 initial releases and 77 translocations. Currently, four packs occur in NM and five packs occur in AZ. The 2005 year-end count determined that 35–49 wolves occurred in the Mexican Wolf Blue

Range recovery area. In 2006, one initial release of a group of 4 wolves occurred in AZ, and two translocations (one of 2 wolves and one of 3 wolves) occurred in NM. This year's mid-year minimum number of wild wolves is 28 wolves in NM and 19–22 wolves in AZ. The average home-range size calculated for twelve packs in 2005, using the 95% MCP method, was 191 square miles, ranging from 18–416 sq mi with wolves occupying 6,271 sq mi during 2005. The diet of Mexican wolves is primarily elk, with 91% of 105 confirmed or probable wolf kills being elk. From 1998 to 2005 there have been 66 confirmed or probable livestock depredations. Thus far in 2006 there have been 24 confirmed and 5 probable livestock depredations. There has been an average of 20 depredations per 100 wolves per year. The project has completed a 5-year review and will be moving forward with recommendations to improve its success in the future.

Monitoring Gila River Drainage Warmwater Fish Assemblages: Patterns or Random Change?

David L. Propst,[1] Jerome A. Stefferud,[2] and Yvette M. Paroz[1]

[1]New Mexico Department of Game and Fish, Santa Fe, NM

[2]USDA Forest Service (retired)

Since the late 1980s, warmwater fish assemblages have been monitored annually at six locations in the Gila–San Francisco catchment of southwest NM. Five native fishes (*Agosia chrysogaster*, *Rhinichthys osculus*, *Tiaroga cobitis*, *Catostomus clarki*, *Catostomus insignis*) were present at each site, at least sporadically. Other natives (*Meda fulgida, Gila nigra, Gila robusta*) were present only at Gila drainage site(s), and three (*Gila intermedia*, *Oncorhynchus gilae,* and *Poeciliopsis occidentalis*) did not occur at study sites. Fifteen non-native species were collected among permanent sites. Abundance of all native species have declined throughout the basin, particularly since the mid-1990s. Non-native fishes, habitat modification, and drought likely caused observed declines.

Hydrology, Geomorphology, and Management: Implications for Sustainability of Native Southwestern Fishes

John N. Rinne[1] and Dennis Miller[2]

[1]Rocky Mountain Research Station, 2500 S. Pineknoll Dr., Flagstaff, AZ 86001, jrinne@fs.fed.us

[2]Department of Natural Sciences, Western New Mexico University, Silver City, NM 88062, millerd@wnmu.edu

Native southwestern fishes have declined markedly in range and numbers. The factors responsible for their decline are many and varied. However, the primary stressors to native fish assemblages in southwestern rivers and streams can be grouped under habitat alteration and introduction of non-native species. We present data comparing fish assemblages in two desert rivers, the Verde and Gila, over periods of 8–13 years. The two rivers contained contrasting fish assemblages. We also present data on hydrographs, broad-scale and local geomorphology, and past fisheries, water, and land-management activities. Peak flow, mean volume of flow, variability of flow, canyon-bound and alluvial reaches, dams, and introduced fishes are all either directly or indirectly related to fish assemblages in southwestern rivers and streams. We suggest that three primary influencing factors—two natural and one human-induced, are critical features in delimiting native fish assemblages in these two and other southwestern rivers and streams. Conserving and sustaining native fish assemblages in these two and other southwestern rivers and streams will require land managers to cumulatively corroborate all subcomponents of these three major influencing factors.

