97-035WPF
MULESHOE RANCH
FINAL REPORT
TNC

The Nature Conservancy
OF ARIZONA

AWPF PROJECT NUMBER 97-035
WATERSHED IMPROVEMENT TO RESTORE RIPARIAN AND AQUATIC HABITAT ON THE MULESHOE RANCH CMA

FINAL REPORT
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The Arizona Water Protection Fund Commission has funded all or a portion of this report. The views and findings represented in this deliverable are the grantees and do not necessarily represent those of the Commission nor the Arizona Department of Water Resources

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Acknowledgements

This Arizona Water Protection Fund project would not have been successful without the dedicated contributions of numerous individuals. The authors thank all that supported the project, starting with review of the grant application up to the completion of this final report.

Bob Rogers, Muleshoe Ranch Cooperative Management Area Operations Manager, was the cornerstone of all the field activities associated with this project and his ability to take on all challenges with enthusiasm and professionalism was remarkable.

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Arizona Water Protection Fund Project 97-035
Watershed Improvement to Restore Riparian and Aquatic Habitat on the Muleshoe Ranch CMA

Project Summary

This Arizona Water Protection Fund (AWPF) project was initiated on May 6, 1998 and terminated June 6, 2001. The project location is the Muleshoe Ranch Cooperative Management Area (CMA) located 28 miles northwest of Willcox Arizona. During this grant period there have been significant project activities of diverse nature including: treatment with prescribed fire of nearly 17,000 acres of the Hot Springs upland watershed, development and implementation of an extensive multifaceted monitoring program for upland vegetation, riparian vegetation, native fish, streamflow and geomorphology, community outreach efforts within the project area, construction of over 3 miles of fence and signage of significant riparian habitats.

The overall budget for this grant was $220,363 with $128,315 contributed by AWPF and $92,048 contributed matching funds. We were fortunate during this project that conditions were favorable for prescribed fire each year and that agency partners had access to matching funds, thus allowing for completion of the prescribed fire component and treating more acreage than originally planned. Overall, it was possible to meet expenses on all tasks and the only significant changes to the original contract were two amendments to reallocate unused funds to future tasks.

Background

The Muleshoe Ranch CMA is owned and managed by The Nature Conservancy (TNC), U.S. Bureau of Land Management (BLM), and U.S. Forest Service (USFS). There are 7 perennial streams on the CMA, 4 of these streams are in the Hot Springs watershed; they include Hot Springs, Bass, Double R and Wildcat creeks. These streams support mixed broadleaf deciduous riparian forest and assemblages of 2-5 native fish species (Gila chub, longfin dace, speckled dace, Sonoran sucker and desert sucker), which is noteworthy in the Southwest. Gila chub, a fish that is declining throughout its range and is now quite rare, occurs in Bass, Hot Springs and most recently in Wildcat. All or most of the watersheds for these 4 perennial streams are contained within the CMA boundary; the dominant watershed vegetation type is semidesert grassland.

Despite their high ecological value, these 4 perennial streams persist in a degraded condition. Between 1980 and 1995 frequent intense floods removed mature trees and streambank vegetation and limited recruitment of woody seedlings resulting in a reduced density of riparian trees and understory vegetation, unprotected streambanks, and a reduced age-class diversity of riparian trees compared to better condition reference sites (BLM 1998). In addition, these floods have eroded the channel and floodplain resulting in bed-lowering and reduced baseflows (W. Ostercamp, pers. comm.). Finally, reduced baseflows and frequent floods have decreased the extent and quality of aquatic habitat (D. Gori, personal observation) which reduces native fish populations (Hardy et al. 1990). Redfield Creek was identified as a reference site for streams in the Hot Springs watershed because the Redfield watershed has been ungrazed for several decades, wildfires have been allowed to burn there, and perennial grass cover was high and dominated by tall- to mid-statured bunchgrasses. The number and quality of pools, the amount of instream cover, and the abundance of pool specialists, Gila chub and Sonora sucker, were all significantly greater in Redfield than in Bass and Hot Springs in 1994 suggesting some potential for improvement in the latter streams (BLM 1998; TNC monitoring data). In general native fish populations have declined over the last several decades throughout Arizona and the Southwest (e.g., Minckley and Deacon 1968; Williams et al. 1985; Rinne and Minckley 1991; Marsh et al. 1990; Warren and Burr 1994; Minckley 1995).

Because of the relationships between watershed vegetation, watershed hydrological processes, stream hydrology and riparian and aquatic habitats, the preferred approach to restoring riparian and aquatic habitat on the Muleshoe CMA is to improve watershed condition, i.e., restore the structure and composition of watershed vegetation. Through this project a significant portion of the Hot Springs watershed was treated through a series of prescribed fires with the primary goal being to initiate restoration of this structure and composition. The extensive monitoring component of the grant was intended to establish a baseline and document the progress of these watershed treatments. The fencing component was intended to exclude neighboring cattle from upper Bass Canyon. The signage component was implemented to inform ORV users of the sensitive nature of the riparian areas. The community outreach component included both regular educational interaction with project area neighbors and multiple presentations to lay and professional audiences.

Goals and Objectives

The overarching long term goal of this project is to initiate the restoration of riparian and aquatic habitat in 4 perennial streams on the CMA by restoring watershed vegetation and function and to take active measures to minimize adverse livestock or ORV impacts in riparian areas. All support mixed broadleaf riparian forest and assemblages of 2-5 native fish species (Gila chub, longfin dace, speckled dace, Sonoran sucker, desert sucker), all of which are classified as species of concern by the Arizona Game and Fish Department. Gila chub occurs in Bass, Hot Springs and Wildcat. All or most of the watersheds for these 4 perennial streams are contained within the CMA boundary. To achieve this overall goal we have been working in a variety of ways both on the ground and within the greater Muleshoe area. Within this final report the 15 Tasks will be presented as 5 project components. For instance, Tasks 3-8 is the prescribed fire planning and implementation component. By representing the activities in this way we hope to better represent the integrated nature of the project.

The five components of this project are prescribed fire planning and implementation, development and implementation of an extensive monitoring plan, community outreach, fencing and signage. The objectives established at the beginning of this grant for these project components are:

Objective #1:
Conduct prescribed burns to improve watershed condition; change the composition and structure of watershed vegetation by increasing the frequency and cover of perennial grasses, especially mid- to tall-statured species and by decreasing the cover of shrubs.

Benefits: Improved watershed conditions should result in decreased frequency and intensity of floods, increased baseflows, improved water quality through reduced sediment yields, improved aquatic habitat for native fish particularly an increase in pool habitat, improved riparian vegetation development.

Objective #2:
Construct additional perimeter fencing to exclude trespass livestock from Bass Creek and its watershed.

Benefits:
Better control and management of livestock will improve watershed conditions, enhance recruitment of riparian trees, increase the density and cover of riparian vegetation, reduce erosion and increase aquifer recharge during floods.

Objective #3:
Continue and expand ongoing monitoring program for watershed vegetation, riparian vegetation, streamflow, floodplain geomorphology, native fish and aquatic habitat.

Benefits:
The monitoring program will provide pre- and post-burn information on the composition and structure of watershed vegetation, quality of aquatic habitat and size of native fish populations, streamflows, and condition of riparian forest vegetation. The monitoring program will be critical in determining how quickly watershed and riparian vegetation, native fish, aquatic habitat and stream hydrology are responding to prescribed burns and improved livestock management and when the resource objectives articulated in the draft Ecosystem Management Plan have been achieved.

Objective #4:
Post signs at the downstream boundary of Muleshoe CMA in Hot Springs wash to discourage off-road vehicle (ORV) access into lower Hot Springs riparian area.

Benefits:
Signage will help reduce ORV traffic into Hot Springs which will improve recruitment success of tree seedlings, increase the density of near channel vegetation, stabilize streambanks and reduce impacts on native fish.

Objective #5:
Demonstrate how watershed management techniques can improve both riparian habitats and associated rangeland.

Benefits:
Results from this project can be shared with other landowners and resource managers. By disseminating this information, similar watershed improvement projects may be implement at other locations in Arizona.

Project Tasks

This grant contained 15 tasks.

Task1: Obtain required permits and authorizations
Task 2: Development of baseline and post-burn monitoring plans
Task 3: Prepare site fire plan for the Double R Fire Unit
Task 4: Conduct Prescribed burn(s) on the Double R Fire Unit
Task 5: Prepare site fire plan for the Hot Springs Fire Unit
Task 6: Conduct prescribed burn(s) on the Hot Springs Fire Unit
Task 7: Prepare site fire plan for the Wildcat Fire Unit
Task 8: Conduct prescribed burn in the Wildcat Fire Unit
Task 9: Fence Construction
Task 10: Fence Maintenance
Task 11: Baseline monitoring and data summary
Task 12: Post-burn monitoring and data summary
Task 13: Distribute project information to other watershed managers
Task 14: Post signs at Hot Springs Wash
Task 15: Semi-annual and final reports

Progress Report 10-01-2000 through 4-30-2001

During this reporting period activities were scheduled for Tasks 10, 12, 13 and 15. All other Tasks have been completed and reported in previous semi-annual reports.

Task 10: Fence Maintenance.
During this reporting period Muleshoe Preserve Staff checked and repaired the fence 2 times during the winter and spring. Only minor damage was noted due to erosion around fence corners during winter storms. Preserve staff did note that livestock use outside of the fence has been minimal during this period.
Percent of Task Completed: 100%

Task 12: Post Burn Monitoring and Data Summary.
As was expected, extensive progress has been made on this Task during this reporting period. TNC Ecologists Dave Gori and Dana Backer have completed the post burn data summary and analysis and this information is documented extensively in the monitoring section of this final report.
Percent of Task Completed: 100%

Task 13: Distribute project information to other watershed managers.
Activities associated with this Task include informal contacts and visits with neighboring property managers and formal presentations and events designed to present the results to target audiences.
Percent of Task completed: 100%

Community Interaction:

October 12-14, 2000. Bob Rogers and BLM staff met at the project site with Arizona Game and Fish and US Forest Service personnel. At this meeting they discussed the various components of AWPF and Heritage Grants that were in progress on the Muleshoe Ranch CMA.

November 5 and November 12, 2000. Bob Rogers and Wes Hutcherson led interested CMA visitors on tour of project and CMA, discuss watershed restoration activities.

January 11, 2001. TNC gathering of site practitioners at the Muleshoe, review of AWPF project progress.

January 31, 2001. Ed Brunson met with three foundation representatives to present the Muleshoe AWPF restoration results, discuss future support for continuation of the effort.

February 12, 2001. Ed Brunson and Arizona State Lands Department reviewed AWPF Project results and possibilities for future projects in the upper Hot Springs watershed.

Presentations:

November 14, 2000. The Nature Conservancy National Conservation Strategies Conference, Colorado Springs, CO. Ed Brunson made a PowerPoint presentation of the results of this project at the Watershed Restoration session of this conference, attended by 150.

November 29, 2000. Fire Ecology Association, San Diego, CA. Ed Brunson presented the results of this project in the Fire and Watershed Restoration session at the national association conference.

January 9, 2001 Malpai Borderlands Conference, Douglas, AZ. Dana Backer presented WATERSHED IMPROVEMENT: A WAY TO RESTORE RIPARIAN AND AQUATIC HABITAT.

January, 2001. Willcox NRCD Meeting. Bob Rogers presented the project to the NRCD group, answered questions primarily focused on the grassland aspects of the project.

March 13-14, 2001. Ed Brunson informally presented the watershed restoration project as a case example to work group of TNC and federal staff at a Fire Policy roundtable in Flagstaff, AZ.

April 2001. University of Arizona, School of Renewable Natural Resources. Dave Gori and Dana Backer presented a departmental seminar at the University, focusing on the Watershed and Riparian Processes aspect of the project.

April 1-2, 2001. Tours of the Project were conducted on two concurrent days. A total of 72 participants attended from multiple federal and state agencies, private property owners and non profit entities. This tour is discussed in the community outreach portion of this report.

May 2001. Dave Gori met with a University of Arizona Resources graduate student, Alex Conley, to discuss the monitoring components of this project. He and his advisor, Dr. Maria Fernandez, are conducting a funded study of how monitoring data are used to inform management decisions; they have selected the Muleshoe Project as one of 4 in-depth case studies.

Task 15 Semi-annual and Final progress reports
This is the final semi-annual and final report. Five previous reports have been submitted during the course of this contract.
Percent of Task Completed: 100%

FIRE MANAGEMENT COMPONENT

There are six Tasks (3-8) associated with either prescribed fire planning or burn implementation. Overall, they represent the collective work of identifying areas to be burned, development of the cooperative plans and finally conducting complex large prescribed burns. This discussion focuses on a) plan development and b) prescribed fire activities.

The fire management component of this grant has been by far the most cooperative in nature. Four federal agencies (BLM, USFS, National Park Service (NPS), Bureau of Indian Affairs BIA)), one Arizona State department (Arizona State Land Department (ASLD) and five adjacent property owners have been involved in one or more of the prescribed burns. In the grant application it was proposed that 6600 acres be burned but due to favorable environmental and administrative conditions over 17,000 acres were actually treated, and the grant-associated costs were well below expectations.

Fire planning and implementation took place on land administered by the BLM, USFS, TNC, ASLD and private land of Saguaro Juniper Corporation, Dave Harris and Larry Young. Approximately 92% of the treated area is either BLM administered or TNC owned. The BLM and TNC were the primary cooperators each of the three years with BLM being the lead agency. This project would not have been successful without the leadership of the BLM in planning and completing these challenging landscape scale burns.

Plan Development

Of the three years, developing the fire plan the first year (1998) for the Double R burn was the most difficult. Essentially, BLM and TNC developed a template process and format that worked well and it was repeated in 1999 and 2000 with modifications to address the specifics of the burn unit and to incorporate lessons learned from the previous year(s). As was proposed in the grant application, prescribed burn plans were prepared each year and subsequently the plans were implemented in the spring of each year. The plan schedule and applicable area are detailed in the following table.

PLAN AREA	PLANNING PERIOD	PLANNING PARTNERS	ACRES BURNED
Double R	Nov., 1997 to May, 1998	BLM, TNC	4720
Hot Springs	December, 1998 to May, 1999	BLM, TNC	5515
Hooker	December 1999 to April, 2000	BLM, TNC, ASLD, Private	6950

Preparation of an approved prescribed burn plan is a complex task, and it was initiated months before the target burn dates. Each year BLM and TNC staff met multiple times on the proposed burn site and in offices to address logistical details. Each of these burns required NEPA review, staff conducted these during the winter months preceding each burn. These burns were all cooperatively funded, and a cost share agreement was developed between TNC and BLM. This arrangement worked very well as it allowed for the pooling of resources and completion of larger projects. Because of this opportunity and recognition of the economy of scale associated with burning in a place like Muleshoe we chose to plan burn units larger than specified in the grant application. In the end this proved to be a successful strategy.

The final products of these planning efforts are reviewed and approved BLM burn plans that have been submitted in previous semi-annual reports. The resource and burn objectives in these plans are aligned with the overall watershed improvement goals for the CMA and this grant. Larry Humphrey, Fuels Specialist with the BLM in Safford is the primary author of these plans and each year he refined and improved them based on results from previous years. These plans can serve as examples for others on how to work cross-jurisdictionally to complete landscape scale burns in a cost-effective way.

Prescribed Fire Activities

In order to successfully implement the strategy of using prescribed fire to improve watershed conditions significant portions of the watershed must be treated with fire under the desired conditions. The burns conducted during this project were consistent with specific prescriptions that were designed to have the desired effect. In general terms, the goal was to apply fire to all upland vegetation within the planned areas through the use of aerial ignition. Through the planning process areas were identified where favorable fuel conditions existed. Those conditions include a significant amount of fine fuel (grass and forb material), shrub cover from 30 to 80 percent, adequate fuel breaks to use as burn unit perimeters, and limited amounts of riparian area that had a high likelihood of ignition. The fine fuel is needed as a medium to carry fire and to generate heat and flame under shrubs and small trees. We targeted areas with significant shrub cover as a primary objective was to reduce this cover type. Safe and manageable perimeters were critical for safety reasons. Riparian areas were minimized to reduce negative fire impacts.

The prescription used for these burns was designed with two primary goals. The first guiding factor was safety, the prescriptions were developed to insure that the burn could be conducted in a safe manner. In this regard wind speed is the most critical single parameter. The second guiding factor was desired effects on vegetation, particularly shrub mortality. It was necessary to generate sufficient heat and flame lengths to top kill small shrubs and to carry fire through dense stands of *Agave schottii.* These factors translate into a prescription with temperatures in the 90s (F), relative humidities of 10-12 % and moderate breezes of approximately 5 miles per hour at eye level.

In order to safely and efficiently treat burn units of several thousand acres in a remote inaccessible area like Muleshoe it was necessary to utilize aerial ignition for the majority of the unit. To ignite entirely by hand from the ground would require several crew members to walk up and down slopes for several miles, all within the unit. In rough terrain such as at Muleshoe this is not a safe or practical technique. Only the unit perimeters next to the road or within ¼ mile of buildings were ignited by hand.

The tool of choice for aerial ignition was a Premo aerial ignition device, commonly called a "ping pong ball machine". This device is mounted in a helicopter and drops small plastic spheres from an altitude of 100-200 feet. Through a delayed chemical reaction, these spheres start small spot fires within 1 minute after hitting the ground. The Ignition Boss rides in the helicopter and controls where and when the spheres are dropped. Using this technique it is possible to safely ignite several thousand acres in one day.

The grant objective was to burn an average of 2200 acres per year for a total of 6600 acres. The prescribed fire objectives were to consume or scorch 70-80% of the shrubs and *Agave schottii* and in the long term reduce the percent of shrub cover in the upland by 50%. It was also a goal to not burn the riparian areas and for the most part that objective was met each year. It should be noted that these prescribed fires were only applied to upland vegetation, not riparian areas. One unique thing about prescribed fire is that it is highly dependent on weather conditions, and we knew from the outset that we might not be able to burn one or more of the years. As it turned out, the weather was favorable each year with only minor postponements required in 1998 and 1999, in 2000 the Hooker burn was implemented on the target date. As mentioned above, larger burn units were chosen for administrative efficiency. Basically, it just made sense to do larger burns when it required little additional expense or work and the resource benefits were multiplied. The Double R, Hot Springs and Hooker burns are shown on Map 1, following this section of the report.

BURN	WATERSHED	ACRES	YEAR	PARTNERS
Double R	Bass, Double R	4720	1998	BLM, NPS, USFS, TNC
Hot Springs	Wildcat, Hot Springs	5515	1999	BLM, USFS, BIA, TNC
Hooker	Hot Springs	6950	2000	BLM, TNC, ASLD, Private

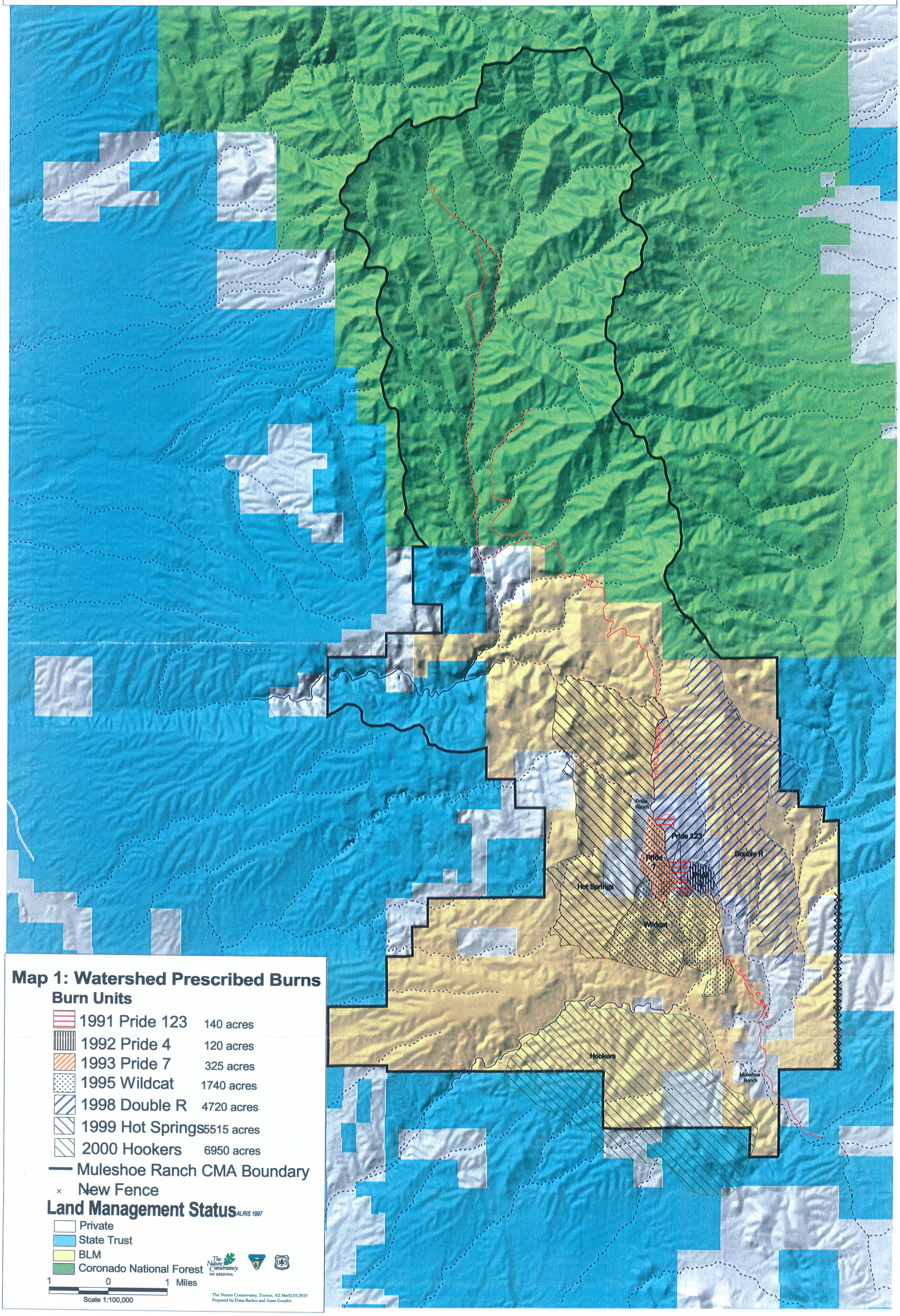
These burns took place in the watershed above several of the native fish transects discussed in the monitoring section of this report. The following table indicates the streams, fish monitoring stations and affecting burns.

STREAM	FISH MONITORING SITE	BURN
Bass	1-6	None
	7-8	Double R burn
Double R	2 & 3	Double R burn
Wildcat	1 & 2	Hot Springs burn
Hot Springs	1-5	Double R & Hot Springs burns

The Double R burn was conducted in 1998 under BLM command with support from TNC. The USFS provided a helitack crew and helicopter and NPS provided two crew members. This two-day burn covered 4720 acres of BLM, TNC, ASLD and USFS land. The full plan and report was submitted with the September 1998 semi annual report. Overall this burn met the resource objectives for percent of area burned, shrub mortality and minimizing riparian impact. There was minor slop over on the NE side of the unit that at no time presented a threat to any sensitive area or facility. This area burned slowly though heavy shrubs and the fire effects matched the burn objectives.

In 1999, the 5515-acre Hot Springs burn was conducted on the west side of Jackson Cabin road. Due to the experience of the Double R burn, a large secondary area was included within the plan area to provide for management of any potential slop over. As it turned out this area was not needed, but it provided more flexibility in determining the best way to manage the fire once it was underway. Again, this burn successfully met the shrub mortality and percent of area burned goals. Approximately 1300 acres within this unit had been previously burned

MULESHOE RANCH CMA BURN UNITS 1991-2000



in 1995. This area burned very well, but has recovered relatively slow in the two years since being burned. This is more fully addressed in the monitoring and analysis section of this report. This burn was conducted under BLM leadership and command with support from TNC. The USFS helitack crew also participated.

Year 2000 brought the Hooker burn on the southwest side of Hot Springs Canyon. This was a burn on 6950 acres of BLM, TNC, ASLD and other private land that had not been previously treated with prescribed fire. It also represented the first time significant acreage's of ASLD and non-TNC private lands were burned. Whereas with the Double R and Hot Springs burns natural barriers and roads were utilized for containment, with the Hooker burn a grazed pasture was used as a containment line on the south edge. It was also determined that the best way to safely treat this steep and remote area was to burn across fence lines and repair the fence afterward. Therefore, post-burn repair of the remote fence became part of the overall strategy for this burn. Again, this burn was conducted under BLM command with support from TNC. The ASLD reviewed the burn plan as did private landowners Dave Harris, Larry Young and Saguaro Juniper Corporation. Approximately 80% of the planning area burned and shrub mortality met the established objectives. This burn was unique in that it involved almost no direct fireline activity for ignition or control. It was ignited entirely by aerial ignition and stayed within the planned perimeter of Hot Springs wash on the north and west and grazed pasture on the south and west.

Recommendations regarding planning and conducting large scale watershed restoration burns:

As noted earlier, the planning and implementation of the prescribed burns was the most <u>collaborative</u> component of this entire project. Because of this collaborative effort acreage goals were exceeded by over 150%. This collaborative approach allowed activities to happen on a scale that made this project successful and caused significant changes in the Hot Springs watershed. In areas like Muleshoe it is clearly important whenever possible to be planning on landscape scales regardless of property ownership. These plans and burns are examples of collaboration that worked well for all parties involved.

During this project burns were planned and implemented each year on an individual basis. This approach resulted in a duplication of process and it limited the options for burning any given year. Future watershed restoration projects may benefit from a more comprehensive burn plan approach that creates a variety of potential units, any one of which can be implemented depending on local weather conditions, available fire management resources and grazing rotations. This approach would require more work initially but result in greater flexibility. The completion of an approved Muleshoe EMP before this project started laid the groundwork for the applied work included in this project. Future watershed restoration projects using fire will require additional environmental review if a similar process has not been completed.

The Double R burn in 1998 was planned for and conducted on land managed exclusively by BLM and TNC. In the end this approach made the burn more challenging, and subsequent burns were planned for larger areas including additional property owners. The lesson of the Double R burn is a good one for other fire practitioners as well. Larger burn units with more lateral options for management can support safer, more efficient operations.

Fire activity photos are included in Appendix A.

FENCING COMPONENT

The fencing component of this project was straightforward – construct 3.0 miles of fence on the southeast side of the CMA to keep neighboring livestock from entering upper Bass Canyon riparian area. The goal was simple, but this is very rough country with no vehicular access, so constructing the fence was labor intensive. Before the fence construction an AWPF funded archeological survey was conducted in 1998 on contract by Desert Archeology of Tucson. Hopkins Fence Company of Wickenburg built the fence during the early months of 1999. A crew of 4 worked for approximately six weeks with the result being a fire proof (all steel) fence that meets federal wildlife friendly standards. The fence construction went slow because all material was hauled to the fenceline by pack mule and all construction was done with hand labor. The three mile fence includes several gates that allow TNC staff or neighbors to move trespassing livestock throughout the area. The fence location is shown on Map 1.

Muleshoe staff has been maintaining the fence since it's completion. Approximately 2 times per year they patrol the fence and repair any damage that is found. To date the fence is holding up well with minimal damage due to wildlife crossing and monsoonal caused erosion.

SIGNAGE COMPONENT

Several of the sensitive riparian areas on the Muleshoe are accessible by all terrain vehicles or off road vehicles (ORVs). The Muleshoe Ecosystem Management Plan (1998) calls for the elimination of ORV use in these riparian areas. In order to support the implementation of that strategy and to reduce adverse ORV impacts, the AWPF funded the purchase and installation of signs at 10 strategic locations where historically ORV access has been a problem. The location of the signs is shown on map 3. The signs were purchased from the Carsonite Company and were installed during the second year of this grant. A replacement set of signs was purchased in anticipation of the need to periodically replace lost or damaged signs. To date none of the signs have been destroyed or stolen and they seem to be having the desired effect. Preserve staff patrol the areas where the signs are located on a regular basis as they conduct a variety of on-site management activities. During these patrols they have noted minimal travel beyond the signs, certainly less that was evident before the signs were in place. The only complaints have been from two hunters who visited the headquarters and were unhappy about not being able to drive in the riparian area. An example of the signs is included in Appendix K.

MONITORING METHODS, RESULTS AND DISCUSSION

INTRODUCTION

Four streams in the Hot Springs watershed--Double R, Bass, Wildcat and Hot Springs--support mixed broadleaf deciduous riparian forest and assemblages of 2-5 native fish species. Gila chub (*Gila intermedia*), a native fish endemic to the Gila River basin and a Candidate for federal listing by the U.S. Fish and Wildlife Service, is present in 3 of the 4 streams (Table 1). Despite their ecological values, these 4 perennial streams persist in a degraded condition. Frequent, intense floods have (1) reduced the density of mature riparian trees; (2) stripped away streamside vegetation, leaving stream banks unprotected and subject to erosion; and (3) limited recruitment of tree seedlings and saplings compared to other, better condition riparian reference sites on the Muleshoe (BLM 1998). Frequent floods have also (4) eroded the channel and floodplain resulting in bed-lowering, reduced aquifer storage and reduced baseflows (W. Ostercamp, pers. comm.). Finally, frequent floods and reduced baseflows have (5) reduced the extent and quality of aquatic habitat for native fish, especially pool specialists, compared to a better condition reference site on the Muleshoe (Hardy et al. 1990; BLM 1998).

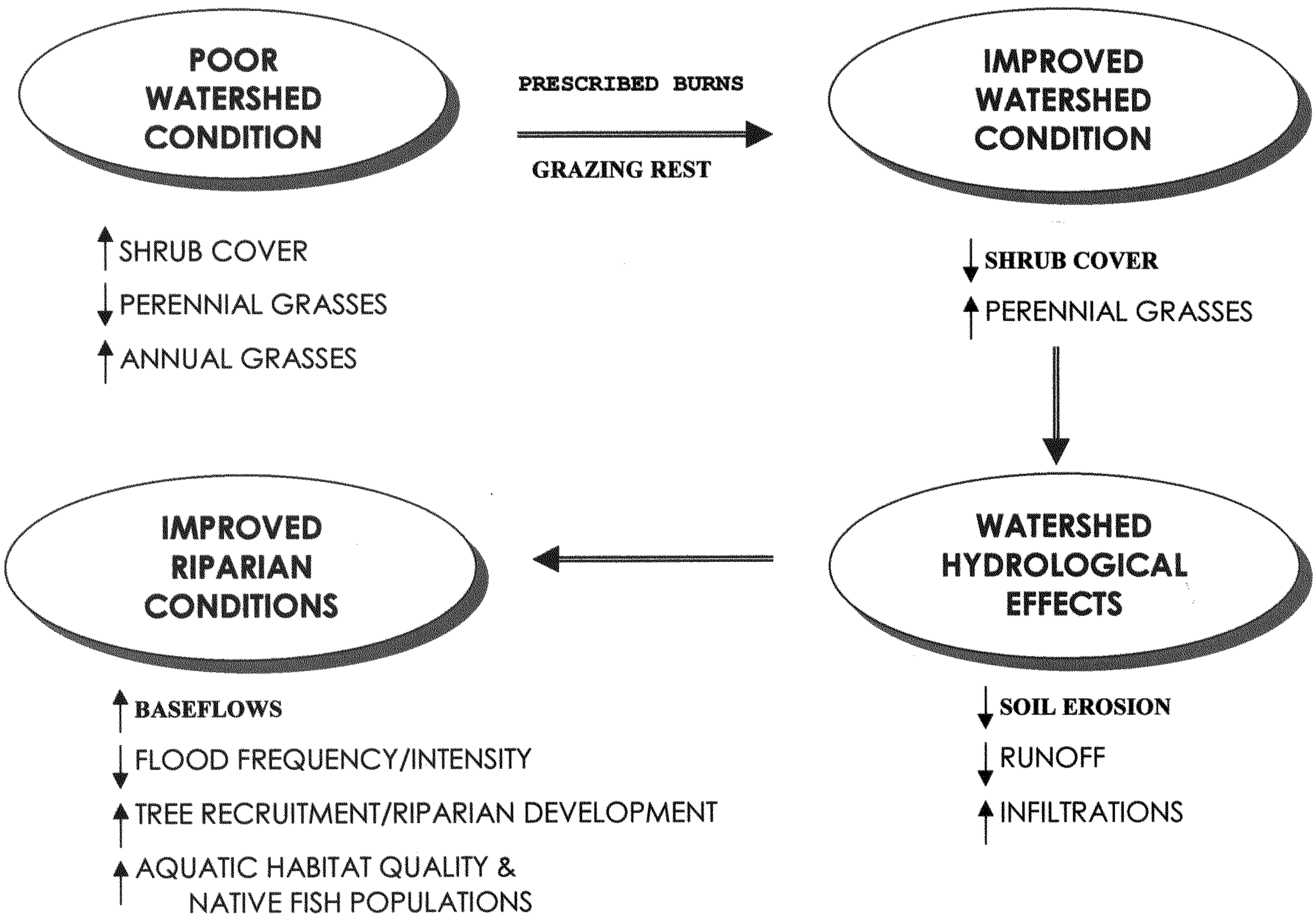
To restore and enhance riparian and aquatic habitat in the four perennial streams, the Conservancy and Bureau Land Management (BLM) have initiated a long-term project to improve watershed condition--specifically, the goal is to increase the abundance and cover of perennial grasses and reduce cover by shrubs (BLM 1998). This vegetation change is being accomplished by restoring fire as a natural process to the Hot Springs watershed using prescribed burns and continued grazing rest.

Several lines of evidence suggest that wildfires were frequent in semi-desert grasslands in Arizona prior to the 1870's. Fire history reconstructions using fire-scarred trees indicate an average fire frequency of every 2-10 years for pine-mixed conifer forests in borderland mountain ranges (Baisin 1988; Swetnam et al. 1989; Swetnam and Betancourt 1990; Baisin and Swetnam 1995; Swetnam and Baisin 1996); the assumption is that lower-elevation semi-desert grasslands burned at least at the same frequency. Kaib et al. 1996 used synchronous fires in adjacent canyons in the Chiricahua Mountains to estimate grassland fire frequencies and found intercanyon intervals between 7.4 and 8.1 years between 1600 and 1875. Pollen cores taken from borderland cienegas surrounded by grasslands contained abundant charcoal suggesting continuous, high frequency fire events prior to 1900. Finally, Bahre (1985) summarized local newspaper accounts of wildfires in southeastern Arizona and found that large grassland fires declined after 1882.

Over the last century, grazing by livestock has reduced the extent and frequency of these wildfires (by reducing the density of fine fuels needed to carry these fires) with the result that semi-desert grassland watersheds, like those at the Muleshoe, have become invaded by shrubs (e.g., Cable 1967, Wright 1974, Wright and Bailey 1982, Archer and Smeins 1991). Livestock grazing has also had direct impacts on the vegetation in semi-desert grasslands, reducing the abundance and cover of perennial grasses, especially tall- and mid-statured bunchgrasses (Humphrey and Mehrhoff 1958, Buffington and Herbel 1964, Bydenstein 1966, Hazel 1967, Bahre and Bradbury 1978, Heitschmidt 1990, Briske 1991, Stuth 1991). These vegetation changes have had profound effects on watershed hydrological processes and stream hydrology (e.g. Bosch and Hewlett 1982, Davis 1984, Debano and Schmidt 1990, Debano et al. 1984, Heede and Rinne 1990, Horton 1937, Lewis 1968, Simanton et al. 1977, Stabler 1985, Stephens and Knowlton 1986, Thurow 1991, Wilcox et al. 1988, Woolhiser et al. 1990, USDA 1940).

The relationships between watershed vegetation, watershed hydrological processes, stream hydrology, and riparian condition are summarized in Figure 1. These relationships have been documented in a number of studies conducted in semi-desert grassland, chaparral, woodland and forested plant communities (see above references, also Stromberg et al. 1991, 1996; Hardy et al. 1990; Johnson and Carothers 1982). However, these studies focus on only portions of the overall model and there is no comprehensive study at a single site that attempts to document all (or most) of these relationships. For this reason, we established long-term monitoring of upland and riparian vegetation, stream flow, floodplain and channel geomorphology, aquatic habitat and native fish populations at the Muleshoe.

WATERSHED-RIPARIAN PROCESSES MODEL



METHODS

UPLAND VEGETATION MONITORING

To investigate changes in semi-desert grassland vegetation in response to the prescribed burns, permanent monitoring plots (50 m x 45 m) were set up within and adjacent to the burn units. For the Double R burn, eight plots were established in the unit; these were first measured in fall (September-October) 1996 and re-sampled in fall 1998, i.e., the first growing season after the burn, and, again, in fall 1999, two growing seasons after the burn. All of these plots were burned. For the Hot Springs burn, permanent plots located in the burn unit were measured in fall, 1998, before the burn and re-sampled in fall, 2000, two growing seasons after the burn, as were control plots located in and adjacent to the burn unit. These plots represent three different treatment groups: 8 plots were burned a single time, i.e., during the Hot Springs Burn; 6 plots were burned either 2 or 3 times in a 5-year period, ending with the Hot Springs Burn; and 6 plots were left unburned as controls. These three treatment groups are hereafter referred to as: burn, repeat, and control groups.

All of the above plots were selected in representative vegetation for that portion of the unit or, in the case, of control plots were selected to be representative or similar to plots in the burned area. The corners of each plot were permanently marked with rebar and rock cairns and the location of the northwest corner stake determined using a hand-held GPS unit (Garmin 12XL) to facilitate relocation.

To determine changes in shrub cover, five 40-m long transects were set up in each plot and canopy cover by species was measured along each of these transects using a line-intercept method. The transects were located at 10-meter intervals in each plot; the same transects were re-measured in subsequent surveys.

To determine changes in grass abundance, the presence or absence of annual and perennial grasses in nested quadrats along 10 transects was recorded (i.e., frequency sampling). Three quadrat sizes were used: 10 cm x 10 cm; 40 cm x 40 cm; 1 m x 1 m; these nested quadrats were placed along transect lines at 2-m intervals for a total of 20 quadrats per transect and 200 quadrats per plot. The transects were located randomly within plots using a stratified random design, with a single transect placed in each 5 m-segment of the plot to ensure an adequate distribution of transects within plots. The location of transects was re-assigned each time plots were re-sampled. Since frequency of occurrence is measured in percent, the ability to detect change is limited when frequencies are less than 20% or greater than 80%. Nested quadrats permit simultaneous tracking and comparison of species and functional groups that differ greatly in abundance or that increase or decrease over time by up to several orders of magnitude. In these cases, the *proportionate* change in frequency is the normalized metric for comparison.

To determine changes in substrate composition, two methods yielding similar results were employed. For the Double R burn, cover of different, non-overlapping substrate categories was determined by placing a U-shaped pointer at the four corners of each 40 cm x 40 cm quadrat along transects and recording the cover type hit. Cover categories included: rock, soil, gravel, litter, and live basal--the latter defined as the living basal area of annual and perennial grasses and herbs. A total of 80 points (hits) per transect and 800 points (hits) per plot were recorded. For the Hot Springs burn, starting in 1998, we began measuring substrate cover in a different way. Using the 10 frequency sampling transects and the 5 shrub transects and extending them to 50 meters, point intercept measurements were made at 1-meter intervals along each transect using a 10" long pointer. For each measurement, we recorded whether the pointer hit the base of a grass or herb (by species) and, if no live cover was intercepted, we recorded the substrate at that point (i.e., soil/gravel, litter, and rock). A total of 50 points (hits) per transect and 750 points (hits) per plot were recorded. In addition to measuring substrate cover by category, this method also provides another estimate of perennial and annual grass abundance to augment that obtained from frequency sampling.

To determine changes in grass/herbaceous composition, particularly the relative change in herbs by weight, the three most abundant (by weight) grass and herb species were ranked in the 40 cm x 40 cm quadrats placed along frequency sampling transects; quadrats were placed at 2-m intervals for a total of 20 quadrats per transect and 200 quadrats per plot. Dry weight rank, as this method is called, is a standard range monitoring technique and is reviewed in Ruyle (1990).

A plant species list from the vegetation monitoring plots is in Appendix B.

STREAM FLOW MONITORING

To determine changes in stream flow resulting from variation in annual precipitation and watershed vegetation changes, we monitored stream flow (baseflow) each month using a Marsh-McBirney flow meter at a single permanent site along Hot Springs, Bass, and Wildcat Creeks. Stream flow measurements were taken by trained TNC field technicians following the methodology described in The Nature Conservancy's Hydrologic Monitoring Manual (TNC 1996) which was reviewed by Arizona Department of Water Resources.

We also mapped the extent of surface flow on USGS 7.5'quads in Bass, Double R, Wildcat and Hot Springs Creeks in May, 1998, using topographic landmarks. In May, 2000, the extent of surface flow was re-mapped using a hand-held GPS unit.

NATIVE FISH AND AQUATIC HABITAT MONITORING

In 1991, we established 8 permanent monitoring stations for native fish and aquatic habitat along the perennial portion of Bass, 5 permanent stations along Hot Springs and 2 permanent stations in Double R; in 1995, 2 permanent stations were established along Wildcat Creek. These stations ranged from 50 m to 200 m in length and were located adjacent to permanent stream or canyon features, making them easy to relocate. At each station (transect), we sampled all of aquatic habitat along that station for native fish using seines or a backpack electroshocker depending on the stream. Hot Springs and Bass were sampled using seines while Double R and Wildcat were sampled with an electroshocker because the latter are too shallow to seine and the substrate is predominately cobbles. Although Double R has been sampled since 1991, we switched from seining to electroshocking in 1995 because we felt that our estimates of fish population size from seining were unreliable. Because the numbers of fish captured by the two methods differ making comparisons difficult, only data collected after 1995 were analyzed for trends. In addition, Wildcat and Double R were sampled "to depletion". This involves blocking-off a 5-10 m portion of the stream at both ends with seines and collecting fish over sequential passes with the shocker until the number captured on a pass is less than 10% of the number captured on the initial pass. In Bass and Hot Springs Creeks, transects were vigorously seined so that all aquatic habitat was sampled at least once; individual seine hauls never exceeded a distance of 2 times the width of stream.

In Hot Springs, Bass, and Double R, prior to sampling, the stream transect was divided into macrohabitats using the classification of McCain et al. (1989) and each macrohabitat was sampled independently and completely. The number of fish captured by species and by age-class (juveniles and adults, determined by size) in each seine haul or shocking period was recorded for each macrohabitat along with the distance of the seine haul or the number of shocking seconds in that macrohabitat. From these data, we calculated relative abundance by species and age-class for each station or the entire stream. In addition, we estimated absolute abundance (density) by dividing fish numbers by the distance seined or time spent electroshocking (i.e., number of fish/meter seined or number of fish/seconds shocking). This controls for year-to-year differences in sampling effort. Table 1 identifies the fish species that occur in the four streams.

Table 1: Native fish fauna in Muleshoe Preserve CMA Streams

	Hot Springs	Bass	Double R	Wildcat
Agosia chrysogaster Longfin Dace	X	X	X	X
Catostomus insignis Sonoran Sucker	X	X		
Gila intermedia Gila Chub	X	X		X
Pantosteus clarki Desert Sucker	X	X		
Rhinichthys osculus Speckled Dace	X	X	X	X

For each of the sequential macrohabitats along a stream transect in Bass, Double R, and Hot Springs, we recorded the length of that macrohabitat, width, 8-10 random depth measurements, maximum depth, cover of woody debris (in meter2) and length of undercut bank (in meters). Transects in Wildcat Creek were sampled in segments but no macrohabitat data were taken.

To further investigate aquatic habitat changes in Hot Springs Creek, in April 1999, we re-sampled a permanent monitoring transect established and measured for the first time by BLM in 1994. The transect was approximately 600 m in length. For each survey, the transect was divided into sequential macrohabitats (see above) and the length, width, average depth, and maximum depth of each was recorded. In addition, all instream cover was classified and measured. Cover categories included: overhanging vegetation (< 1 m high and extending over the water surface); emergent and floating vegetation; and woody debris, all measured in meter2; undercut bank, measured in meters; and riparian canopy cover, measured in percent.

To investigate short-term impacts of the Double R Burn on native fish resulting from off-site effluent emanating from the burn area (i.e., runoff with elevated nutrient or sediment levels), we established four 50-m stream reaches in Bass, two located above the Double R confluence (unaffected, control reaches), the other two located below the confluence (affected reaches). These reaches or stations were sampled seasonally in April-May and October in 1998 and 1999 to determine the effects of winter and summer runoff events on fish populations and aquatic habitat. Fish numbers were estimated using an electroshocker and depletion sampling and aquatic habitat was sampled as described above for the permanent fish-aquatic habitat stations in Bass Creek. Habitat parameters and fish population estimates were compared in the affected and control reaches before and after burning.