An Analysis of Selected Breeding Bird Population Changes in Response to Gila River Habitat Restoration

Roland S. Shook

Department of Natural Sciences, Western New Mexico University, Silver City, NM 88062, shookr@wnmu.edu

In the mid-1990s the Forest Service initiated a series of habitat restoration projects to stabilize bank erosion and to provide habitat for the endangered Willow Flycatcher in the Gila River Bird Area. From mid-May 1996 through August 2005, a total of 582 periodic census trips were made in the Gila River Bird Area to evaluated changes in avian populations. Statistical analysis was performed on 21 breeding indicator species to determine if significant change in detections per km sampled were occurring over the 9½ years of this study. No significant change in average detections per km censused during the breeding season was found in populations of Common Black-Hawk (*Buteogallus anthracinus*), Wild Turkey (*Meleagris gallopavo*), Yellow-billed Cuckoo (*Coccyzus americanus*), Northern Flicker (*Colaptes auratus*), (Southwestern) Willow Flycatcher (*Empidonax trailii extimus*), Black Phoebe (*Sayornis nigricans*), Lucy's Warbler (*Vermivora luciae*), Common Yellowthroat (*Geothlypis trichas*), Summer Tanager (*Piranga rubra*), Red-winged Blackbird (*Agelaius phoeniceus*), Hooded Oriole (*Icterus cucullatus*), or Lesser Goldfinch (*Carduelis psaltria*). Significant change in average detections per km censused during the breeding season was found in populations of Mallard (*Anas platyrhynchos*), Killdeer (*Charadrius vociferus*), Western Wood Pewee (*Contopus sordidulus*), Brown-crested Flycatcher (*Myiarchus tyrannulus*), Bell's Vireo (*Vireo bellii*), Yellow Warbler (*Dendroica petechia*), Yellow-breasted Chat (*Icteria virens*), Northern Cardinal (*Cardinalis cardinalis*), and Bullock's Oriole (*Icterus bullockii*).

A Preliminary Distributional Analysis of Published Bird Records from the Gila River Valley of NM

Roland S. Shook[1] and Dale A. Zimmerman[2]
[1]Department of Natural Sciences, Western New Mexico University, Silver City, NM 88062, shookr@wnmu.edu
[2]Professor Emeritus, Department of Natural Sciences, Western New Mexico University, Silver City, NM 88062

The NM bird records published in *Birds of New Mexico* by Florence M. Bailey, *Revised Check-list of the Birds of New Mexico* by John P. Hubbard, the New Mexico Ornithological Society's *Field Notes*, and National Audubon Society's *Audubon Field Notes* and successive publications will be analyzed as to their distribution from the AZ border to the upper reaches of the West, Middle, and East Forks of the Gila River. Analysis will show which portions of the Gila River Valley have been historically studied, and to what degree, as well as which portions are lacking in documentation of the avifauna.

Rare Plants in the Mogollon Floristic Region of NM

Robert Sivinski
New Mexico Forestry Division, P.O. Box 1948, Santa Fe, NM 87501, robert.sivinski@state.nm.us

The Mogollon floristic region of NM consists of several adjacent or interconnecting mountain ranges extending from the Mogollon and San Francisco mountains on the AZ border, east to the San Mateo Mountains and Black Range near the Rio Grande. This region contains twenty-two plant taxa that are regional endemics, and an additional nine that are more widespread but rare throughout their range. Five of these plants have not been seen in NM for more than half a century.

Butterflies of the Gila National Forest and Vicinity

Dale A. Zimmerman
Professor Emeritus, Department of Natural Sciences, Western New Mexico University, Silver City, NM 88062

Over the past half-century, frequent collecting and surveying on the Gila National Forest have resulted in specimen records of 172 butterfly and skipper species together with considerable information on the status of each. An additional six species have been reliably recorded within two miles of national forest lands. (Three others have been reported on the basis of questionable data.) The 178 species positively recorded from the Gila Region represent over half of those known in NM. This diverse fauna reflects the varied topography, altitudinal diversity, numerous distinct plant communities, and the area's proximity to Mexican borderland habitats. Taxonomically, the Gila's diurnal Lepidoptera represent 20 families and subfamilies. The fauna is particularly rich in skippers (Hesperioidea), with at least 65 species recorded. The brush-footed butterflies (Nymphalidae) are represented by over 50 species. The Gila supports several local "Mexican" butterflies of particular interest to lepidopterists, and a few rarities such as the Nokomis Fritillary (*Speyeria nokomis*) whose management is of particular concern.