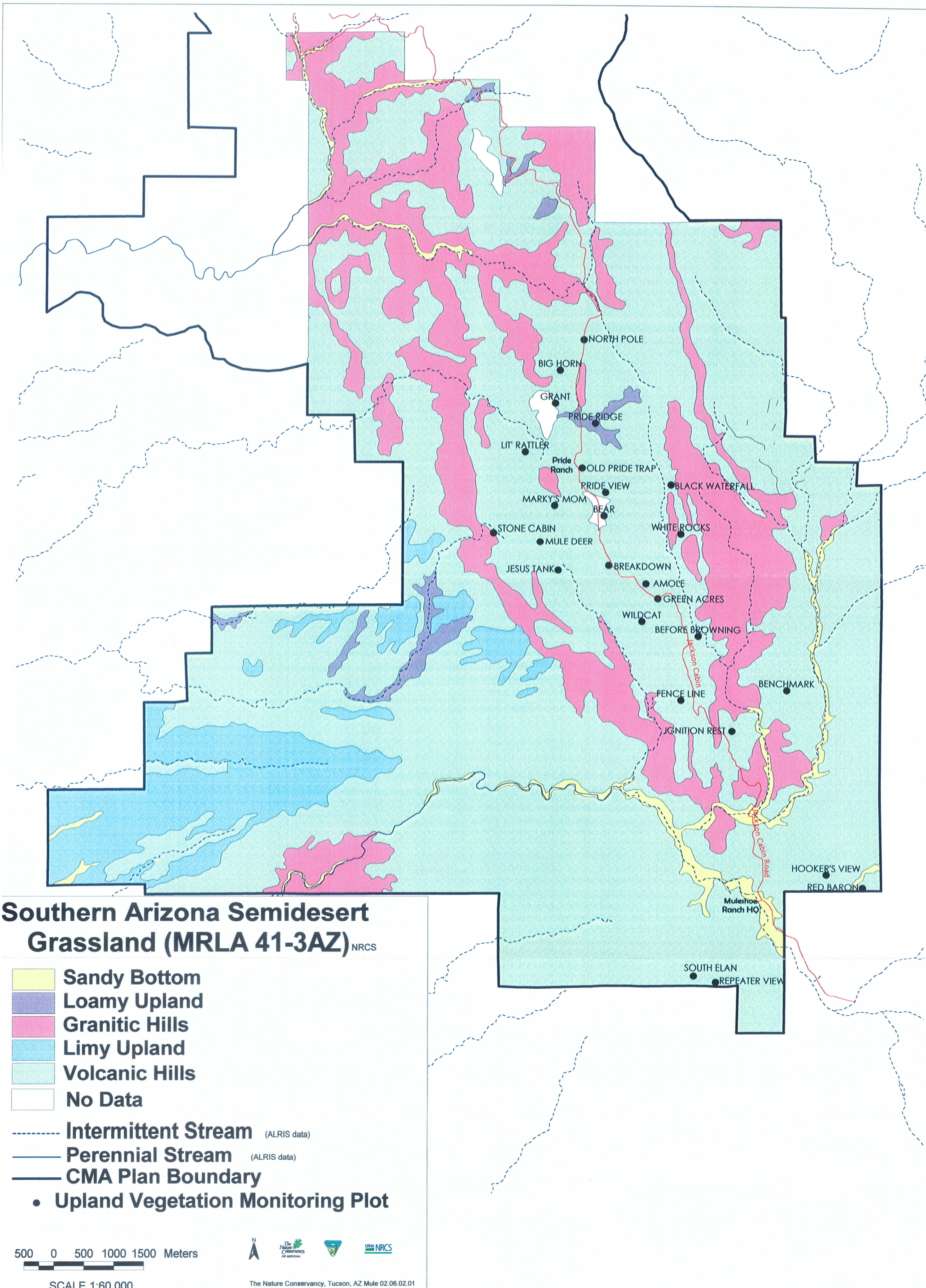
FLOODPLAIN AND CHANNEL GEOMORPHOLOGY MONITORING

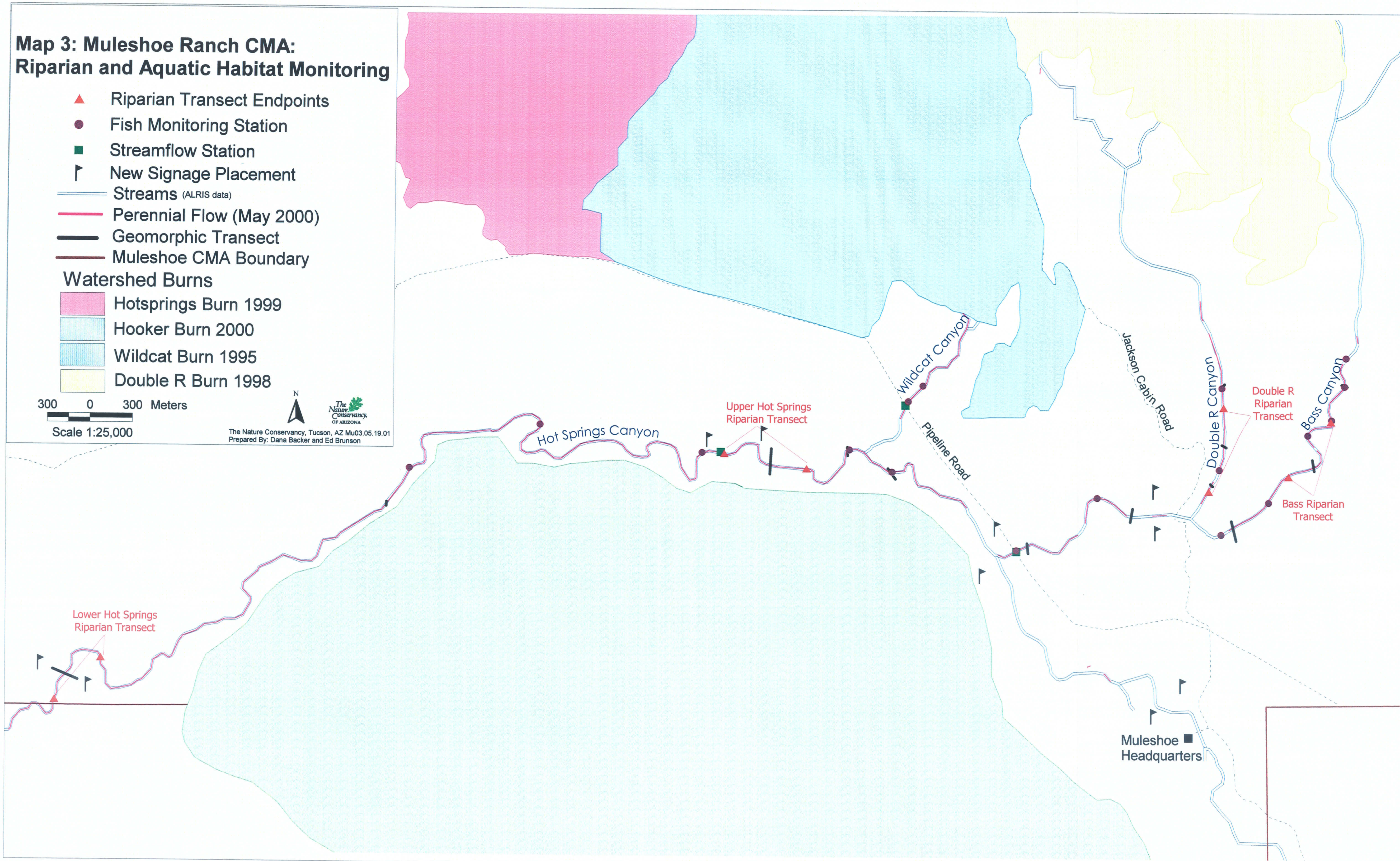
Thirteen permanent transects spanning the width of the floodplain were established in 3 streams. Each was surveyed for its elevational profile (cross-section), using a TOPCON Auto-Level transit. In March 1999, five floodplain cross-sections were established in both Bass and Hot Springs and three in Double R. The transects were distributed uniformly along the length of these streams. Both ends of the transect were permanently marked with rebar and a survey cap and their locations determined with a hand-held GPS unit; photos were taken of the rebar and surrounding area to aid in relocation. Transects will be re-surveyed after 10 years and the frequency of monitoring evaluated and determined for the next 10-year period. The floodplain cross-section data will be compared between sampling periods to identify changes in floodplain morphology and for evidence of sediment aggradation and terrace development.

RIPARIAN VEGETATION MONITORING

An objective of the project is to increase the density of riparian trees in non-seedling size classes and to improve the ratio of sapling to adult trees in Hot Springs, Bass, and Double R (BLM 1998). To detect these changes, three monitoring stations--two in Hot Springs and one in Bass--were established and monitored by BLM in 1994 and a new station was established in Double R in 1998; these were surveyed in spring 1998 and 2000. Stations ranged from 600 to 800 meters in length. Ten to twelve belt transects, 10-feet in width, and spanning the entire floodplain, perpendicular to the stream, were set up at each site; the transects were not permanent so precise relocation was not required. The distance between transects was approximately 75 meters. Within each belt transect, the number of seedlings, saplings, adult trees were counted by species. The length of each transect was also recorded so that densities of the different age-classes could be calculated. In addition, the number of adult and mature trees were counted by species between consecutive belts and recorded separately. Seedlings were operationally defined as plants < 1 cm in diameter at breast height (dbh) or < 2 m tall; saplings were defined as plants 1- 15 cm dbh or > 2 m tall; and adult trees were > 15 cm dbh.

Map 2: Muleshoe Ranch CMA: Upland Vegetation Monitoring Plots and Ecological Sites





Map 3: Muleshoe Ranch CMA:
Riparian and Aquatic Habitat Monitoring
Riparian Transect Endpoints
Fish Monitoring Station
Streamflow Station
New Signage Placement
Streams (ALRIS data)
Perennial Flow (May 2000)
Geomorphic Transect
Muleshoe CMA Boundary
Watershed Burns
Hotsprings Burn 1999
Hooker Burn 2000
Wildcat Burn 1995
Double R Burn 1998
300 0 300 Meters
Scale 1:25,000
N
The Nature Conservancy, Tucson, AZ Mu03.05.19.01
Prepared By: Dana Backer and Ed Brunson
Hot Springs Canyon
Upper Hot Springs Riparian Transect
Wildcat Canyon
Pipeline Road
Jackson Cabin Road
Double R Canyon
Double R Riparian Transect
Bass Canyon
Bass Riparian Transect
Lower Hot Springs Riparian Transect
Muleshoe Headquarters

PHOTOGRAPHIC MONITORING

Photographic monitoring was performed in conjunction with all field monitoring (upland vegetation, riparian vegetation, native fish and aquatic habitat) and was designed to augment quantitative monitoring and document qualitative changes in community structure and composition. Datasheets provided in the Arizona Water Protection Fund's Outline for Photographic Monitoring Plan for initial photographic takes and retakes at each photopoint were completed. Photographs were made at the time of field monitoring.

For upland vegetation, photopoints were established at the four corners of each vegetation plot, marked with rebar and rock cairns, and two photographs were taken at each photopoint showing vegetation within and surrounding the plot.

For native fish and aquatic habitat, a single photopoint was established at the upstream and downstream end of each permanent native fish/aquatic habitat monitoring station in Bass, Hot Springs, Wildcat, and Double R. Two photographs, one looking upstream and the other downstream, were taken at each photopoint location. Precise relocation of photopoints was not critical since the objective was to augment aquatic habitat measurements.

For riparian vegetation, a single photopoint was established at the upstream and downstream end of each of the monitoring stations (reaches). Two photographs were taken at each photopoint, one looking upstream and one looking downstream. Given the dynamic nature of the floodplain, we were unable to permanently mark the photopoint locations, which were approximately in the middle of the channel. In addition, transect locations within the monitoring station were not permanent.

RESULTS

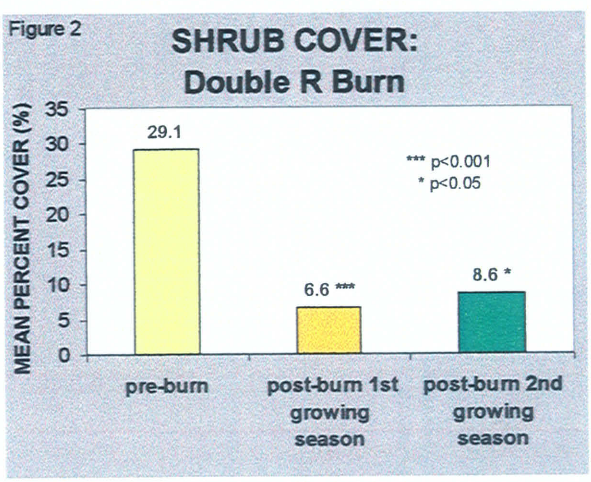
A variety of statistical tests were used to investigate changes in vegetation, aquatic habitat and fish populations pre- and post-burn and over time; two-tailed probability levels for these tests are reported unless otherwise noted. However, one-tailed tests are justified when an a priori directional prediction can be made. This is the case for many of the comparisons presented here given the known effects of fire on semi-desert grassland vegetation and the established relationships between watershed vegetation, watershed hydrological processes, and the condition of riparian and aquatic habitats. The significance level for statistical comparisons was set at $p < 0.05$. In comparisons involving variables expressed in percent, an angular transformation was used on the data prior to conducting the test to normalize variances; reported mean values and their standard errors were calculated on untransformed data. SYSTAT Version 6.0 (1996) was used for statistical analysis. Where appropriate, type of analysis, significant levels and degrees of freedom are provided.

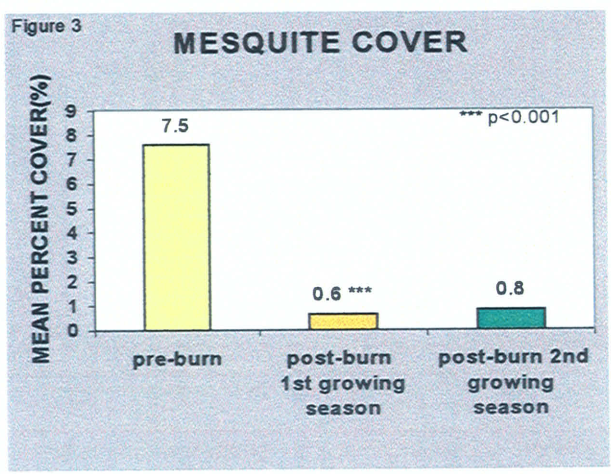
Tables summarizing monitoring data collected during the project funded period are found in Appendix E. Maps 2 and 3 indicate the location of the vegetation, riparian and aquatic monitoring activities. Other maps depicting soil complexes, watershed boundaries, and ecological grassland states (BLM 1998) are included in Appendix H.

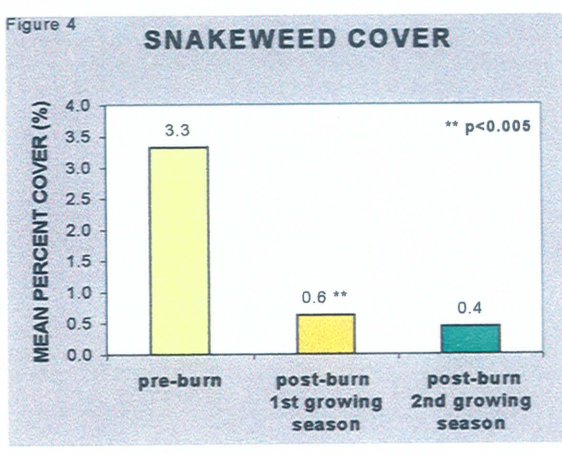
UPLAND VEGETATION

Double R Burn

The Double R burn resulted in a more than 77% reduction in the mean cover of shrubs on plots immediately after the burn (paired t-test; $t = 5.9$, 7 df, $p < 0.001$; Figure 2). However, by the second growing season post-burn, there was a small, i.e. 2%, but significant increase in shrub cover on plots due primarily to resprouting of individuals that survived the burn (paired t-test; $t = 2.6$, 7 df, $p < 0.05$). Shrub species responded differently to burning: species like mesquite (*Prosopis velutina*) were either killed outright or, more frequently, were top-killed and then resprouted from a surviving root stock (Figure 3); for others, like amole (*Agave schotti*) or soap weed (*Yucca arizonica*) that grow in large patches, most ramets were killed by the burn but some in the patch survived and began reproducing vegetatively. Still, others, like snakeweed (*Guitterizia sarothrae*), were killed by the burn but could potentially re-colonize via seedling recruitment after wet winters. Post-burn recruitment of snakeweed was



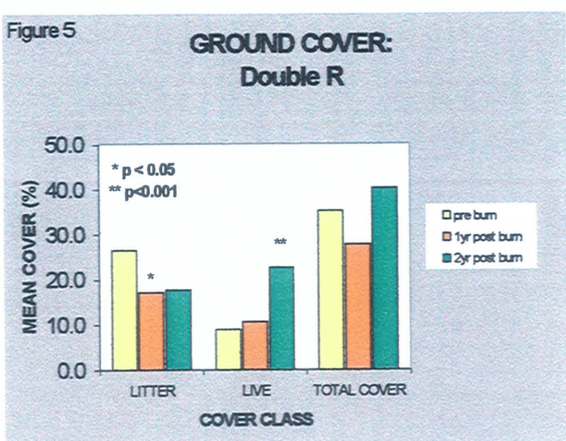


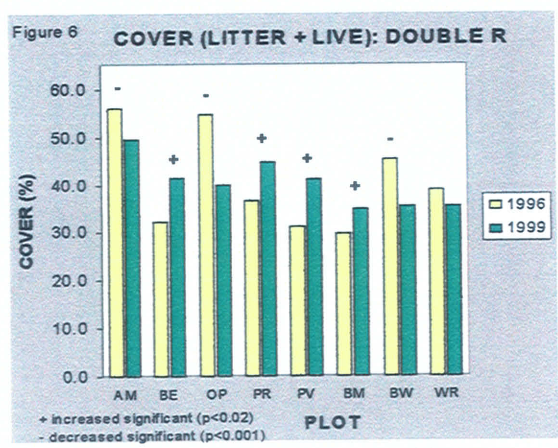


not evident on plots after two-growing seasons (Figure 4; paired t-test, $t = 0.08$, $p > 0.93$). Thus, repeated burns are needed to kill young shrubs and knock back, i.e., top-kill, others.

To investigate the effect of the burn on substrate cover, we compared litter, live basal cover, and total ground cover in plots pre- and post-burn. Live basal cover includes grasses (perennial and annual) and herbaceous vegetation. Total ground cover, calculated as the simple arithmetic sum of litter and live basal cover, is an important indicator of watershed condition since it measures the watershed's capacity to capture and retain precipitation runoff, prevent soil erosion, and encourage infiltration (Horton 1937; USDA 1940; Simanton et al. 1977; Woolhiser et al. 1990; Thurow 1991). Furthermore, Wilcox et al. (1988) have shown that grass cover was the dominant factor in reducing runoff and increasing infiltration while shrub cover had no significant effect. Trombel et al. (1974), Meeuwig (1970) and Dortignac and Lover (1961) found litter cover to be important in infiltration.

Mean litter cover in plots was significantly reduced by the Double R Burn, from a pre-burn value of 26.6% down to 17% in the first growing season after the burn (Figure 5; paired t-test, $t = 2.67$, 7 df, $p < 0.05$). However, there was no significant increase in litter cover by the second growing season (paired $t = 0.6$, 7 df, $p > 0.57$). Live basal cover fully recovered to pre-burn levels one growing season after the burn (paired $t = 0.83$, 7 df, $p > 0.40$), and more than doubled from 10.7% to 22.7% over the second growing after the burn (Figure 5; paired $t = 5.4$, 7 df, $p < 0.001$). This increase was presumably due, in part, to the reduction in shrubs, which increased water availability for growth and recruitment of herbaceous vegetation including grasses. Consistent with this, total ground cover was reduced by the burn--from 35.3% to 27.7% (paired $t = 2.21$, 7 df, $p = 0.06$)--but fully recovered to 40.3% by two growing seasons after the burn. The apparent increase in 1999 over the pre-burn level was not

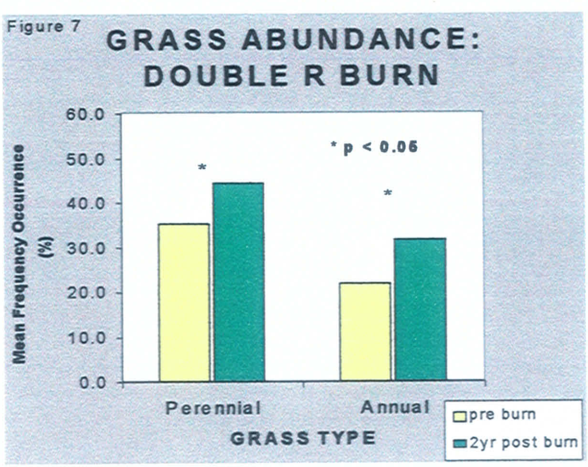


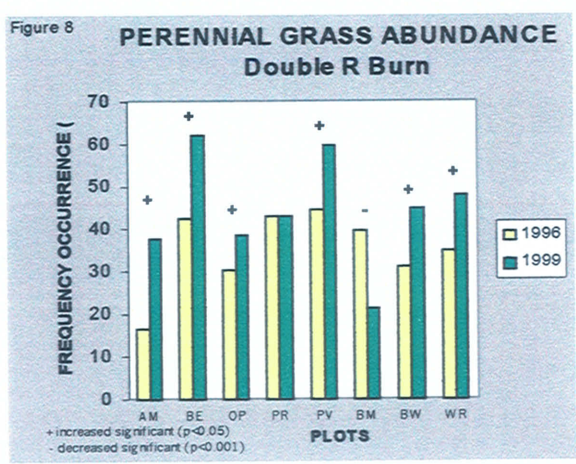


statistically significant (paired $t = 1.25$, 7 df, $p > 0.25$). However, this result does not mean that no change occurred because with only 8 plots statistical power was low. Therefore, it is instructive to examine the change in total ground cover in individual plots. Five out of eight plots showed significantly greater total cover (litter + live basal) two growing seasons after the burn compared to pre-burn levels (Figure 6; all X^2's > 5.3, 1df, all p's < 0.02); one plot (OP) had significantly less total cover ($X^2 = 28.8$, 1 df, $p < 0.001$), and 2 of 8 plots (BW,WR) showed no change in total cover between 1996 and 1999. In the latter plots, ground cover in 1999 was less than pre-burn levels because litter had not fully recovered after the burn. Thus, the majority of plots experienced an increase in total cover over pre-burn levels suggesting that watershed condition had improved over most, but not all, of the unit after only two growing seasons.

Did the increase in live basal cover after two growing seasons represent an increase in annual grasses, perennial grasses or both? To measure changes in grass abundance, we compared the frequency of perennial and annual grasses in quadrats, combining species into the two functional groups. We used the 0.16 m^2 quadrat size for annuals and the 0.01 m^2 quadrat for perennials so that frequencies for both would fall between 20-80% (see Methods). The frequency of occurrence of annual grasses increased significantly from 21.8% before the burn (1996) to 31.6% two growing seasons after the burn (1999), a proportionate increase in abundance of over 40% (Figure 7; paired t-test, 1-tailed; $t = 2.4$, 7 df, $p < 0.05$). This estimated increase is conservative since frequency sampling measures only presence or absence and doesn't distinguish between quadrats containing 1 vs. 20 individuals. Similarly, the abundance of perennial grasses increased significantly from 35.3% before the burn to 44.4% two growing seasons after the burn, a proportionate increase of over 25% (Figure 7; paired t-test, 1-tailed; $t = 2.1$, 7 df, $p < 0.05$). Looking at the individual plots, 6 out of 8 plots showed a significant increase in perennial grass abundance two growing seasons after the burn compared to pre-burn levels (all X^2's > 2.8, 1 df, all p's < 0.05), 1 plot (BM) showed a significant decrease ($X^2 = 15.0$, 1 df, $p < 0.001$), while another plot (PR) showed no difference in perennial grass abundance pre- vs. post-burn (Figure 8).

Thus, the Double R Burn in 1998 resulted in a decrease in shrub cover and an increase in annual and perennial grass abundance in plots after only two growing seasons. In addition,

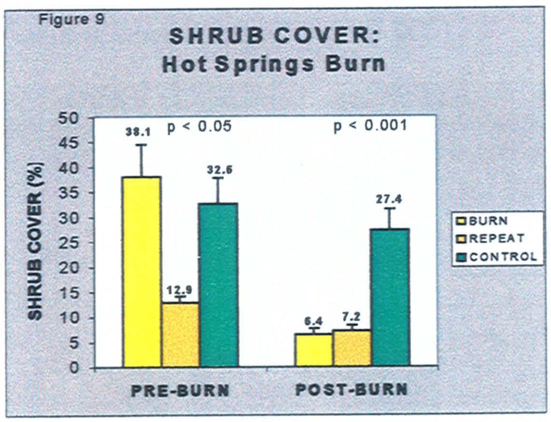




total ground cover, a summation of litter and live basal cover, increased significantly after the burn in a majority of plots in the unit. Since grass cover is the dominant factor reducing runoff and increasing infiltration (Wilcox et al. 1988), there is good evidence that the burn improved watershed condition within two growing seasons. With additional time and growth of the newly recruited grasses, litter and live basal cover should continue to increase, leading to further improvement in watershed condition.

Hot Springs Burn

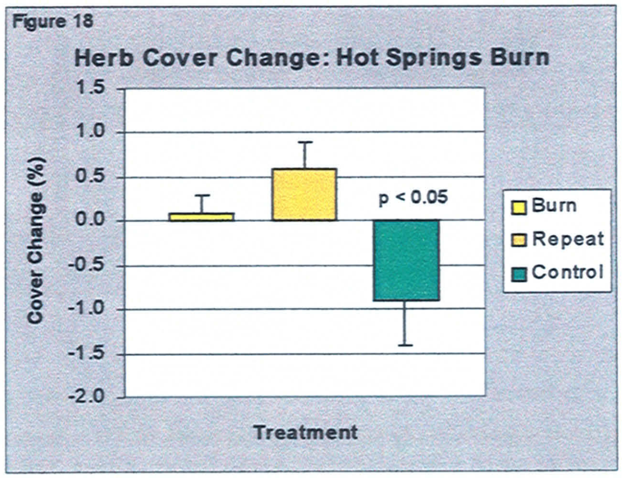
Like the previous burn, the Hot Springs burn resulted in a substantial reduction in shrub cover on burn and repeat burn plots compared to controls. Prior to the burn, there were significant differences in shrub cover between treatment groups (Figure 9; ANOVA, $F_{2,15} = 4.9$, $p < 0.05$); in particular, shrub cover on repeat plots was significantly lower than on burn and control plots (Fisher's Least Significant Difference Test, both p's < 0.05). This difference was presumably due to the effect of previous prescribed burns on shrub cover in repeat plots. By two growing seasons after the burn, shrub cover was significantly reduced on burn and repeat plots compared to controls (Figure 9; ANOVA, $F_{2,15} = 22.0$, $p < 0.001$). Shrub cover was reduced to a similar level on burn and repeat plots two growing seasons after the burn (6.4% and 7.2% respectively; Fisher's LSD test, $p > 0.65$). However, cover on control plots



remained high (27.4%). In relative terms, shrub cover was reduced most on burn plots (82.7%), followed by repeat plots (40.8%) and showed little change on controls (1.1%). These relative changes are all significantly different from one another (Fisher's LSD test; all p's < 0.05). Thus, prescribed burns reduce shrubs and repeated burns remain effective in keeping shrubs knocked back, periodically reversing the increase that occurs after a burn.

To assess how various shrub species were affected by prescribed burns, we compared the proportionate change in cover pre- vs. post-burn for 5 common shrub species: *Acacia constricta, Guitterizia sarothrae, Prosopis velutina, Agave schotti, and Juniperus coahuilensis*. Proportionate change was calculated as the difference in mean cover before and after burn divided by the mean pre-burn cover. Although sample sizes were small, the relative reduction in cover due to the burn was similar for 4 of the 5 species and ranged from 77% to 98% (Fisher's test, all p's > 0.25). Juniper differed from the other 4 species, showing a significantly smaller reduction (19.2%) after the burn (Fisher's test, all p's < 0.001).

To investigate the effect of the Hot Springs burn on grass abundance, we compared the frequency of perennial and annual grasses in nested quadrats pre- vs. post-burn. There was no herbs on burn and repeat plots increased in absolute terms by 0.08% and 0.6%, respectively, while cover decreased on control plots by 0.9% (Figure 18). Although these changes were small, the differences between control plots vs. burn and repeat plots were significant (Fisher's test, p's < 0.05).



To summarize the above results, the abundance and basal cover of perennial grasses was similar before and after the burn on burn plots such that the burn appeared to mitigate the decrease in perennial grass cover observed on control plots. This beneficial effect of burning may be restricted to areas or plots that were burned only once. Repeated burns over a 5-year period resulted in a reduction in the abundance but not basal cover of perennial grasses on plots suggesting that burning at this frequency can be stressful to perennial grasses. The burn increased annual grass abundance and cover on plots, with repeated burns over a 5-year period increasing annuals to a greater extent than a single burn did. This greater increase on repeat plots was presumably due not only to a reduction in shrubs (compared to control plots) but also a reduction in perennial grass abundance (compared to burn plots). Similarly, the burn increased the basal cover of herbs on burn and repeat plots compared to controls. In this case, however, the change on burn plots was similar to that on repeat plots.

To investigate the effect of the burn on litter, live basal, and total ground cover, we compared burn and control groups. Before the burn, litter and live basal cover were similar on plots (Figure 19; t-tests; $t_{litter} = 1.5$, 12 df, $p > 0.18$; $t_{live} = 1.8$, 12 df, $p = 0.13$), although, total ground cover was significantly on control plots than on burn plots (51.2% and 34.2% respectively; t-test, $t = 3.7$, 12 df, $p = 0.003$). By two growing seasons after the burn, litter cover was significantly lower on burn plots compared to controls (21.9% and 38.0% respectively; $t = 4.0$, 12 df, $p = 0.002$; Figure 19) presumably because litter was consumed by the fire while increasing on controls. After the burn, live basal cover was greater on burn plots compared to controls (12.1% and 4.3% respectively; $t = 6.2$, 12 df, $p < 0.001$) as was total ground cover but the latter difference was only marginally significant ($t = 2.09$; 12 df, $p=0.059$).

unchanged. These young trees self-thin as they compete for available nutrients and light, accounting for this decrease over time. Because of the absence of flood events between 1998 and 2000, recruitment of cottonwood, willow and sycamore would be minimal and would not offset the mortality from competition. Since 1998, the number of adult trees within the belt transects and the density of adults increased in all reaches with the exception of Lower Hot Springs. The density of sapling plus adult trees was highest in 1998 and decreased slightly in all reaches since then except in Double R Canyon. Because of their spatial distribution, it is unlikely that more than one adult tree will occur within a 10-foot belt. Therefore in 1998, we began counting the number of adult trees within and between successive belts to obtain the total number of trees along the length of the monitoring reach or station (referred to as block density). Table 3 compares adult tree density estimated from the belt transects with that estimated from the entire block. We believe the latter is a more accurate measure of tree density within the floodplain because it eliminates sampling error. Using this estimate, tree density increased at all sites between 1998 and 2000, approaching but not reaching the targeted densities set in the plan.

The density of riparian trees is considered one of the best indicators of properly functioning condition because tree density affects bank-building, bank armament, terrace development, and dissipation of flood energy. Sapling to tree ratios are a measure of the structural diversity of the riparian community and recruitment of young trees.

Table 2: Muleshoe Riparian Area Vegetation. Sapling and tree densities for 2000, 1998 and 1994, expressed as number of individuals per acre. Target densities and ratios (from Muleshoe Ecosystem Management Plan) are shown.

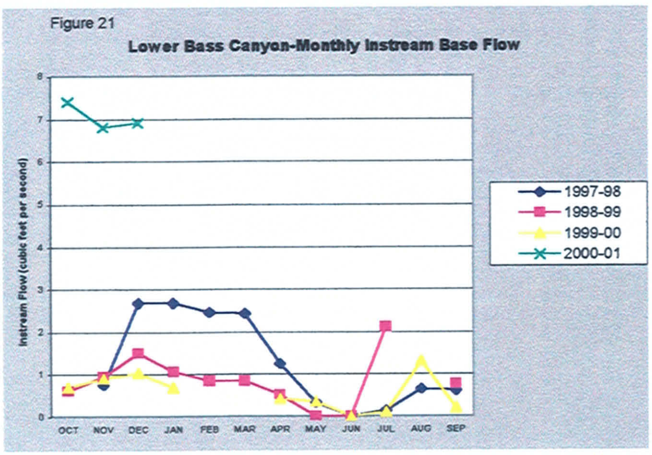
	Density (per acre) Sapling +Adult Trees *based on belt transect*			Density (per acre) Adult Trees *based on belt transect*			Ratio of Densities (per acre) Sapling:Tree *based on belt transect*			Target Sapling + Tree Density	Target Tree Density	Target Ratio Sapling:Tree
	2000	1998	1994	2000	1998	1994	2000	1998	1994			
Upper Hot Springs	992	1044	60	36	29	8	26.5 (956:36)	35.2 (1015:29)	6.5 (52:8)	>200	60	3.0 (180:60)
Lower Hot Springs	622	820	202	46	108	64	12.6 (577:46)	6.5 (935:143)	2.2 (138:64)	>450	128	3.0 (384:128)
Bass Canyon	856	943	116	79	47	45	9.9 (778:79)	19.1 (896:47)	1.6 (71:45)	>425	116	3.0 (348:116)
Double R Canyon	272	250		59	47		3.6 (213:59)	4.4 (203:47)				

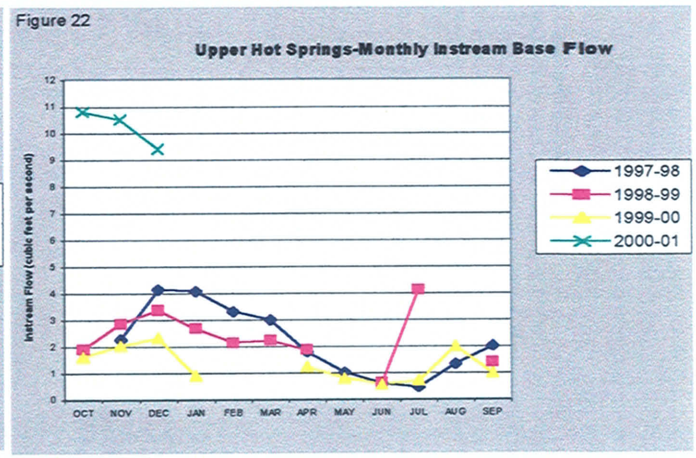
Table 3: Number and Density of Adult Trees in Belt Transects and Block

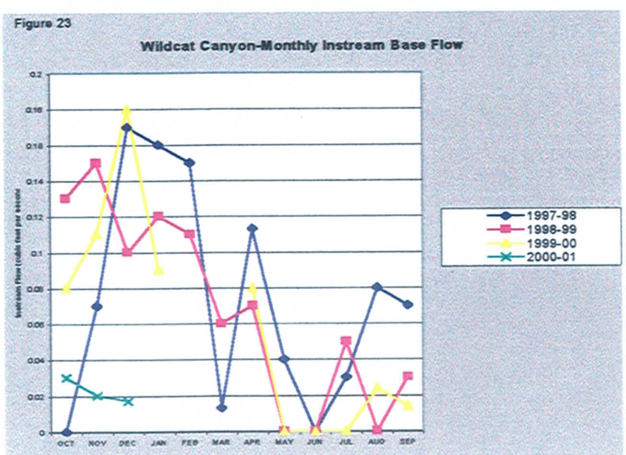
		Number trees in Belt Transect	Number trees between Belt Transect	Total Number of Trees	TREE **BELT** DENSITY (#/acre)	TREE **BLOCK** DENSITY (#/acre)
Upper Hot Springs						
	2000	15	227	242	36.1	26.2
	1998	13	60	73	28.9	6.8
Lower Hot Springs						
	2000	14	187	201	45.6	26.7
	1998	29	14	43	108.5	5.9
Bass Canyon						
	2000	38	430	468	78.8	42.9
	1998	22	175	197	46.8	18.8
Double R Canyon						
	2000	24	261	285	59.4	30.8
	1998	17	199	216	46.6	25.8

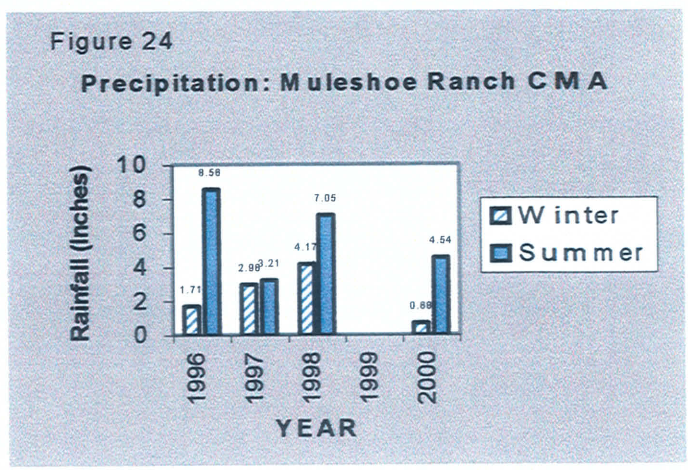
STREAMFLOW

The results of analyses of stream flow data are presented in the following section. Monthly instream flow measurements, in cubic feet per second, are recorded in Table 4 and Figure 21 through 23. Map 6 depicts the extent of perennial flow in May 1998 and May 2000 in Bass, Hot Springs, Wildcat and Double R creeks. The extent of perennial flow observed May 2000 was slightly less than that in May 1998 in all streams; presumably due to the lack of precipitation during the winter months of 2000 (Figure 24).

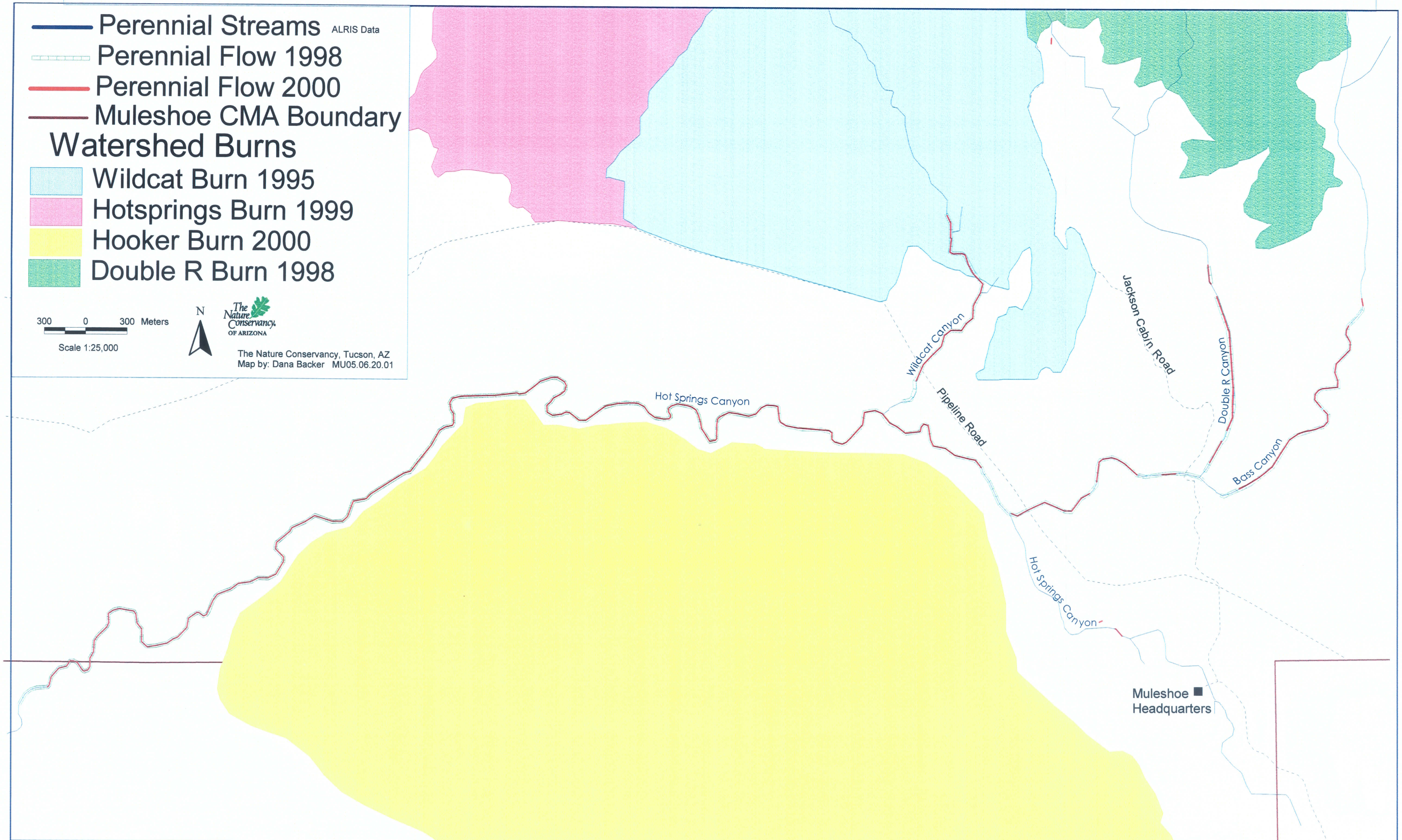








Map 6: Muleshoe Ranch CMA: Perennial Flow recorded in May 1998 and May 2000

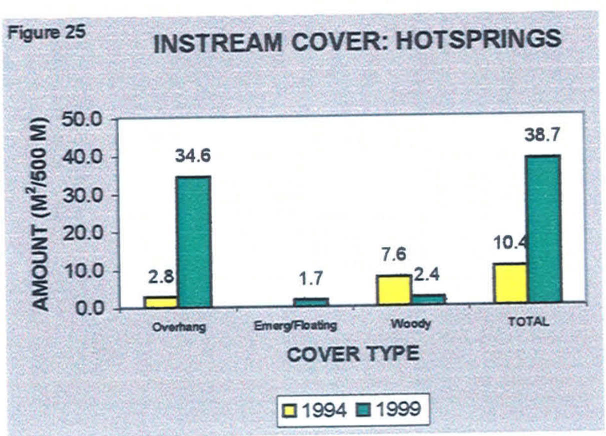


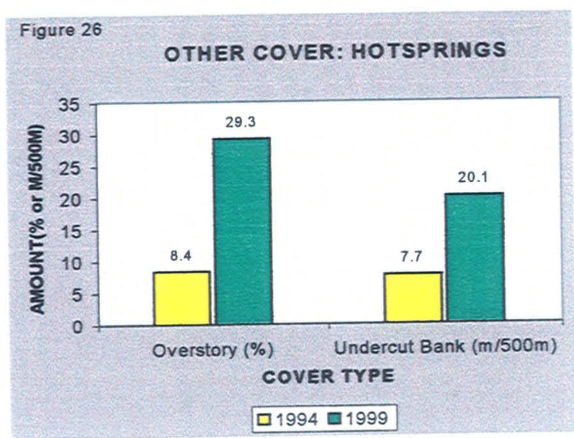
AQUATIC HABITAT AND NATIVE FISH POPULATIONS

Based on the conceptual model, the effect of improved watershed conditions should benefit aquatic habitat and native fish populations. Data collected in several streams from 1991 to 2000 indicate significant improvements in both.

Hot Springs Creek

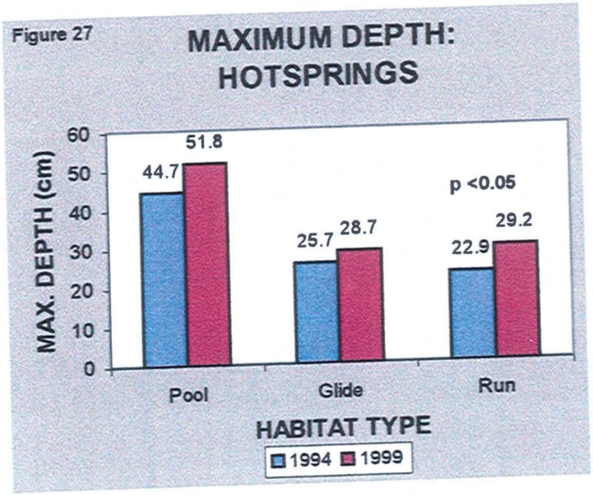
To investigate changes in aquatic habitat quality, we compared the amount of several types of instream cover present on the BLM aquatic habitat monitoring station in 1994 and 1999. Instream cover is an important component of aquatic habitat since it provides structural complexity and protective cover for fish. Between 1994 and 1999, total instream cover increased by over 3.7 times along the transect (Figure 25). This includes increases in emergent, floating and overhanging vegetation, the latter of which increased by over 12 times between 1994 and 1999. Similarly, undercut bank increased from 7.7 m/500 m of stream to 20.1 m/500 m (Figure 26). Percent cover by overstory riparian trees also increased by more than 3.5 times (t-test, $t = 5.4$, 74 df, $p < 0.001$) which presumably resulted in cooler water temperatures and greater concentrations of dissolved oxygen.

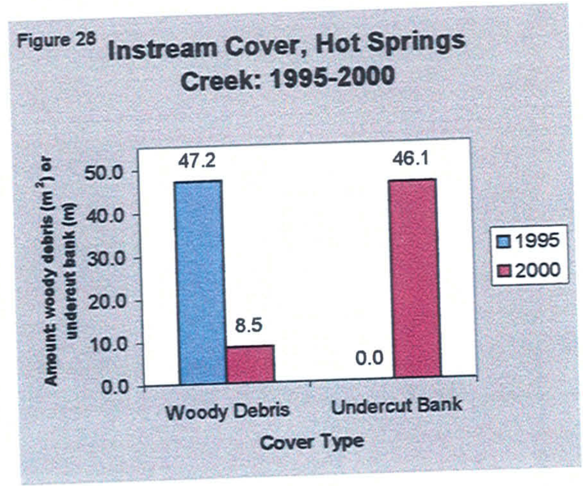




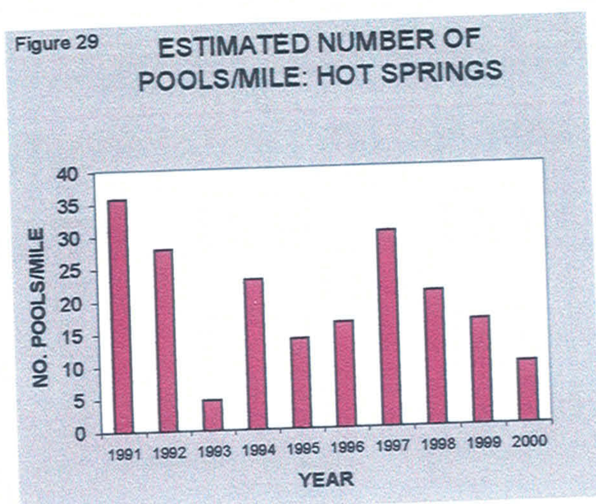
The maximum depth of all aquatic macrohabitats showed a small, but significant increase between 1994 and 1999 (ANOVA, $F = 2.8$, 1 df, $p < 0.05$, one-tailed test). Figure 27 summarizes the changes in mean maximum depth for pools, glides, and runs, the habitats that showed the greatest increase in depth along the transect.

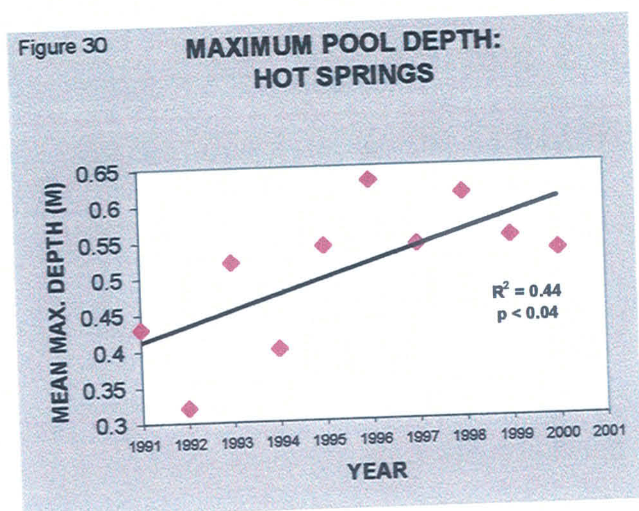
Consistent and parallel improvements in aquatic habitat and native fish populations were evident when analyzing data collected along the 5 permanent "fish" transects between 1991 and 2000. The amount of woody debris on transects declined between 1995, when these cover measurements were initiated, and 2000, while the amount of undercut bank increased dramatically over this period (Figure 28).

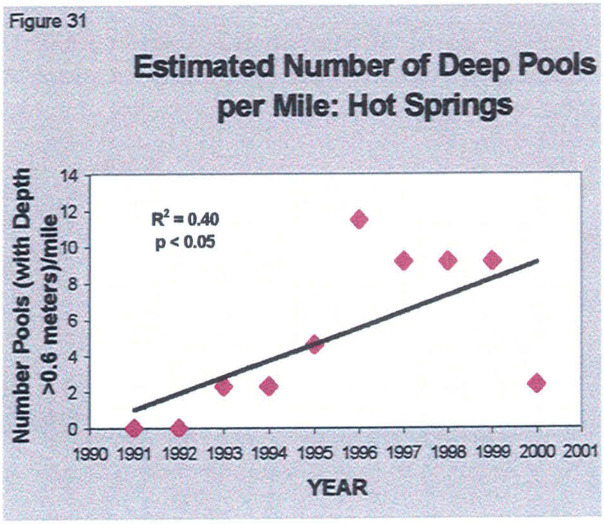


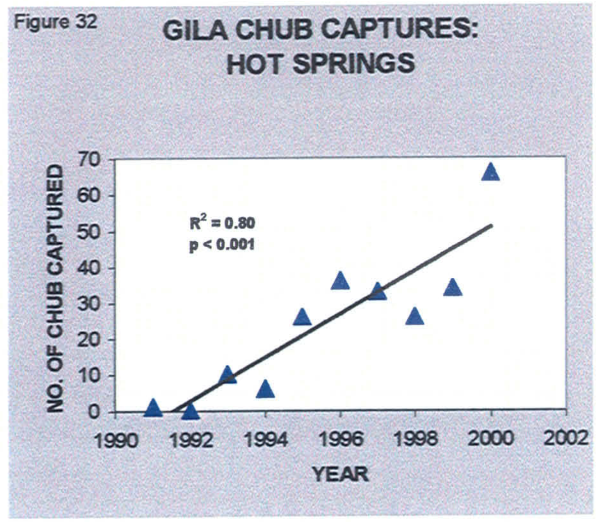


Much of our analysis is focused on pools, the preferred habitat of Gila chub (*Gila intermedia*) because the species is a candidate for federal listing by US Fish and Wildlife Service and because pool habitat is targeted in the Muleshoe Ecosystem Management Plan. The number of pools per mile, estimated from the 5 permanent transects, varied from year to year with no directional trend evident for the 10-year period (Figure 29; $R^2 = 0.17$, $p > 0.20$). The mean maximum depth of pools, however, has increased significantly since 1991 (Figure 30) as has the number of deep pools per mile, defined as pools with a maximum depth greater than 0.6 meters (Figure 31). Interestingly, the correlation coefficients for the latter regressions were larger for the 1991-1999 time period suggesting that some other factor(s) affecting habitat depth have come into play since 1998 or 1999. We will discuss several possible reasons for this decrease in the discussion.



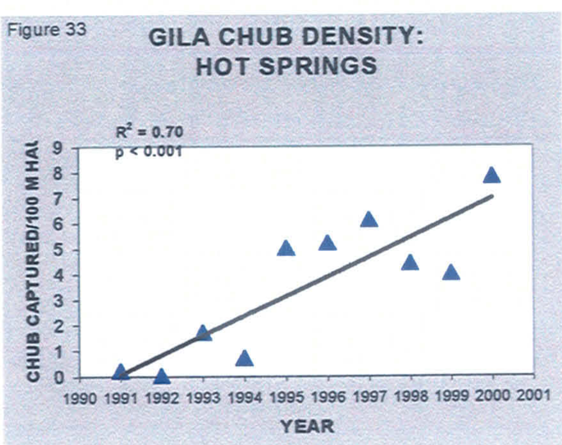


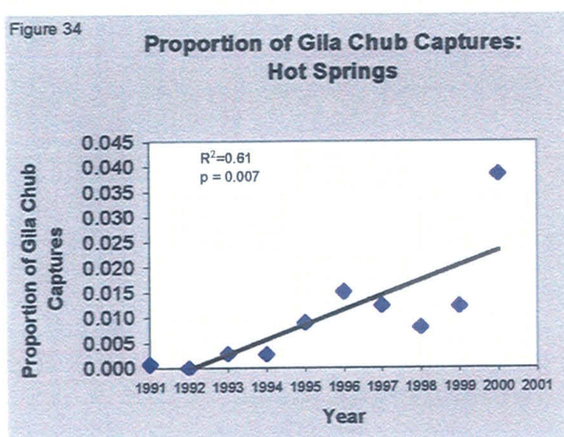


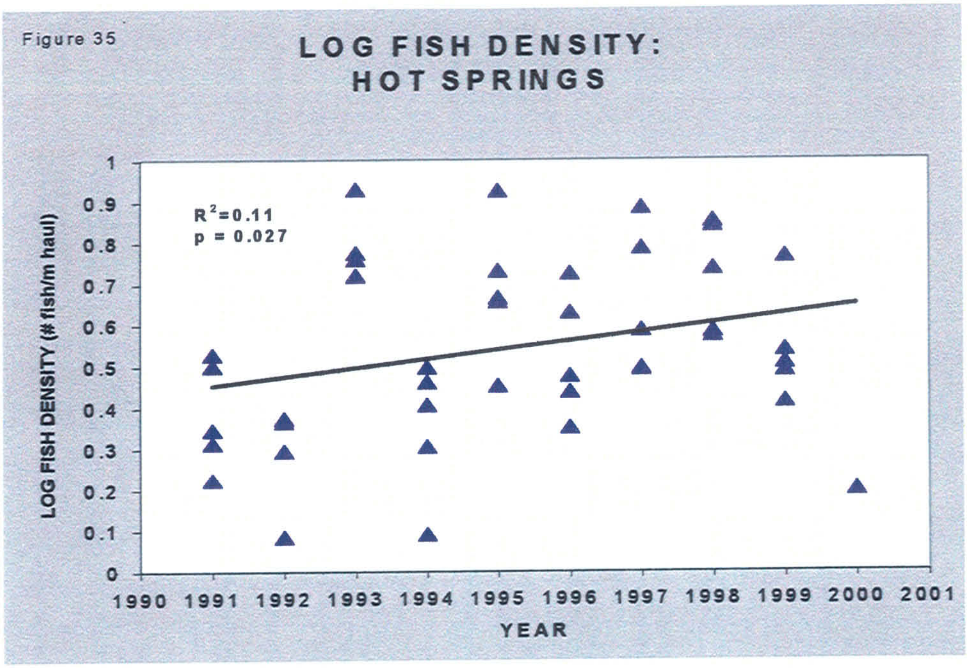


The increase in the depth of pools and other habitats since 1991 was not due to increasing stream flow. In fact, stream flow for January, March, April, May and June have all decreased significantly between 1991 and 2000 (all p's ≤ 0.006) presumably in response to reduced summer and winter rainfall that has occurred regionally over the last decade (see Discussion). This suggests that the increase in habitat depth has resulted from a change in channel morphology.

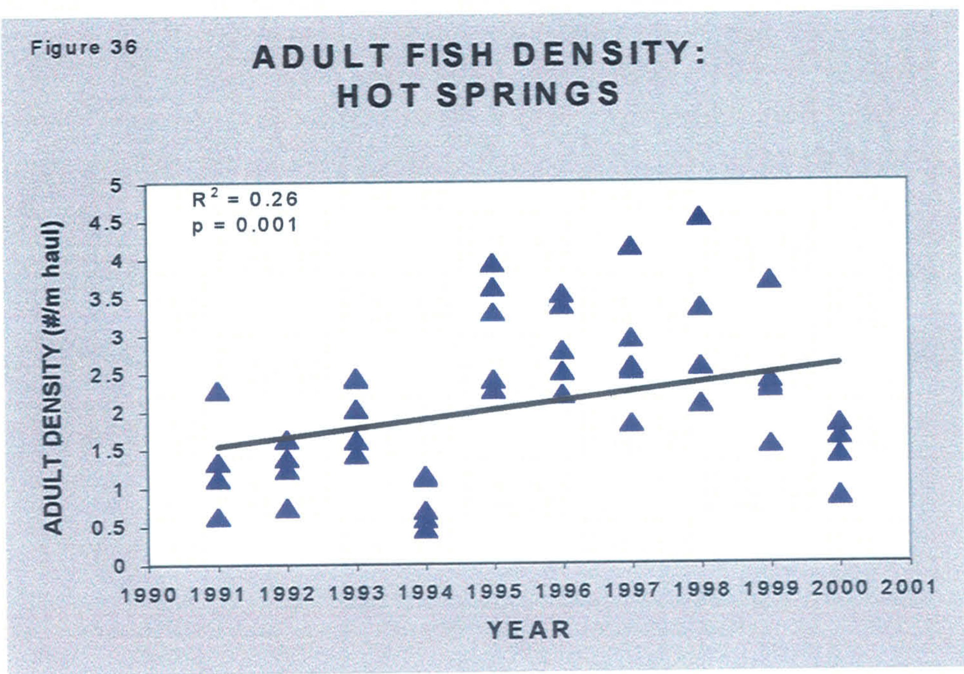
Gila chub have responded favorably to the increase in instream cover, maximum pool depth, and the density of deep pools. The number of chub captured per year and chub density have both increased significantly since 1991 (Figure 32). During the 10-year period, chub density increased at a mean annual rate of 32.8% (Figure 33). The proportionate representation of chub among the fish fauna in Hot Springs has also increased (Figure 34). Chub accounted for only 0.007% of fish captures in 1991 while in 2000 they accounted for 3.8%, a more than 500-fold increase over the 10-year period.







Fish density, expressed as the logarithm of the number of fish captured per meter haul, increased significantly since 1991 as did the density of adult fish (Figures 35, 36). Fish density increased at a mean annual rate of 2.2% while adult density increased by 4.4%. The

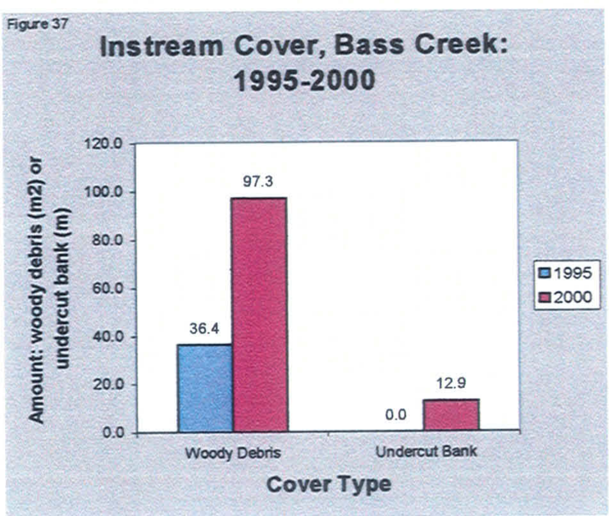


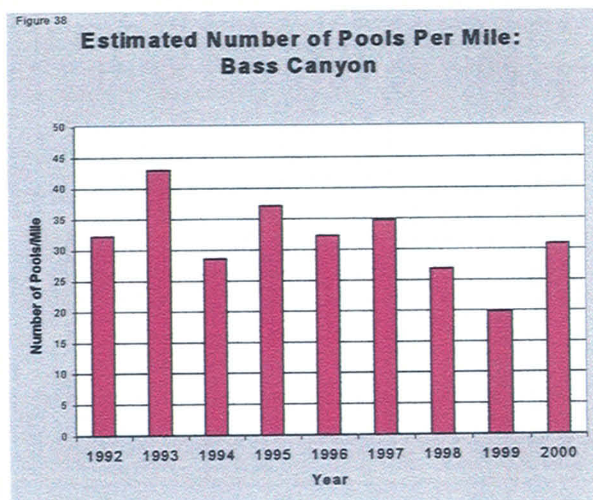
regressions for 1991-1999 had larger correlation coefficients indicating stronger increasing trends for fish density and adult density for this time period. A logarithmic or exponential model for population change better fit the fish density data than a linear model.

Bass Creek

Improvements in aquatic habitat and native fish populations were also evident when analyzing data collected along the 8 permanent "fish" transects in Bass Creek between 1992 and 2000.

The amount of woody debris and undercut bank on transects increased between 1995 and 2000 (Figure 37). The number of pools per mile varied from year to year but there was no directional trend (Figure 38; $R^2 = 0.32$, 8 df, $p = 0.11$). The mean maximum depth of pools, increased significantly since 1992 (Figure 39) but the number of deep pools per mile showed no consistent trend with time ($R^2 = 0.21$, 8 df, $p > 0.20$). The increase in the maximum depth of pools since 1992 cannot be attributed to an increase in stream flow because stream flow in January, March, April, May and June have all decreased significantly between 1992 and 2000 (all p's ≤ 0.03). Again, this suggests a change in channel morphology. In contrast to the situation in Hot Springs, all of the pool habitat regressions had larger correlation coefficients from 1992-2000 than from 1992-1999 suggesting that habitat improvements are continuing in Bass Creek.





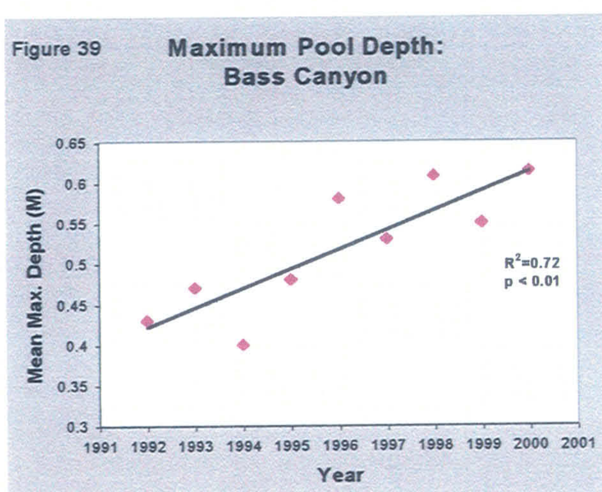


Figure 40

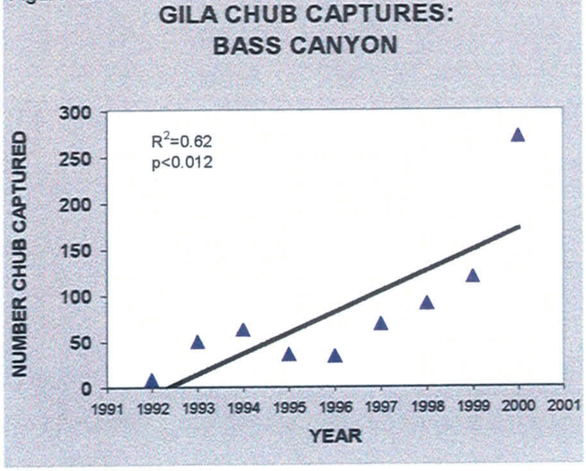


Figure 41

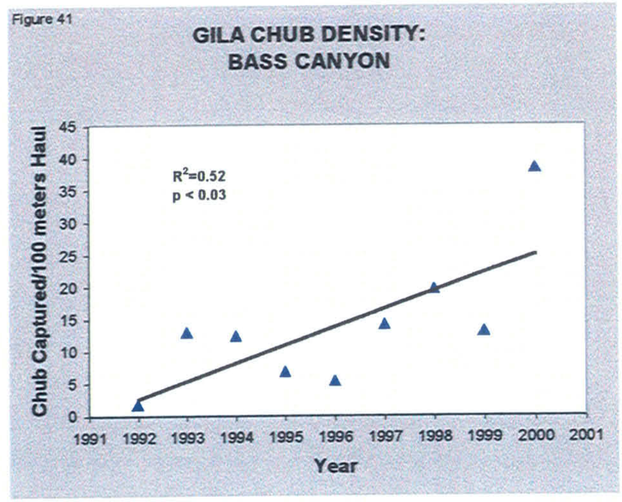


Figure 42

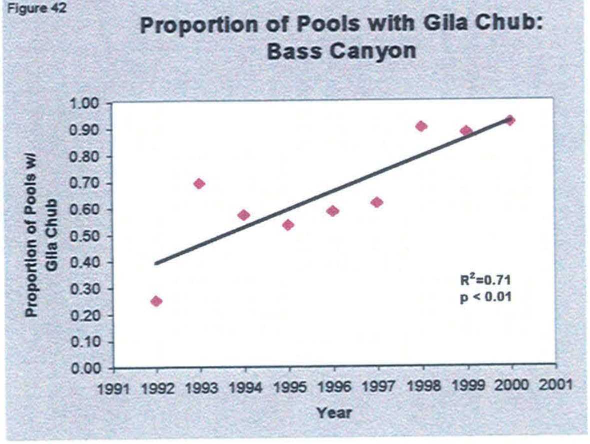
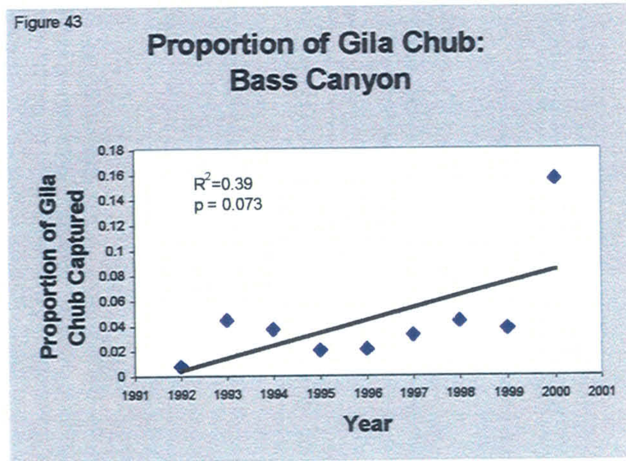
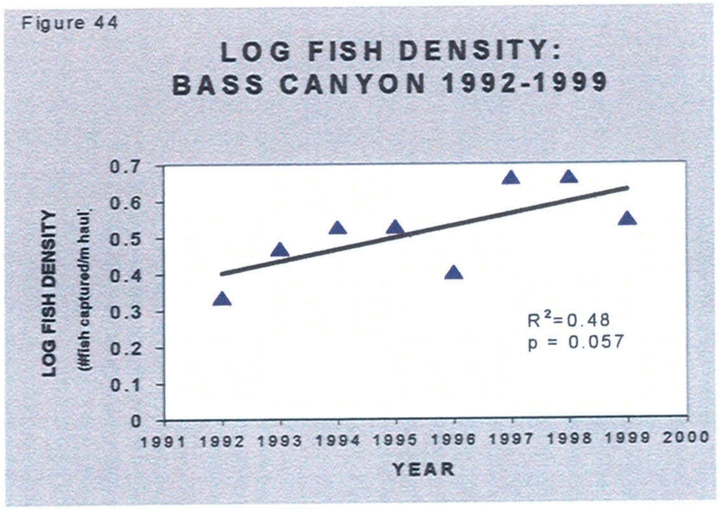


Figure 43



The number of chub captured per year and chub density have both increased significantly since 1992 (Figures 40, 41). The mean rate of density increase was 25.2% per year for the 9-year period. The proportion of pools with chub also increased significantly since 1992 suggesting that chub are occupying more of the available habitat (Figure 42). Consistent with this, the proportionate representation of chub among the fish fauna in Bass increased since 1992 (Figure 43) with chub accounting for only 0.8% of fish captures in 1992 compared to 15.6% in 2000, a more than 19-fold increase since 1992.

Fish density increased significantly between 1992 and 1999 (Figure 44) but the trend disappeared when the 2000 data were added ($R^2 = 0.12$, 8 df, $p > 0.35$). Adult density showed no significant trend either from 1992-1999 or from 1992-2000 (R^2's < 0.10, 7,8 df, p's > 0.45).



Double R Creek

Consistent with the results for Hot Springs, the amount of woody debris on transects decreased between 1995 and 2000 while undercut bank increased (Figure 45). The maximum depth of all habitats increased from 1995 to 2000 (ANOVA, $F_{1,69} = 8.0$, $p = 0.006$) including the maximum depth of pools ($R^2 = 0.72$, 5 df, $p < 0.05$). The number of pools per mile showed no directional trend for the 6-year period ($R^2 = 0.32$, $p = 0.11$). Double R Creek is small and shallow with no deep pools; as a result only speckled dace and longfin dace, the smaller, shorter-lived species occur there (Table 1). Like Wildcat Creek, streamflow is low to immeasurable in May and June and from November to January appears (to the experienced observer) to be less than 0.2 cfs.

The increase in the maximum depth of habitats was *probably* not due to increasing stream flow over this period although this cannot be directly demonstrated as no measurements were made in Double R. On the one hand, stream flow in Bass and Hot Springs were highly correlated between 1992 and 2000 so it seems likely that stream flow in Double R, a tributary of Bass (and Hot Springs) also decreased over this period. However, Wildcat, another tributary of Hot Springs (but not of Bass and Double R) did not show as strong a pattern of declining flows since 1992 suggesting that inferences from other streams should be applied cautiously.

Despite the apparent improvement in aquatic habitat, fish density and adult fish density in Double R decreased between 1995 and 2000 although the latter trend was only marginally significant (Figure 46; $R^2_{adult\ density} = 0.27$, 11 df, p = 0.086). Fish density declined at a mean rate of 19% per year, while adult density declined by 11% per year. The decline in fish density, but not adult density, was also evident between 1995 and 1999 although the strength of the trend was weaker compared to 1995-2000 and only marginally significant ($R^2 = 0.34$, 9 df, p = 0.079). Double R fish monitoring in 2000 occurred a week after a large flood on October 10-11. The decrease in fish density and adult density in Double R was probably due in part to the October flood although the 1995-1999 results suggest that a declining trend for fish density was already underway.

Figure 45

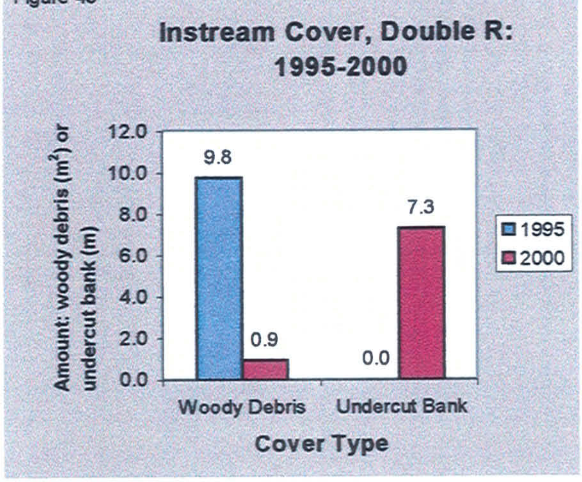
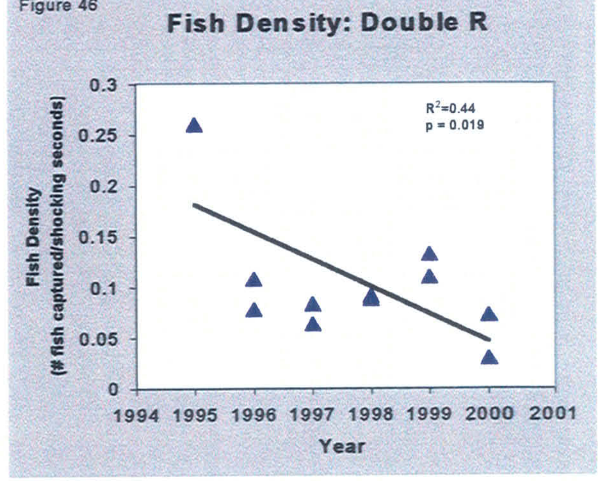


Figure 46



Wildcat Creek

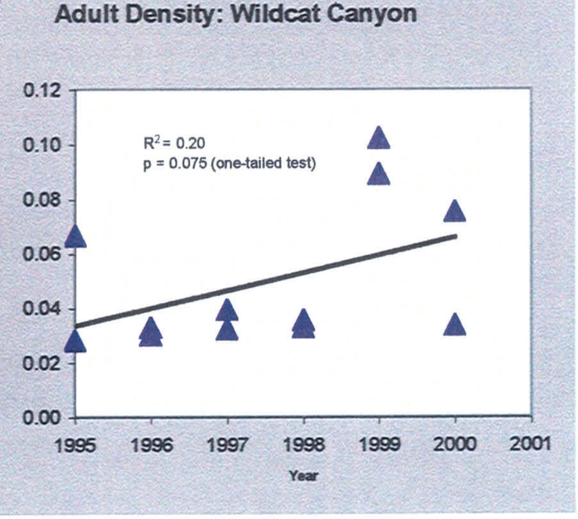
No habitat information was collected in Wildcat. Stream flows in March and May showed a marginally significant decline between 1992 and 2000 ($R^2_{March} = 0.46$, 6 df, p = 0.094; $R^2_{May} = 0.37$, 8 df, p = 0.082); for all other months, there was no apparent trend in stream flow with time.

Fish density varied between 1995 and 2000 but no increasing or decreasing trend was discerned ($R^2 = 0.004$, 11 df, $p > 0.8$). However, adult density increased in Wildcat over this period but the change was only marginally significant (Figure 47; $R^2 = 0.20$, 11 df, p = 0.075, 1-tailed test). This increasing trend was stronger between 1995 and 1999 ($R^2 = 0.30$, 9 df, p = 0.05, 1-tailed test). Sampling in 2000 occurred after the October flood so that densities for that year were reduced compared to pre-flood values; this would contribute to the weaker increasing trend observed in 1995-2000 compared to 1995-1999.

SHORT-TERM BURN EFFECTS ON AQUATIC HABITAT AND NATIVE FISH

This component of the study was conducted as a Master's Thesis; a copy of the thesis can be found in Appendix F. After its completion, errors in the thesis Figures 6, 7, 9 and 10 were discovered and corrected. Revised figures can be found in Appendix J.

Figure 47



PHOTOGRAPHIC MONITORING

During the life of the grant, over 700 photos associated with all aspects of the monitoring were taken. Examples of the pre- and post-burn upland vegetation, native fish and aquatic habitat, and riparian vegetation monitoring photos are documented in Appendix D. These photos permit qualitative comparisons over time of pre-burn and post-burn vegetation and aquatic habitat conditions.

The Nature Conservancy, Tucson Office, will maintain the original photographs. Digital copies of the photos are provided to AZ Department of Water on five compact discs with directory structure in Appendix G.

DISCUSSION

SHRUBS

Single prescribed burns reduced shrub cover by an average of 77% to 83%, however surviving shrubs began increasing immediately. In the Double R burn, this increase (2%) during the second growing seasons post-burn was due mostly to resprouting from the rootstock by mesquite and white-thorn acacia, but also, to a lesser extent, to vegetative reproduction by shindagger. Thus, periodic burns are needed to keep shrubs knocked back as demonstrated by the Hot Springs burn results. After the burn, shrub cover was reduced by 40.8% in areas burned 2 or 3 times during a 5-year period, although post-burn cover was similar in areas burned once vs. multiple times.

The effect of single burns in reducing shrubs has been well documented in the literature (e.g., Cable 1967, Wright 1974, Wright and Bailey 1982, Archer and Smiens 1991). Considerable information exists for mesquite and less information for other species. Cable (1967) found a 21% kill rate for mesquite less than 5 cm in diameter and a 10% kill of trees larger than 5 cm while Reynolds and Bohning (1956) reported a 9% kill rate for a June prescribed burn. In a wildfire, White (1969) reported a 20% mortality of mesquite trees in moderately and severely burned areas. Occasionally, much higher kill rates have been achieved. Humphrey (1949) reported mesquite mortality of 50% and 100% at two sites and after 15 years mesquite was still drastically reduced at both. Our observations also indicate that kill rates for mesquite may be quite high. Factors contributing to higher mortality rates include slope, aspect, climatic factors, high fuel loads, and general plant vigor (Wright and Bailey 1982). Repeated burns increase the likelihood that optimal conditions for mortality will occur.

In contrast to mesquite, snakeweed appears to be easily killed by fire (Humphrey and Everson 1951, Cable 1967, Reynolds and Bohning 1956); these studies report 95% to 100% mortality rates. Recruitment by seed following wet winters may result in rapid reestablishment (recovery) of snakeweed after a fire, i.e., 4 years (Cable 1967) but Humphrey (1949) found that burroweed failed to reinvade a site 15 years after a wildfire.

Our results indicate that prescribed burns were less effective at reducing junipers than 4 other common shrubs including shindagger, acacia, mesquite and snakeweed. Grass cover tends to be sparse around junipers so fuel loads are inadequate to completely ignite the crown, which can reach a height of 3-4 meters. The first burn, then, typically kills only a portion of the tree. However, fine fuels should be heavier following the first burn, increasing the likelihood of fire reaching the crown and igniting woody material within it in subsequent burns. Junipers do not appear to resprout after their canopies are burned.

The notion that repeat burns will be more effective in killing shrubs that were top-killed but resprouted after a single burn has been discussed in the literature but not adequately tested (Robinett 1994, Cable 1967). According to the argument, dead woody material left after the first burn will burn at a higher temperature and have a longer residence time when ignited in a subsequent fire, thereby increasing the probability that the root stock is killed. Cable (1965, 1967) reported only a 5% mortality of mesquite after a second burn compared to 31% after a single burn suggesting that repeat burns do not increase the mortality rate of mesquite. However, burning appeared to inhibit the establishment of mesquite seedlings so that even with low mortality rates over time repeated burns may greatly reduce densities, though not through the mechanism discussed above.

Clearly, more information is needed on the recovery rates of different shrub species and on the effectiveness of repeated burns in reducing them. We plan to continue conducting prescribed burns and monitoring upland plots in order to collect this information so that we can establish a fire frequency that will achieve our management objectives for shrubs.

GRASSES, HERBS, AND WATERSHED CONDITION

Burns were effective in increasing the abundance and cover of annual and perennial grasses and herbs or in mitigating their decline during drought periods. The response of perennial grasses to the two burns was qualitatively similar but differed in the details. In the Double R burn, perennial grasses recovered to pre-burn levels one growing season after the burn and increased by 25% two growing seasons after the burn. We believe this increase was the result of the burn and not above-average summer rainfall in 1999. Unfortunately, the tipping bucket on the RAWS rain gauge at the Muleshoe was inoperative for most of that year so we do not have rainfall records to address this. Summer rainfall at other sites in southeastern Arizona was above-average in 1999, however our impression was that it was only an average monsoon season at the Muleshoe. A number of large storm systems circled around the Muleshoe in summer 1999 and then moved to adjacent ranches before raining; in addition, the number of flash floods recorded in Bass and Hot Springs Creeks in summer 1999 by our on-site manager was not large and no greater than in 1996, an average summer rainfall year (B. Rogers, personal observation).

In the Hot Springs burn, perennial grass abundance and cover recovered to pre-burn levels after two growing seasons in portions of the unit that were burned once but decreased in unburned areas. This difference in response--an absolute *increase* in perennial grasses in the Double R burn and a *maintenance* of cover and abundance in the Hot Springs burn while unburned areas decreased--may be due to differences in the amount of summer rainfall after the burns. According to our hypothesis, when summer precipitation is average or above-average, burns result in an increase in perennial grasses after two growing seasons whereas when rainfall is below-average after the burn, burns can maintain perennial grass cover and abundance and compensate for the effects of drought in unburned areas.

Unfortunately, without summer rainfall records for the Muleshoe in 1999 we cannot test this hypothesis completely, but we *can* test the portion of it that applies to the Hot Springs burn. (We assume when testing the hypothesis that annual summer rainfall during the year of monitoring determines cover and frequency values of perennial grasses that year and that preceding years have little to no effect.) According to the NRCS Ecological Site Guide, Arizona semi-desert grasslands receive an average of 12 to 16 inches of rainfall each year which is split 30:70 percent between winter (October-June) and summer precipitation (July-September). Rainfall data collected from the RAWS (Remote Area Weather Station) at Muleshoe is summarized in Figure 44. Summer rainfall was average in 1998 and below-average in 2000. This would explain the decline in perennial grass cover and abundance on control plots in 2000 and supports the hypothesis that prescribed burns can mitigate the impact of drought on perennial grasses. Similar results for perennial grasses in burned and unburned areas were obtained for the Wildcat burn and were supported by the weather data (Gori 1999). We feel our results are conservative since they reflect only changes after two growing seasons. In addition, perennial grass seedlings were abundant in plots but contributed little to our results for cover. As these seedlings become established and grow, perennial grass cover should increase to an even greater extent in burned areas. Continued monitoring will show this effect.

Few studies have reported increases in native perennial grasses following burns in semi-desert grasslands. Reynolds and Bohning (1956) found that the density of Santa Rita three-awn (*Aristida californica*) increased by 34% the first growing season after a burn (a dry year) and by the end of the second growing season (another dry year) its density had doubled. Following a 15-year burn study on the Santa Rita Experimental Range, Cable (1967) concluded that fire had no lasting effects, beneficial or detrimental, on perennial grass cover or production. However, the experimental and control sites were grazed throughout the study and Cable acknowledges "a concentration of grazing on burned areas". It is unclear how details of the grazing management system influenced his results. Valone and Kelt (1999) found no change in the density of red three-awn (*A. longiseta*) one and two growing seasons after a burn. Furthermore, the density of all perennials (grasses and herbs) was greater one growing season after the burn on burn plots compared to controls but by the second growing season, density was similar. They attributed the weak perennial grass response to below-average summer precipitation after the burn. However, snakeweed, the dominant shrub at their site, decreased to a similar extent on burn and control plots, in the latter case due to drought. This could also account for their failure to detect a difference in perennial grass density since water availability increased on both burn and control plots.

There is concern among ranchers and resource managers that prescribed burns followed by drought may have a negative impact on perennial grass production and survivorship. Several studies appear to support this view although they focus on single species rather than perennial grasses as a group; suffer methodologically from lack of replication and confounded grazing effects; and often represent transitory negative effects that are ameliorated after wet years. For example, Nelson (1934) and Reynolds and Bohning (1956) found that droughts following fire lengthened the recovery period for black grama and, when compounded with moderate grazing, it never recovered to pre-burn basal area levels (Canfield 1939). Arizona cottontop and tanglehead were mildly harmed by fire during dry years but recovered quickly during wet years (Reynolds and Bohning 1956; Cable 1967).

Our results indicate that burns can benefit perennial grasses even during drought periods. However, during drought and non-drought periods, grasses should be given enough time to recover after a burn before livestock are re-introduced and utilization should be carefully monitored to determine the stocking level and duration of pasture use that is appropriate to rainfall conditions. Our results indicate that two growing seasons after a burn is the *minimum* period of grazing rest needed for recovery of perennial grass to pre-burn levels. Longer periods of rest are strongly recommended to allow seedling grasses germinating after the burn to become established and to ensure some net benefit from the burns, i.e., improvement of rangeland or watershed condition.

In our study, herbs showed a similar pattern to perennial grasses in the Hot Springs burn. That is, they recovered to pre-burn levels in the burn unit after two growing seasons but decreased in unburned areas. Thus, prescribed burns increase herb production and cover but climate plays an important role in determining how this fire-mediated increase is expressed. Herbs are generally not mentioned in the literature for semi-desert grassland communities so little is known about their response to fire. Bock and Bock (1978) reported that some species were more common in sacaton communities after summer burning including *Amaranthus, Ipommoea, Bidens, Convolvulus, Portulaca, Chenopodium, and Ambrosia*. Valone and Kelt (1999) reported that 5 herb species responded positively to a burn and 2 negatively in the first growing season after the burn but the effect (positive) persisted for only one species in the second growing season; 6 out of 7 species were annuals.

Our results show that prescribed burns increased annual grasses in both average and below-average rainfall years. This increase is presumably due to reduced competition from shrubs (which are reduced by the burn) leaving more water and nutrients available for annuals. Valone and Kelt (1999) reported increases in six-week grama one and two growing seasons after a burn in years when summer rainfall was below-average. Cable (1967) and Humphrey (1949) reported greater annual grass yields after a burn in wet years but similar yields on burn and control plots in dry years.

This study provides evidence that successive prescribed burns at frequencies of every 2-3 years may stress perennial grasses resulting in their reduced abundance. This result was clear from the analysis of frequency sampling data and was suggested by the analysis of cover data. That is, basal cover *increased* on burn plots and *decreased* on repeat plots, but this difference was not statistically significantly. Based on these results, we have modified our original plan to re-burn units at a frequency of every 3-5 years to decrease shrubs, adjusting the frequency to once every 8-10 years. This is consistent with Kaib et al.'s (1996) result of mean inter-fire intervals of 7.4 to 8.1 years for grasslands around the Chiricahua Mountains. Numerous fire histories completed in Ponderosa pine and pine-oak woodlands on "sky island" mountain ranges also indicate a mean inter-fire interval of 7-10 years prior to 1900 (e.g., Baisan and Swetnam 1995; Swetnam et al. 1989; Swetnam and Baisan 1996). Continued monitoring will allow us to evaluate the effect of this lower burn frequency on shrub and perennial grass and, if needed, to further adjust the frequency so that upland vegetation objectives are met.

Burning at high frequencies may have other unwanted consequences. Frequent wildfires (at a mean interval of every 2.5-3 years) facilitated the spread of Lehmann's lovegrass, reduced plant species diversity and accelerated soil erosion at a grassland site on Fort Huachuca, Arizona (Robinett 1994). In this study, lovegrass abundance was 9% on sites that had burned only once over a 15-year period compared to 96% on the sites burning 5 to 6 times over this period. Robinett recommended a minimum inter-fire interval of 6-7 years and an ideal interval of 10-15 years for sites.

Burning 2 or 3 times over a five year period did not appear to adversely impact herbs or annual grasses. Annual grasses increased more on repeat plots than on burn plots after the burn in both frequency and basal cover analyses. This greater increase may be related to a greater availability of water and nutrients on repeat plots associated with the decrease in perennial grasses there or a greater seed bank associated with their greater abundance after the preceeding burn. Similarly, basal cover of herbs increased more after the burn on repeat plots than on burn plots but this latter difference was not statistically significant suggesting a positive or neutral effect of frequent burns, not a negative one.

GROUND COVER AS A COMPONENT OF WATERSHED CONDITION

The prescribed burns resulted in an overall improvement in watershed condition after only two growing seasons. This improvement was expressed as an increase in total ground cover, a combination of litter and live basal cover. In both burns, litter failed to recover completely to pre-burn levels after two growing seasons. However over time, litter cover should exceed pre-burn values as grasses and herbs especially perennial ones (which increased after the burn) continue to lay down litter in successive growing seasons. Litter influences the amount and chemical composition of rainwater reaching the soil surface, reduces evapotranspiration, alters energy flow by reducing photosynthetic active radiation available at the soil surface and insulates the soil which may delay seedling emergence and root growth and activity to later in the season (Facelli and Pickett 1991). Over time, then, the increase in litter in burned areas should lead to higher soil moistures (i.e., reduced evaporation) which should further enhance recruitment and growth of perennial grasses resulting in a positive feedback loop of accelerating watershed restoration.

Unlike litter, live basal cover increased in the burn units after two growing seasons reflecting increases in the abundance and cover of grasses and herbs there. In the Double R burn, this resulted in a net increase in total ground cover over most of the burn unit. In the Hot Springs burn, total ground cover was maintained at pre-burn levels in the burned area while it decreased in unburned areas due to below-average summer rainfall. Thus, prescribed burns have the capacity to increase ground cover in average or wet years and to buffer the effects of droughts on watershed condition in dry years resulting in greater temporal stability in run-off, infiltration, and soil erosion processes. This stability in conjunction with a general improvement in watershed conditions should lead to beneficial changes in stream hydrology, riparian forest structure, aquatic habitat, and native fish populations. In theory, changes in stream hydrology should include a reduced intensity and frequency of floods and possibly increased baseflows. Unfortunately, there are no continuous stream gages at the Muleshoe so we will be unable to directly observe changes in flood magnitude and frequency. Our streamflow monitoring has shown no increase in baseflow for Bass, Hot Sprngs or Wildcat since 1995 when the first watershed-scale burn was conducted. However, we suspect that that these changes will be subtle and superimposed on climatic variability. Disentangling the effects of rainfall variation from those of management may be possible through regression analysis by first developing relationships between climate and baseflow and then analyzing the residuals for evidence of management effects. Additional years of streamflow and weather data, however, are needed before this analysis is feasible. Beneficial effects of stream hydrology changes will be expressed indirectly through improvements in riparian forest structure, aquatic habitat quality and native fish populations which our monitoring was designed to detect.

RIPARIAN FOREST STRUCTURE

Improved watershed condition appears to be leading to improvements in the structure of the riparian forest in Bass, Hot Springs, and Double R Canyons. Target densities for saplings and saplings plus trees were met and exceeded by 1998 largely due to the dramatic increase in the number of saplings after 1994. From their size, these saplings appear to have recruited in 1995 following the large winter floods that year. The density of adults is also increasing at all sites except Lower Hot Springs as surviving saplings continue to grow and eventually move into the adult size class. We believe that the anomalous result for Lower Hot Springs is an artifact of sampling error. This is so because when all adult trees in the reach were counted and density calculated on the basis of the entire block, adult density *increased* from 1998 to 2000 as it did in all other reaches.

Removal of livestock from riparian areas on the Muleshoe may also be contributing to the changes in riparian forest structure. Numerous studies have documented increases in recruitment and establishment of woody and herbaceous vegetation and changes in floodplain geomorphology and forest structure after excluding livestock from riparian pastures (see review by Belskey et al. 1999).

AQUATIC HABITAT AND NATIVE FISH

The prescribed burns had no apparent short-term negative impacts on water quality or aquatic habitat except that pool volume decreased significantly in the affected reach compared to the control reach. Mooney (2000) attributed the decline to increased sediment run-off from the burn area, which occurred sometime during the 1999 summer monsoon season. However, it is also possible that the sediment run-off event was not directly related to the burn but the result of a large precipitation event that occurred in the Double R portion of the Bass watershed but not in the upper Bass watershed. Unfortunately, we are unable to test this possibility because no rain gauges were installed in various portions of the watershed affecting upper and lower reaches of Bass Creek.

There was some suggestion in Mooney's study that Gila chub may have declined in the affected reach in response to the reduction in pool size there but the chub decrease was not statistically significant. In addition, in fall 2000, a year later, chub density in Bass had reached its greatest value since 1992 so if there was a negative effect of prescribed burning on this species, it was a transitory one. Similarly, the decease in pool volume also appeared to be short-lived. By fall 2000, the number of pools and maximum pool depth had both increased to pre-burn levels (1996-1997). The transitory nature of the burn effects are not unexpected given the dynamic nature of floods and their effects on aquatic habitat (Minckley 1981). Furthermore, the magnitude of burn-related impacts on aquatic habitat appear to be well within the natural range of variation observed in Bass and other Muleshoe streams over the last decade.

Water quality was sampled weekly before and after the burn over a 6-month period that included the 1998 summer monsoon season (Mooney 2000). No changes in water quality were detected. In the event a change did occur and was missed, it apparently had no adverse impact on native fish. In fact, longfin dace increased in the affected reach after May, 1999; this increase may be related to the sediment run-off event which reduced pool volumes, transforming deeper pools into glides with sandy bottoms which is the preferred habitat for this species (Minckley 1981).

Improved watershed condition has contributed to aquatic habitat improvements in Hot Springs, Bass, and Double R and to an increase in fish populations in Wildcat, Hot Springs and Bass Canyons since the early to mid-1990's. The habitat improvements include increases in (1) the maximum depth of habitats including pools; (2) the number of deep pools per mile; and (3) instream cover including undercut bank and woody debris. These improvements have occurred despite the fact that baseflows have decreased over this period due to persistent drought suggesting that they result from physical changes in channel morphology. Associated with these habitat improvements, chub density increased in Bass and Hot Springs as did their relative (percent) abundance in the fish community so that in 2000 they occurred in the highest numbers and greatest relative abundance since monitoring began in 1991-1992. In addition, fish density and adult density increased in Hot Springs and Wildcat respectively, but the (increasing) trend in fish density disappeared in Bass after 1999. In addition, chub colonized Wildcat Creek for the first time in 1999 and persisted there. The only negative trend observed was for fish density in Double R since 1995. Fish populations on the Muleshoe were considered to be in excellent shape in 1990 (AZGF Non Game Heritage Database; D. Hendrickson, pers. comm.) and improvements since then underscore both how little we know about the recovery potential of these populations and the benefits that can be derived from grazing rest, prescribed burning, and watershed improvement.

The correlation coefficients for the trends in maximum pool depth and number of deep pools per mile in Hot Springs were stronger between 1991-1999 than between 1991-2000. In addition, the number of pools has decreased in Hot Springs since 1997. This suggests that some other factor affecting pools (and other aquatic habitats) has come into play since 1998 or 1999. A possible factor is the condition of the watershed off (upstream of) the Muleshoe Ranch where management practices differ. Alternatively, multiple prescribed burns may be increasing channel sedimentation. Consistent with the latter explanation, Bass Creek was far less affected by the burns than Hot Springs and the correlation coefficient for the trend in maximum pool depth for Bass Creek was stronger for the 1992-2000 period suggesting that improvements were continuing there. However, pool number and pool depth continue to increase in Double R despite the fact that a significant portion of its watershed was burned and the entire perennial portion of the stream was subject to sediment run-off from the unit. This suggests that the negative impacts of prescribed burns on aquatic habitat depth, though transitory, are not inevitable but depend on factors such as (1) the size and timing of a precipitation event relative to the recovery (or increase) in total ground cover in the burn area; (2) proportion of the watershed burned; (3) frequency the watershed burns; and (4) condition of the riparian area at the time of the burn.

There was also evidence from Bass, Hot Springs and Wildcat Creeks that fish density and/or adult density trends were stronger prior to 1999 (larger correlation coefficients) and that densities have decreased since 1998 or 1999 (see preceding Figures). These declines were apparently not the result of the prescribed burns since they occurred in all streams including Bass where most of the monitoring stations were unaffected by the burn. A more likely explanation was the reduced stream flow during this period, especially in the pre-monsoon months of May-June, 2000, when the extent of perennial flow was at its lowest point since 1991. The declining flows and seasonal loss of stream habitat may have resulted in increased mortality of adults and juveniles, thereby lowering fish abundance. In addition, there is now evidence from a number of streams in southern Arizona, including two at the Muleshoe, that large floods reduce fish numbers (D. Gori, D. Backer, J. Simms, unpubl. data). All stations in Wildcat and Double R and some stations in Bass and Hot Springs were sampled shortly after a large flood in October 2000, reducing fish densities even further.

Excluding livestock from perennial streams may also be contributing strongly to the observed improvements in aquatic habitat quality and native fish populations. Numerous studies conducted throughout the west but primarily in streams supporting salmonids indicate improvements in substrate composition; instream cover; number and quality of pools; fish species diversity, abundance and productivity; and food availability after removal of livestock from stream bottoms (see excellent reviews by Belsky et al. 1999 and Rinne 1999). This study was not designed to disentangle the effects of grazing rest in the uplands and in riparian areas from the effects of prescribed burning in the uplands. Such a study would be very expensive and, in fact, impossible to implement since there are not enough native fish sites, especially ones with 4-5 species, in the state for adequate replication. Thus, given the current study design, all we can say is that both factors are contributing to the observed improvements in riparian forest structure, aquatic habitat quality and native fish populations.

The long-term benefits of grazing rest and prescribed burning on watershed condition and riparian and aquatic habitats will continue to be documented at the Muleshoe Ranch through continued, long-term monitoring. As more and more data are collected and analyzed, a compelling case for the use of prescribed fire to restore watershed condition riparian vegetation and aquatic habitat is beginning to emerge. Furthermore, as improvements in riparian and aquatic habitats and the species that depend on them continue, we can adjust our standards upward for what can be accomplished in restoration through better fire and livestock grazing management.

COMMUNITY OUTREACH COMPONENT

A primary goal of this project is to gather and distribute good scientifically based information on the use of fire as a restoration tool in landscapes with semi desert grasslands and high quality riparian and aquatic habitats. The target audience for community outreach is diverse; ranging from local ranchers in the Willcox area to nationally dispersed fire and land managers. This work included two types of outreach. On a day to day basis it involved interacting with local neighbors exchanging information on the results of the project. In a more structured way it included many presentations to both local groups such as the Willcox and Redington NRCDs and to state and national gatherings such as the TNC Arizona annual meeting and the National Fire Ecology Conference.

Community outreach results have been predominantly positive. The visual results of the project are most obvious to observe through site visits. However, photographs have communicated the results and success of the project with outstanding accuracy. Long term, it will be important to continue presenting the results, including the analysis to various audiences. Up until this point our conclusions have been preliminary as the data analysis was not complete.

Feedback from our community outreach indicates that there are opportunities throughout Arizona to duplicate this sort of cooperative watershed restoration work using fire across ownership boundaries. The benefits are obvious for ranchers interested in rangeland improvement, biologists focused on wildlife habitat and the general public interested in efficient use of management dollars.

The various community outreach activities have been reported in each semi-annual report. Photographs from the open house are in Appendix I.

Permits

The first deliverable of this grant is for the various permits required. There were no significant difficulties associated with obtaining the required permits. However, the permitting process can be difficult for large prescribed fires. Much of the review work for the past three years burns was completed prior to the start of this project during the Ecosystem Management Planning process. The following permits or approvals were obtained during the course of this grant.

- Archeological Clearance for fence construction, use of prescribed fire, placement of signs on public land. A BLM staff archeologist completed the Double R burn clearance. All other surveys and reviews were done by Desert Archeology.
- Prescribed fire NEPA review.
  The BLM Safford Field Office completed three reviews.
- Prescribed fire plan approval, 1998, 1999, 2000. Approved and signed plans were completed prior to burning. These include air operations, medical, safety, operational and contingency strategies.
- ADEQ Smoke Management Permit. These permits were obtained each year immediately prior to the burns.

Copies of all permits have been submitted with the five previous semi-annual reports.

Budget Summary

Overall, the funding for this project was adequate to conduct the work and produce the results that we proposed. As with any project, as the grant activities progressed we found that in order to make best use of the funds it was necessary to adjust the designated amounts for several tasks. Due to cost sharing with the BLM the prescribed fire activities required less money than anticipated, while the intensive monitoring activities took more time and money than expected. During the course of this contract two amendments were made to address these needs and the result has been a better product as we have been able to really focus on the monitoring of these treatments.

The Nature Conservancy is fortunate to have a skilled Grant and Contract Administrator who has worked with project staff to administer this project and prepare associated financial reports. These reports have been submitted on a semi-annual basis.

Recommendations and Conclusions

If one reviews the objectives on page 4 and 5 that were established at the start of this project it is clear that they have been met and in some cases exceeded. In the past three years this grant has supported a significant amount of progress. However, additional time and monitoring will be required before the full effects of this project's activities can be determined. From the start AWPF and TNC have recognized that this is essentially the start of a long-term restoration effort in a significant natural area. The Nature Conservancy, BLM and the USFS will continue with the work that this project has supported and effectively jump-started.

As with any project, we would do certain things differently if we were to repeat the process. The lessons of this grant are for the most part positive in nature, no insurmountable hurdles were met and in the case of the prescribed fire component we were fortunate to have much greater success than anticipated. We believe the use of prescribed fire as a watershed restoration tool is a valid and effective one. These projects can be most effective if they are planned and implemented not based on property ownership but on natural barriers and optimal management unit designs. Clearly this approach requires coordination across administrative lines. Even with the success of this project, more could have been accomplished with the inclusion of more partners.

To a certain degree this project is testing the watershed-riparian processes model that TNC has developed for semidesert grassland/riparian areas. We underestimated the amount of time and money required to fully monitor a project of this size so that meaningful conclusions can be reached. Future projects of this sort should recognize this and plan and budget accordingly. Fortunately we have been able to amend this project to meet these needs but it would have been difficult to meet the monitoring requirements otherwise. Monitoring results obtained to date support the model: excluding livestock from riparian areas, resting grazing in the adjacent uplands and conducting prescribed burns there will decrease shrubs, increase perennial grasses and increase total ground cover leading to improvements in watershed condition, riparian forest structure, quality of aquatic habitat and native fish populations.

Burns conducted during drought periods do not appear to harm perennial grasses but rather oppose the effects of drought, resulting in more perennial grass and higher overall productivity in burned vs. unburned areas. Thus, planning burns around prevailing climatic patterns is unnecessary. However, the latter will affect how long rangelands need to be rested from grazing before and after a burn. A *minimum* rest of two growing seasons is required for recovery of perennial grasses to pre-burn levels and longer rest is *strongly recommended* to encourage establishment of new seedlings and long-term, persistent increases in cover and watershed condition. When livestock are re-introduced utilization should be carefully monitored to determine the stocking level and duration of pasture use that is appropriate to rainfall conditions.

If management objectives call for reducing shrub cover, our results indicate that burning more frequently, that is 2-3 times in a 5-year period, is clearly advantageous. However, if the objectives include increasing perennial grass abundance and cover, prescribed burns should be conducted no more frequently than every 7-10 years and perhaps at longer intervals, i.e., every 10-15 years, as Robinett (1994) suggests. More work is needed to establish the "optimal" burn frequency: burning too frequently, while effective at reducing shrubs, may reduce perennial grasses while burning too infrequently may lead to increased shrub establishment and reduced mortality after fires; may slow-down or halt the recovery and spread of perennial grasses; and may reduce the intensity and spread of subsequent prescribed burns as shrubs increase at the expense of perennial grasses.

Prescribed burning may have short-term impacts on aquatic habitat as pools decrease in volume from sediment runoff immediately after the burn. However, pool number and depth quickly recover to pre-burn levels (i.e., within two growing seasons after a burn) and no negative impacts were observed on native fish numbers at any time. Thus, the long-term benefits of prescribed burning and improved watershed condition clearly outweigh any short-term impacts so that plans to conduct prescribed burns should not be hindered by concerns over their effects on endangered fish. We recommend that native fish and aquatic habitat be monitored in affected vs. unaffected reaches for 2-3 years after a burn so that additional information on this important issue is collected.

The community outreach component of a project like this should be strong and comprehensive. We have tried to distribute the information to many different audiences, but with additional focus and support more could have been done. In particular, local natural resource groups such as NRCDs, farm bureau, and cattlegrowers are finding our results interesting.

Participant List

Permits and Authorizations:
BLM
ASLD
Arizona Dept. Environmental Quality (ADEQ)
Arizona State Museum
State Historic Preservation Office
Desert Archeology, Inc.
TNC

Fire Management Component:
BLM
USFS
ASLD
TNC
NPS
University of Arizona (U of A)
Natural Resources Conservation Service (NRCS)
Saguaro Juniper Corporation
Dave Harris
Larry Young
TNC Volunteers

Monitoring Component
BLM
TNC
U of A
TNC Volunteers
Arizona Game and Fish (AGFD)
NRCS

Fence and Signage Components
ASLD
BLM
Desert Archeology, Inc.
Hopkins Fence Company
Warbonnet Ranch
Carsonite Company

Community Outreach

BLM	USFS	(TNC National)	Fire Ecology Assoc.
ASLD	TNC	U of A	Malpai Group
NRCS	ADWR	Willcox NRCD	Redington NRCD
Willcox Area Ranchers			

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Appendix A

Fire Activity Photographs

Initial ignition(bottom) and progressive five activity, Double R burn, 1998.

Aerial Ignition of the Double R Burn, June, 1998

Helicopter with aerial ignition device. Hooker Burn, 2000

Appendix B

Upland Vegetation Plant List

MULESHOE and ARAVAIPA UPLAND PLANT MONITORING LIST MASTER

6/2/94 :created

3/23/01 :updated/printed

Species Code	Sort by Family	Genus	Species	Common Name	Shrub(shb) sub (sub) Tree (tr)	Stature
AGCH	AGAVACEAE	Agave	palmeri var. chrysantha	century plant	sh/b	pr
AGPA	AGAVACEAE	Agave	parryi	Parry's century plant, mescal	sh/b	pr
AGSC	AGAVACEAE	Agave	schottii	shindagger,amole	sh/b	pr
DAWH	AGAVACEAE	Dasylirion	wheeleri	sotol, desert spoon	sh/b	pr
NOMI	AGAVACEAE	Nolina	microcarpa	bear grass	sh/b	pr
YUAR	AGAVACEAE	Yucca	arizonica	spanish bayonet	sh/b	pr
YUBA	AGAVACEAE	Yucca	baccata	banana yucca	sh/b	pr
YUEL	AGAVACEAE	Yucca	elata	Spanish bayonet,soapweed, W	sh/b	pr
MOCE	AIZOACEAE	Mollugo	cerviana	thread-stem carpet weed	frb	an
MOVE	AIZOACEAE	Mollugo	verticillata	Indian chickweed	frb	an
AMPR	AMARANTHACEAE	Amaranthus	pringei	amaranth, pig weed	frb	an
GADE	AMARANTHACEAE	Galliminea	densa	small matweed	frb	pr
TILA	AMARANTHACEAE	Tidestromia	lanuginosa	woolly tidestromia	frb	an
RHAR	ANACARDIACEAE	Rhus	aromatica	sumac	sh	pr
ASAS	ASCLEPIADACEAE	Asclepias	asperula	milkweed	frb	pr
SACY	ASCLEPIADACEAE	Sarcostemma	cynanchoides	climbing milkweed	frb	pr
ACNA	ASTERACEAE	Acourtia	nana	desert peony	frb	pr
ACWR	ASTERACEAE	Acourtia	wrightii	brown foot	frb	pr
AMCO	ASTERACEAE	Ambrosia	confertiflora	slimleaf bursage	frb	an
ARDR	ASTERACEAE	Artemisia	dracunculus	wormwood, sagebrush	frb	pr
ARLU	ASTERACEAE	Artemisia	ludoviciana	wormwood, sagebrush	frb	pr
ARTSP	ASTERACEAE	Artemisia	sp.	wormwood, sagebrush	frb	pr
BAPT	ASTERACEAE	Baccharis	pteronioides	yerba de pasmo	frb	pr
BAAB	ASTERACEAE	Bahia	absinthifolia	hairyseed Bahia	frb	pr
BAMU	ASTERACEAE	Baileya	multiradiata	wild marigold	frb	pr
BISP	ASTERACEAE	Bidens	sp.	bur marigold, beggar tricks	frb	pr
BRBA	ASTERACEAE	Brickellia	bacchairdea	resinleaf brickellbush	shb	pr
BRCH	ASTERACEAE	Brickellia	chlorolepis		frb	pr
BRLE	ASTERACEAE	Brickellia	Lemmoni	Lemmon's brickellbush	frb	pr
CHER	ASTERACEAE	Chaetopappo	ericoides	rose heath	frb	pr
CHNA	ASTERACEAE	Chrysothamnus	nauseosus	rabbit bush	shb	pr

CISP	ASTERACEAE	Cirsium	sp.	thistle	frb	pr
COSP	ASTERACEAE	Conyza	sp.		frb	pr
DYSP	ASTERACEAE	Dyssodia	sp.	dogweed species	frb	pr
ERLA	ASTERACEAE	Ericameria	laricifolius	turpentine bush	sub	pr
ERDI	ASTERACEAE	Erigeron	divergens	fleabane, wild daisy	frb	pr
GNWR	ASTERACEAE	Gnaphalium	wrightii	cudweed	frb	pr
GUSA	ASTERACEAE	Gutierrezia	sarothrae	snake weed	sub	pr
HESU	ASTERACEAE	Heterotheca	subaxillaris	telegraph plant	frb	pr
HYSP	ASTERACEAE	Hymenothrix	sp.		frb	pr
HYWI	ASTERACEAE	Hymenothrix	wislizeni	TransPecos thimblehead	frb	pr
HYWR	ASTERACEAE	Hymenothrix	wrightii	Wright's beeflower, Wright's tl	frb	pr
ISAC	ASTERACEAE	Isocoma	acradenius	alkali goldenbush	shb	pr
ISCO	ASTERACEAE	Isocoma	coronopifolia/tenuisca	burrow weed	sub	pr
MAPI	ASTERACEAE	Machaeranthera	pinnatifida	yellow aster	frb	pr
MASP	ASTERACEAE	Machaeranthera	sp		frb	pr
MATA	ASTERACEAE	Machaeranthera	tanecetifolia	purple aster	frb	pr
PEFI	ASTERACEAE	Pectis	filipes	fetid marigold	frb	an
PELO	ASTERACEAE	Pectis	longipes	longstalk cinchweed	frb	pr
PEPR	ASTERACEAE	Pectis	prostrata	fetid marigold	frb	an
PESP	ASTERACEAE	Pectis	sp.		frb	
PSCO	ASTERACEAE	Psilostrophe	cooperi	paper flower	sub	pr
SEFL	ASTERACEAE	Senecio	flaccidus var. dougalii	groundsel	frb	pr
STPA	ASTERACEAE	Stephenomeria	pauciflora	desert straw	frb	pr
VIAN	ASTERACEAE	Viguieria	annua	annual golden eye	frb	an
ZIAC	ASTERACEAE	Zinnia	acerosa	desert zinnia	sub	pr
BEFR	BERBERIDACEAE	Berberis	fremontii		shb	pr
ARPE	BRASSICACEAE	Arabis	perenans	rock cress	frb	pr
LEME	BRASSICACEAE	Lepidium	medium	pepper grass	frb	an
THLI	BRASSICACEAE	Thelypodiopsis	linearifolia	slimleaf plains mustard	frb	pr
COVI	CACTACEAE	Coryphantha	vivipara	pincushion cactus	sh/b	pr
ECTR	CACTACEAE	Echinocereus	triglochidiatus	hedgehog cactus	sh/b	pr
ECSP	CACTACEAE	Echinocerus	sp.	hedgehog	sh/b	pr
FEWI	CACTACEAE	Ferocactus	wislizenii	barrel cactus	sh/b	pr
MMSP	CACTACEAE	Mammillaria	sp.	pincushion cactus	frb	pr
OPAR	CACTACEAE	Opuntia	arbuscula	pencil cholla	sh/b	pr
OPLE	CACTACEAE	Opuntia	leptocaulus	christmas cactus	sh/b	pr
OPPH	CACTACEAE	Opuntia	phaeacantha	prickly pear	sh/b	pr
OPSP	CACTACEAE	Opuntia	spinosior	cane cholla	sh/b	pr

CHNE	CHENOPODIACEAE	Chenopodium	neomexicanum	goose foot	frb	an
EULA	CHENOPODIACEAE	Eurotia	lanata	winter-fat	shb	pr
CLTR	CLEOMACEAE	Cleome	trachysperma	bee plant	frb	pr
COEQ	CONVOLVULACEAE	Convolvulus	equitans	hoary bindweed	frb	pr
EVSE	CONVOLVULACEAE	Evolvulus	sericeus	silver dwarf morning-glory	frb	pr
IPCO	CONVOLVULACEAE	Ipomoea	costellata	annual morning glory	frb	an
IPSP	CONVOLVULACEAE	Ipomoea	sp.		frb	an
APUN	CUCURBITACEAE	Apodanthera	undulata	melon loco	frb	pr
JUCO	CUPRESSACEAE	Juniperus	coahuilensis	Mexican juniper	tr	pr
JUER	CUPRESSACEAE	Juniperus	erythrocarpa	red seed juniper	tr	pr
JUM0	CUPRESSACEAE	Juniperus	monosperma	one-seed juniper	tr	pr
EPTR	EPHEDERACEAE	Ephedera	trifurca	mormon tea	sh/b	pr
ACNE	EUPHORBIACEAE	Acalypha	neomexicana	New Mexican copperleaf	frb	an
ACOS	EUPHORBIACEAE	Acalypha	ostryaefolia	pineland threeseed mercury	frb	pr
CRCO	EUPHORBIACEAE	Croton	corymbulosus		frb	pr
EUSP	EUPHORBIACEAE	Euphorbia	sp.	spurge	frb	pr
JAMA	EUPHORBIACEAE	Jatropha	macrorhiza	ragged nettlespurge	frb	pr
STLSP	EUPHORBIACEAE	Stillingia	sp.		frb	pr
TRNE	EUPHORBIACEAE	Tragia	nepetaefolia	nose-burn	frb	pr
ACAN	FABACEAE	Acacia	angustissima	white-ball acacia	sub	pr
ACCO	FABACEAE	Acacia	constricta	white thorn	sh	pr
ACGR	FABACEAE	Acacia	greggii	catclaw	sh	pr
ASSP	FABACEAE	Astragalus	sp.	milk vetch, loco weed	frb	pr
CAER	FABACEAE	Calliandra	eriophylla	fairy duster	sub	pr
CHNI	FABACEAE	Chamaecrista	nictitans	partridge pea	frb	an
DAFO	FABACEAE	Dalea	formosa	feather plume	sub	pr
DALE	FABACEAE	Dalea	leporina	foxtail dalea	frb	pr
DANE	FABACEAE	Dalea	neomexicana	downy prairy clover	frb	pr
DAPO	FABACEAE	Dalea	pogonathera	bearded vetch	frb	pr
DAPR	FABACEAE	Dalea	pringlei	Pringle's prairie clover	frb	pr
DECO	FABACEAE	Desmanthus	cooleyi	Cooley's bundleflower	frb	pr
DEPR	FABACEAE	Desmodium	procumbens	western trailing ticktrifoil	frb	an
GAWR	FABACEAE	Galactia	wrightii	Wright's milkpea	sub	pr
HODE	FABACEAE	Hoffmanseggia	densiflora		frb	pr
LOGR	FABACEAE	Lotus	greenei	deer vetch	frb	pr
LOOR	FABACEAE	Lotus	oroboides		frb	pr
MIAC	FABACEAE	Mimosa	aculeaticarpa	wait-a-minute, cat's claw	sh	pr
PRVE	FABACEAE	Prosopis	velutina	mesquite	tr	pr

PSTE	FABACEAE	Psoralea	tenuifolia	scurvy pea	frb	pr
SEBA	FABACEAE	Senna	bauhinoides	two-leaf senna	frb	pr
SPCO	FABACEAE	Sphinctospermum	constrictum	hourglass peaseed	frb	an
FOSP	FOUQUIERIACEAE	Fouquieria	splendens	ocotillo	sh	pr
ERTE	GERANIACEAE	Erodium	texanum	heron-bill	frb	an
SASU	LAMIACEAE	Salvia	subincisa	sage	frb	an
ABIN	MALVACEAE	Abutilon	incanum	Indian mallow	frb	pr
ABPA	MALVACEAE	Abutilon	parvulum	dwarf Indian mallow	frb	pr
RHPH	MALVACEAE	Rhynchosida	physocalyx	buffpetal	frb	pr
SIAB	MALVACEAE	Sida	abutolous		frb	pr
SIPH	MALVACEAE	Sida	physocalyx	balloon sida	frb	pr
SPLA	MALVACEAE	Sphaeralcea	laxa	globe mallow	frb	pr
ALIN	NYCTAGINACEAE	Allionia	incarnata	trailing windmills	frb	pr
BOCO	NYCTAGINACEAE	Boerhaavia	coccinea	red spiderling	frb	pr
BOEER	NYCTAGINACEAE	Boerhaavia	erecta	five-winged ringstem	frb	an
BOPT	NYCTAGINACEAE	Boerhaavia	pterocarpa	spiderling	frb	an
MESC	OLEACEAE	Menodora	scabra	yellow menodora	sub	pr
ARMU	PAPAVERACEAE	Argemone	munita	prickly poppy	frb	pr
PIMO	PINACEAE	Pinus	monophylla	single leaf pine	tr	pr
PLSP	PLANTAGINACEAE	Plantago	sp.	plaintain, Indian-wheat	frb	pr
ARAD	POACEAE	Aristida	adscensionis	six weeks three-awn	gras	A
ARLO	POACEAE	Aristida	longiseta	red three-awn	gras	S
ARPU	POACEAE	Aristida	purpurea	purple three-awn	gras	S
ARSC	POACEAE	Aristida	schiedeana		gras	T
ARTE	POACEAE	Aristida	ternipes	three-awn, spidergrass	gras	T
BOTBA	POACEAE	Bothriochloa	barbinodis	cane beard grass	gras	T
BOAR	POACEAE	Bouteloua	aristidoides	needle grama	gras	A
BOUBA	POACEAE	Bouteloua	barbata	six-weeks grama	gras	A
BOCH	POACEAE	Bouteloua	chondrosiodies	spruce top grama	gras	T
BOCU	POACEAE	Bouteloua	curtipendula	side oats grama	gras	T
BOUER	POACEAE	Bouteloua	eriopoda	black grama	gras	T
BOGR	POACEAE	Bouteloua	gracilis	blue grama	gras	I
BOHI	POACEAE	Bouteloua	hirsuta	hairy grama	gras	I
BORA	POACEAE	Bouteloua	radicosa	purple grama	gras	S
BORO	POACEAE	Bouteloua	rothrockii	Rothrock grama	gras	I
BRAR	POACEAE	Brachieria	arizonica	Arizona panicum	gras	A
BRRU	POACEAE	Bromus	rubens	red brome	gras	A
CHVI	POACEAE	Chloris	virgata	feather fingergrass	gras	A

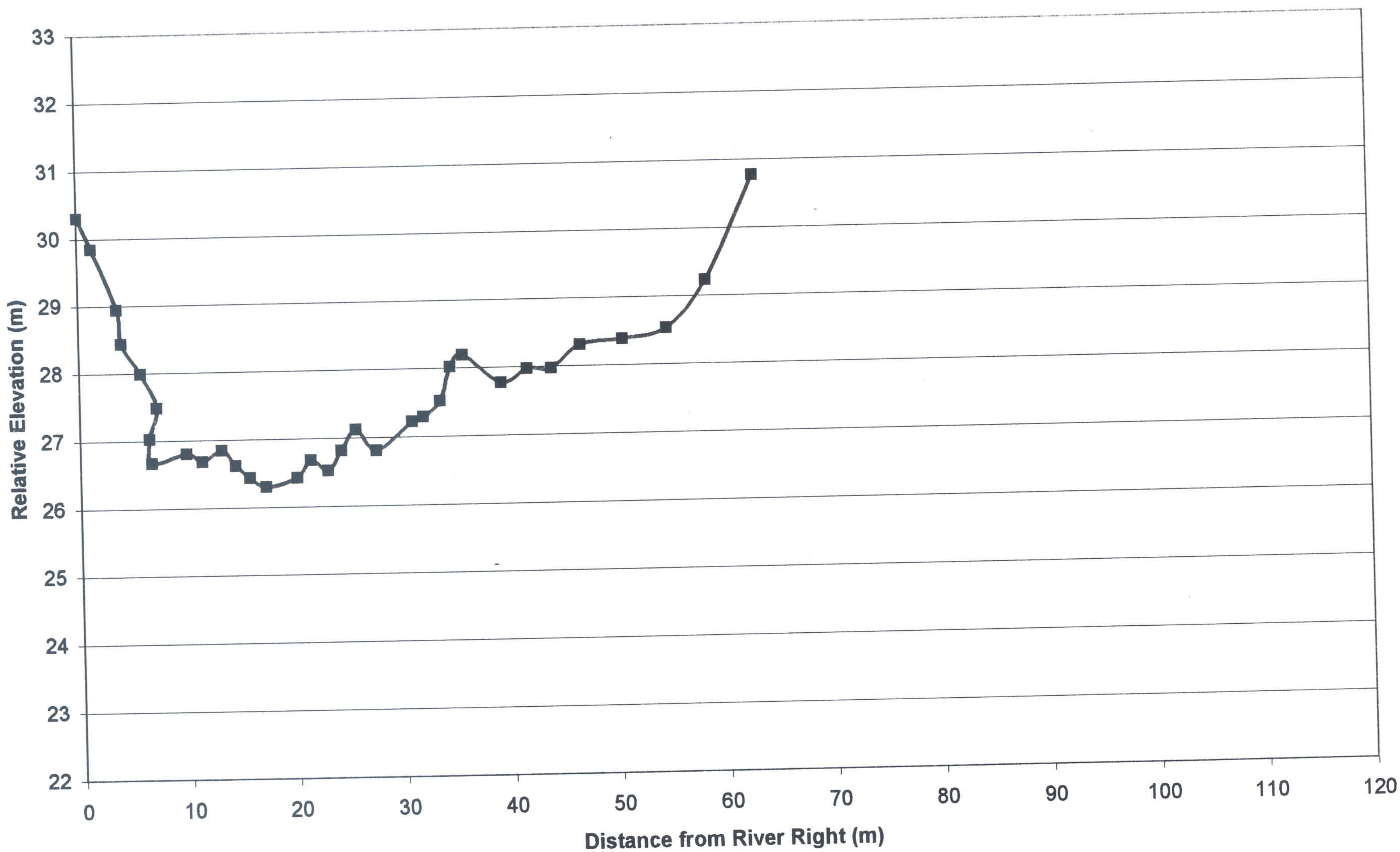
DICA	POACEAE	Digitaria	californica	cottontop	gras	T
DICO	POACEAE	Digitaria	cognata	fall witchgrass	gras	S
ELEL	POACEAE	Elymus	elymoides	squirrel tail	gras	S
ENCE	POACEAE	Enneapogon	cenchroides		gras	A
ENDE	POACEAE	Enneapogon	desvauxii	nineawn pappusgrass	gras	S
ERAR	POACEAE	Eragrostis	arida	desert lovegrass	gras	A
ERBA	POACEAE	Eragrostis	barrelieri	Mediterranian lovegrass	gras	A
ERCI	POACEAE	Eragrostis	cilianensis	stink grass	gras	A
ERIN	POACEAE	Eragrostis	intermedia	plains lovegrass	gras	T
ERLE	POACEAE	Eragrostis	lehmanniana	Lehman's lovegrass	gras	T
ERMEX	POACEAE	Eragrostis	mexicana	Mexican lovegrass	gras	A
ERPE	POACEAE	Eragrostis	pectinacea	lovegrass	gras	A
ERPU	POACEAE	Erioneuron	pulchellus	fluff grass	gras	S
HECO	POACEAE	Heteropogon	contortus	tanglehead	gras	T
HESP	POACEAE	Heteropogon	sp.	Heteropogon species	gras	pr
HIBE	POACEAE	Hilaria	belangeri	curly mesquite grass	gras	S
HIMU	POACEAE	Hilaria	muticus	tobosa	gras	I
LEDU	POACEAE	Leptochloa	dubia	green sprangletop	gras	T
LEFI	POACEAE	Leptochloa	filiformis	red sprangletop	gras	A
LYSE	POACEAE	Lycurus	setosus	wolf tail	gras	S
MERE	POACEAE	Melinis	repens		gras	S
MUAP	POACEAE	Muhlenbergia	appressa	Devils Canyon muhly	gras	A
MUAR	POACEAE	Muhlenbergia	arizonica	muhly	gras	S
MUEM	POACEAE	Muhlenbergia	emersleyi	bullgrass	gras	T
MUFR	POACEAE	Muhlenbergia	fragilis	delicate muhly	gras	A
MUMI	POACEAE	Muhlenbergia	minutissima	muhly	gras	A
MUPO	POACEAE	Muhlenbergia	porteri	bush muhly	gras	T
MURI	POACEAE	Muhlenbergia	rigens	deer grass (riparian)	gras	T
MUSP	POACEAE	Muhlenbergia	sp	Unknown muhly	gras	pr
PAHA	POACEAE	Panicum	Hallii	Hall's panicgrass	gras	S
PAHI	POACEAE	Panicum	hirticaule	panic grass/witch grass	gras	A
PAOB	POACEAE	Panicum	obtusum	vine mesquite	gras	S
POFE	POACEAE	Poa	fendleriana	mutton grass	gras	S
SCCI	POACEAE	Schizachyrium	cirratum	Texas bluestem	gras	T
SELE	POACEAE	Setaria	macrostachya	bristle grass	gras	T
SPCR	POACEAE	Sporobolus	cryptandrus	sand drop seed	gras	T
SPWR	POACEAE	Sporobolus	wrightii	sacaton	gras	T
STNE	POACEAE	Stipa	neomexicana	NM feathergrass	gras	T

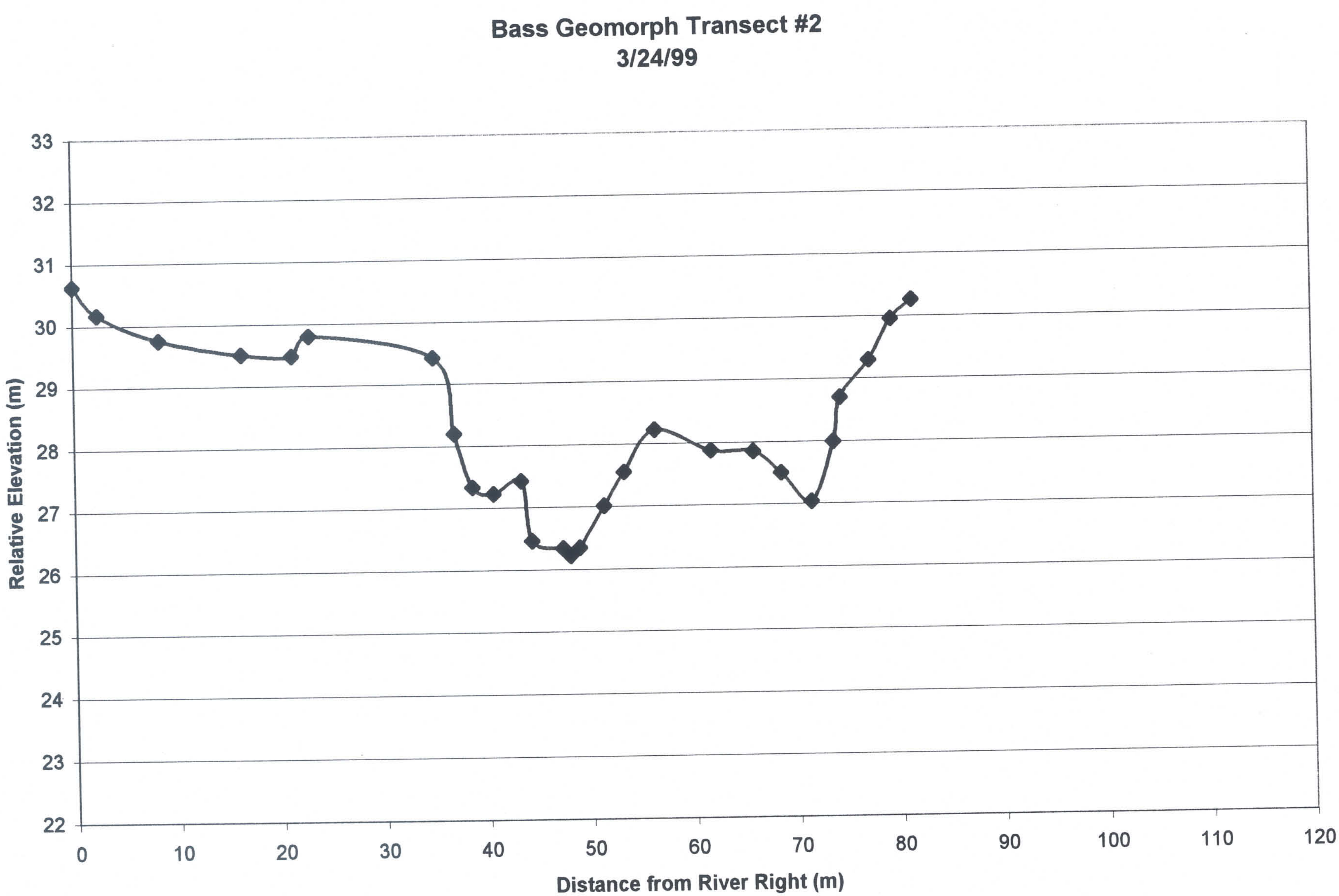
TRSE	POACEAE	Trachypogon	secundus	crinkle awn	gras	T
TRMU	POACEAE	Tridens	muticus	slim tridens	gras	S
VUMI	POACEAE	Vulpia	microstachys	small fescue	gras	A
VUOC	POACEAE	Vulpia	octoflora	six-weeks fescue	gras	A
POOB	POLYGALACEAE	Polygala	obscura		frb	pr
ERWR	POLYGONACEAE	Eriogonum	wrightii	Wright's buckwheat	sub	pr
CHWO	POLYPODIACEAE	Cheilanthes	wootoni	beaded lip fern	frb	pr
NOSI	POLYPODIACEAE	Notholaena	sinuata	wavy cloak fern	frb	pr
PETR	POLYPODIACEAE	Pellaea	truncata	cliff break	frb	pr
WOSP	POLYPODIACEAE	Woodsia	sp		frb	pr
PORE	PORTULACACEAE	Portulaca	retusa	western pusley	frb	an
POSP	PORTULACACEAE	Portulaca	sp.		frb	an
POSU	PORTULACACEAE	Portulaca	suffrutescens	purslane	frb	pr
TAAU	PORTULACACEAE	Talinum	aurantiacum	flame flower	frb	pr
ZIOB	RHAMNACEAE	Zizyphus	obtusifolia	gray-thorn	frb	pr
COLA	SCROPHULARIACEAE	Cordylanthus	laxiflorus	bird beak, club flower	frb	an
LEIN	SCROPHULARIACEAE	Leucospora	intermedia		frb	an
STDU	SCROPHULARIACEAE	Stemodia	durantifolia	whitewoolly twintip	frb	an
LYPA	SOLANACEAE	Lycium	pallidum	wolfberry	frb	pr
PHHE	SOLANACEAE	Physalis	hederaefolia	ground cherry	frb	pr
SOEL	SOLANACEAE	Solanum	elaeagnifolium	silverleaf nightshade; horse ne	frb	pr
ALWR	VERBENACEAE	Aloysia	wrightii	Wright's beebrush	shb	pr
GLBI	VERBENACEAE	Glandularia	bipinnatifida	Dakota mock vervain	frb	pr
TECO	VERBENACEAE	Tetraclea	coulteri	verbena	frb	pr
VESP	VERBENACEAE	Verbena	sp.	verbena species	frb	pr
HYBSP	VIOLACEAE	Hybanthus	sp.	violet species	frb	pr
HYVE	VIOLACEAE	Hybanthus	verticillatus	green violet	frb	pr
KACA	ZYGOPHYLLACEAE	Kallstroemia	californica	California caltrop	frb	an
KAPA	ZYGOPHYLLACEAE	Kallstroemia	parviflora	caltrop	frb	an

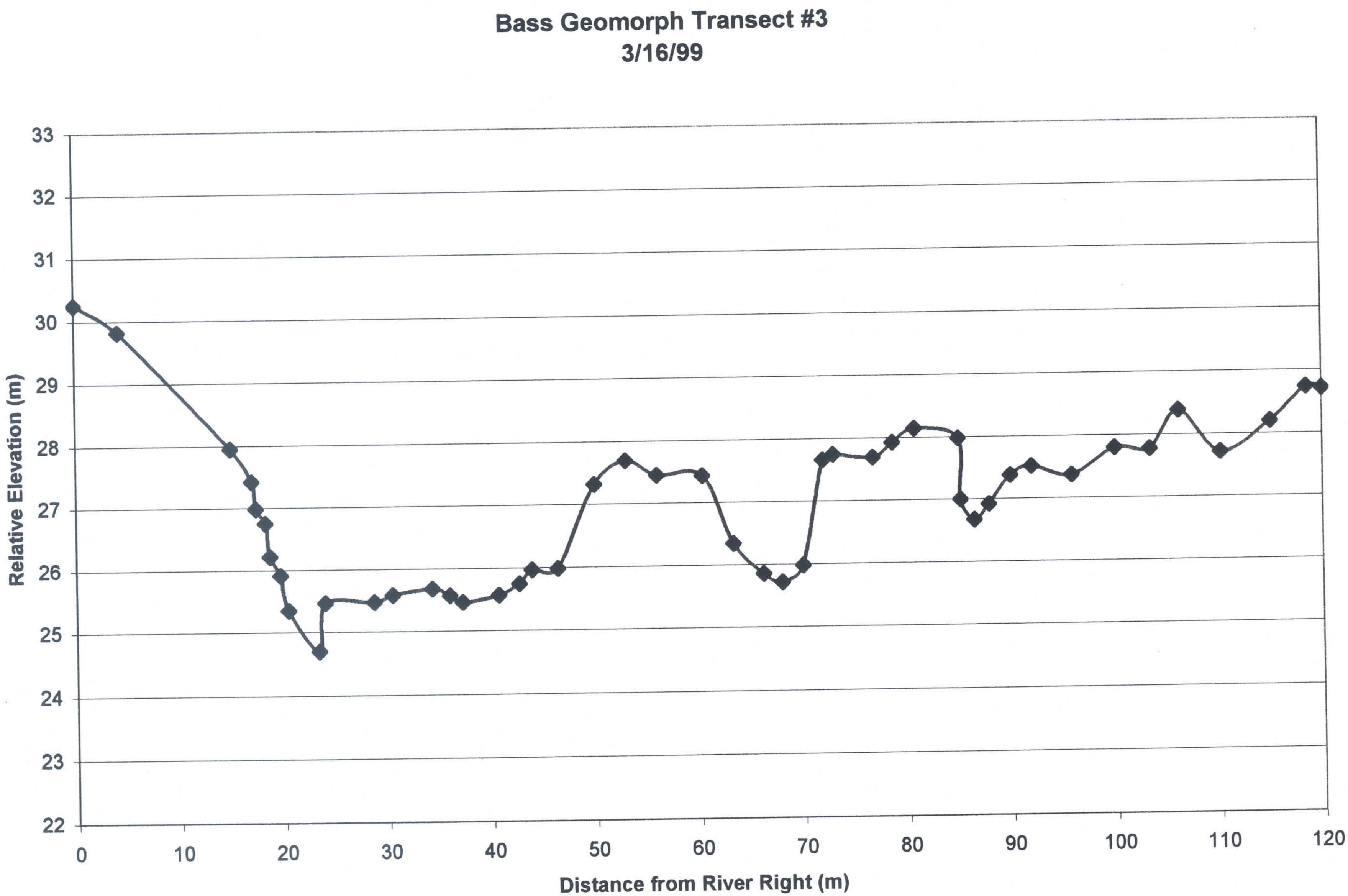
Appendix C

Geomorphic Floodplain Transects

Bass Geomorph Transect #1
3/24/99

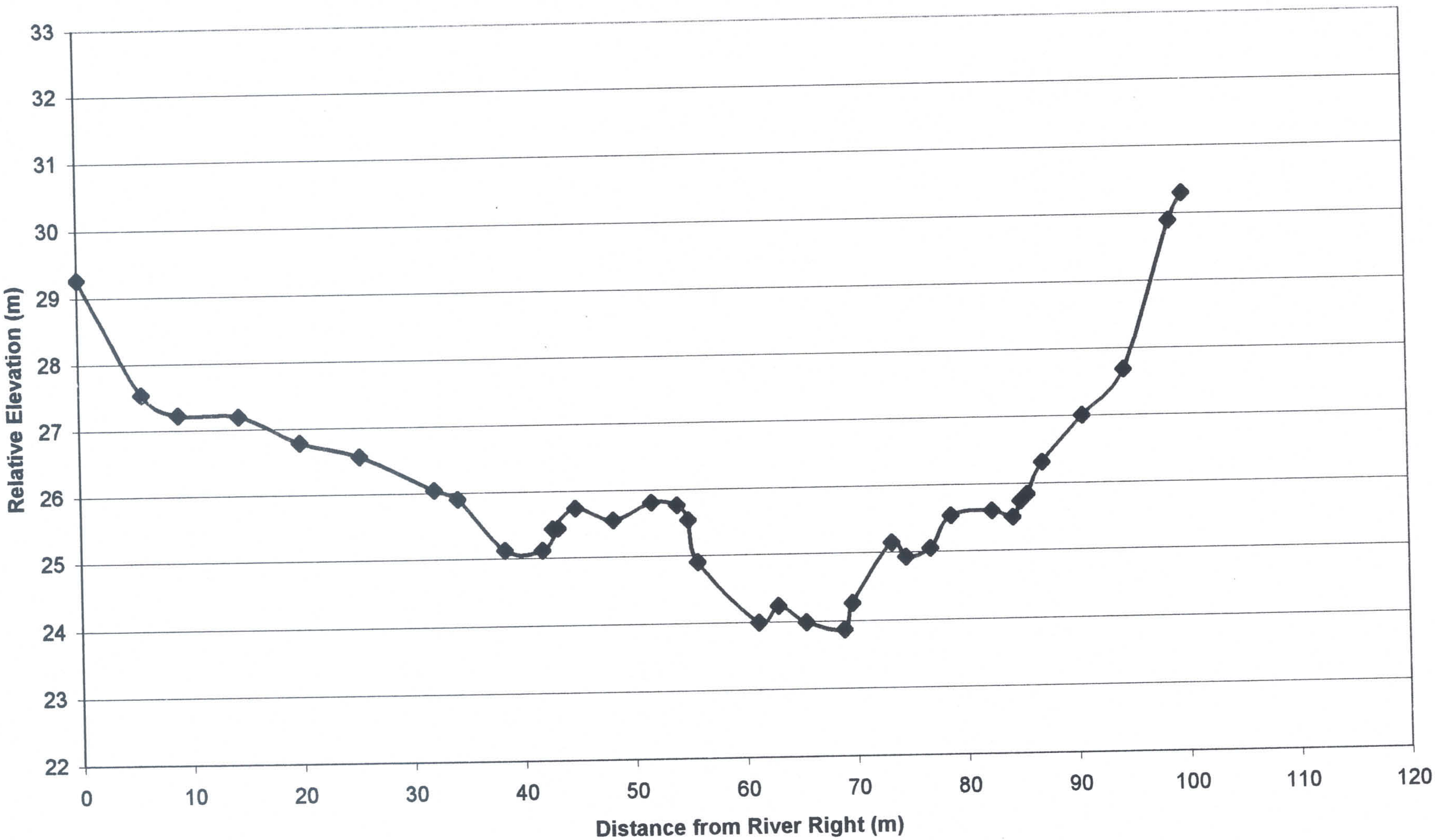


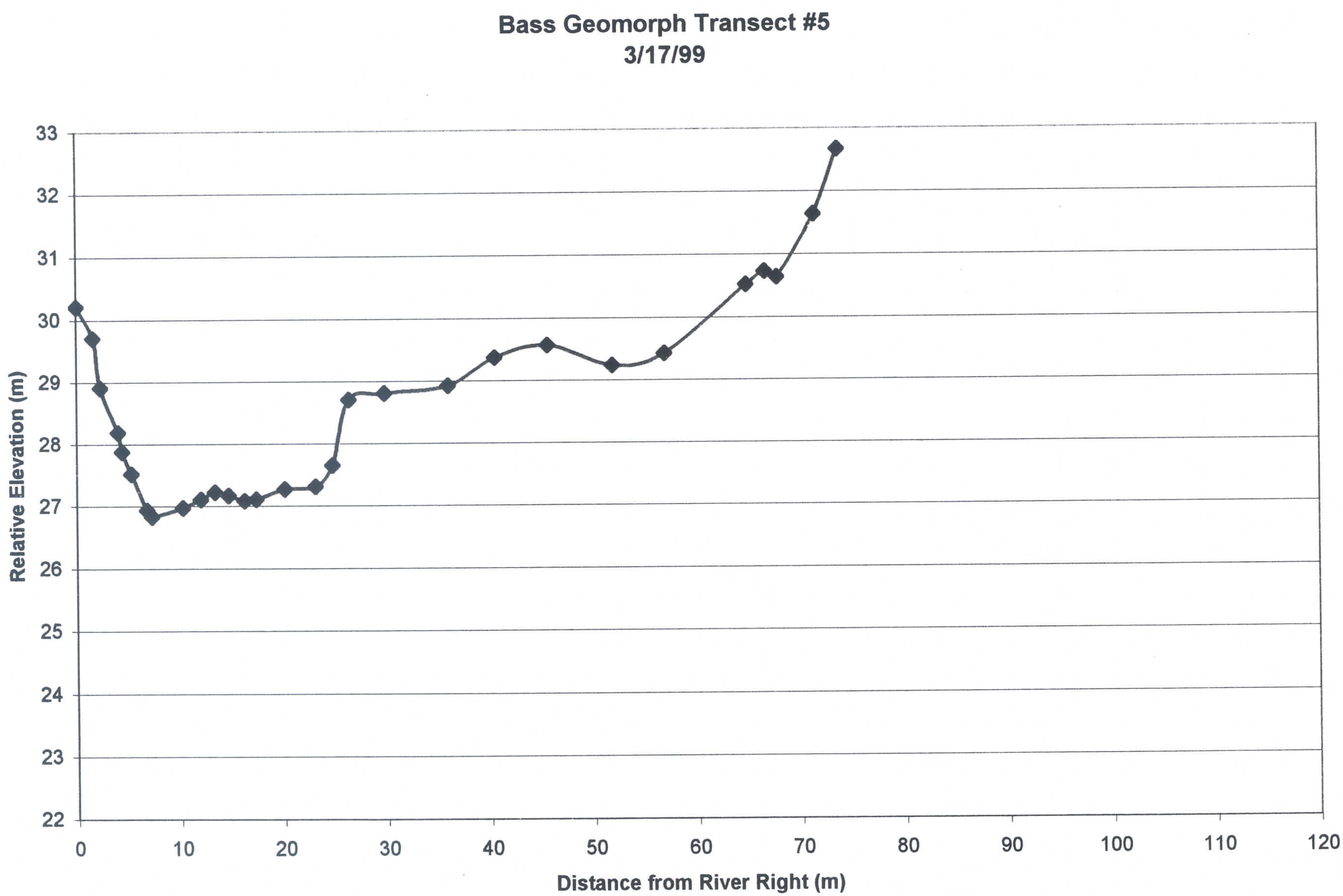

Bass Geomorph Transect #2
3/24/99
Relative Elevation (m)
33
32
31
30
29
28
27
26
25
24
23
22
0
10
20
30
40
50
60
70
80
90
100
110
120
Distance from River Right (m)



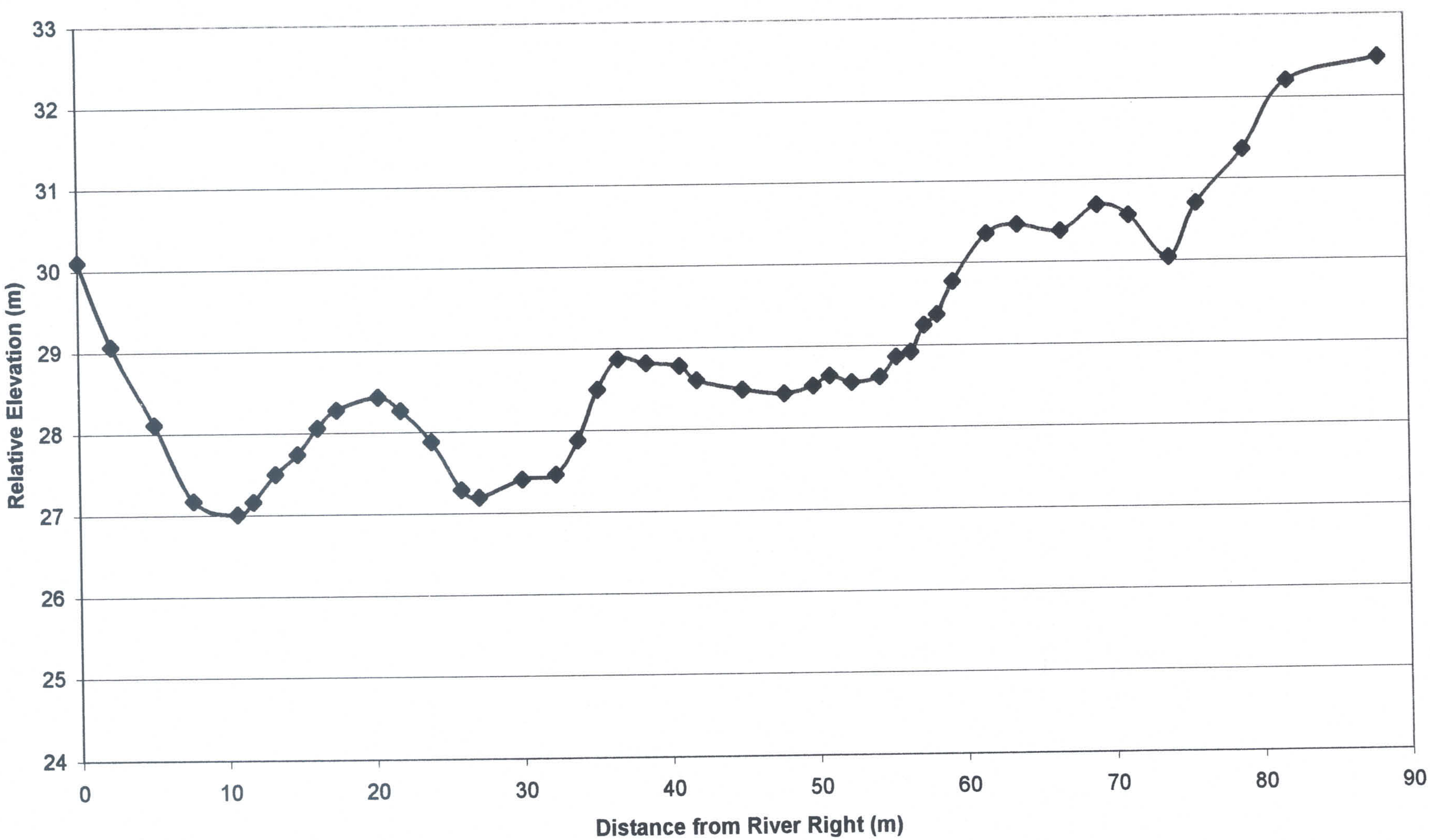
Bass Geomorph Transect #3
3/16/99
Relative Elevation (m)
33
32
31
30
29
28
27
26
25
24
23
22
0
10
20
30
40
50
60
70
80
90
100
110
120
Distance from River Right (m)

Bass Geomorph Transect #4
3/17/99

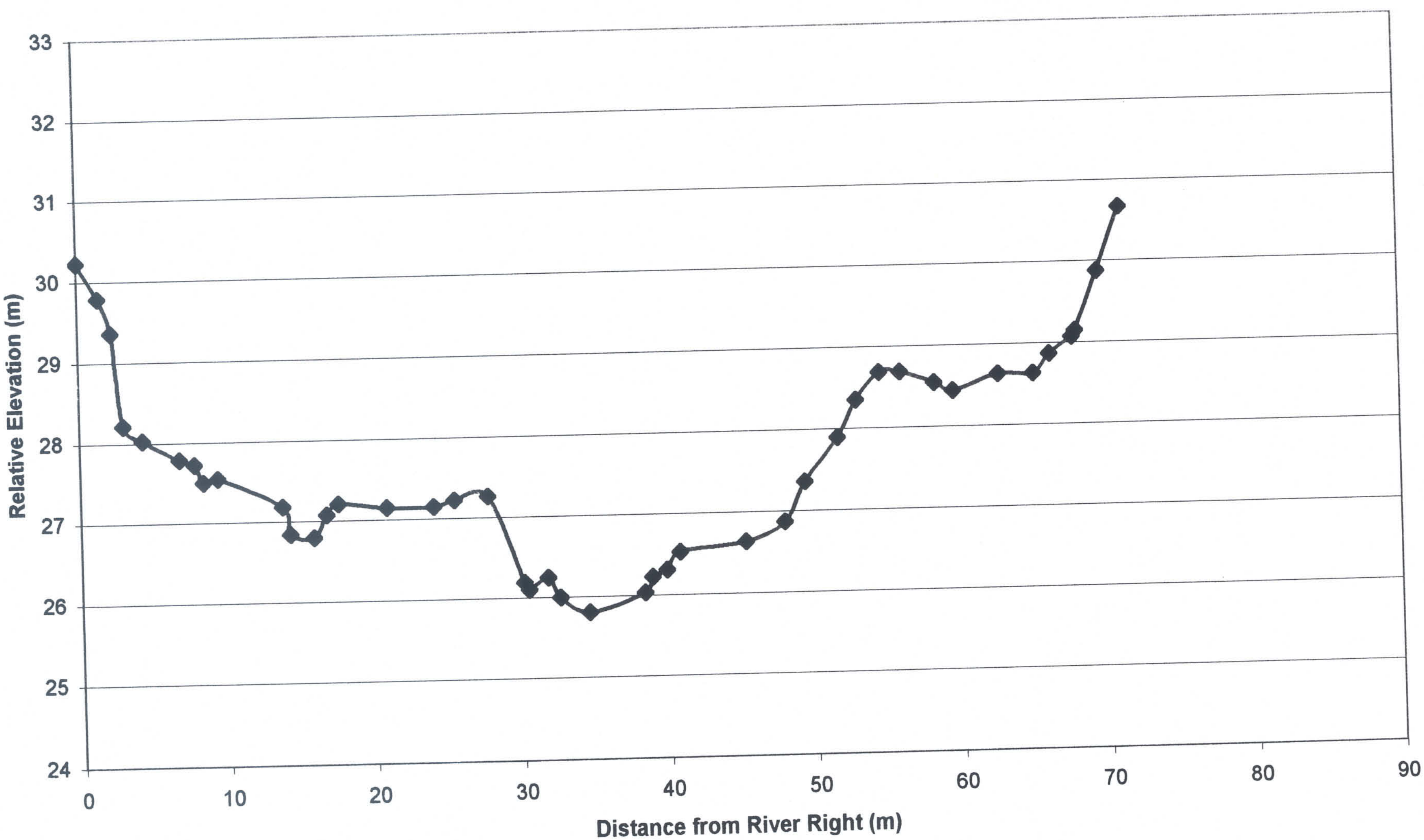


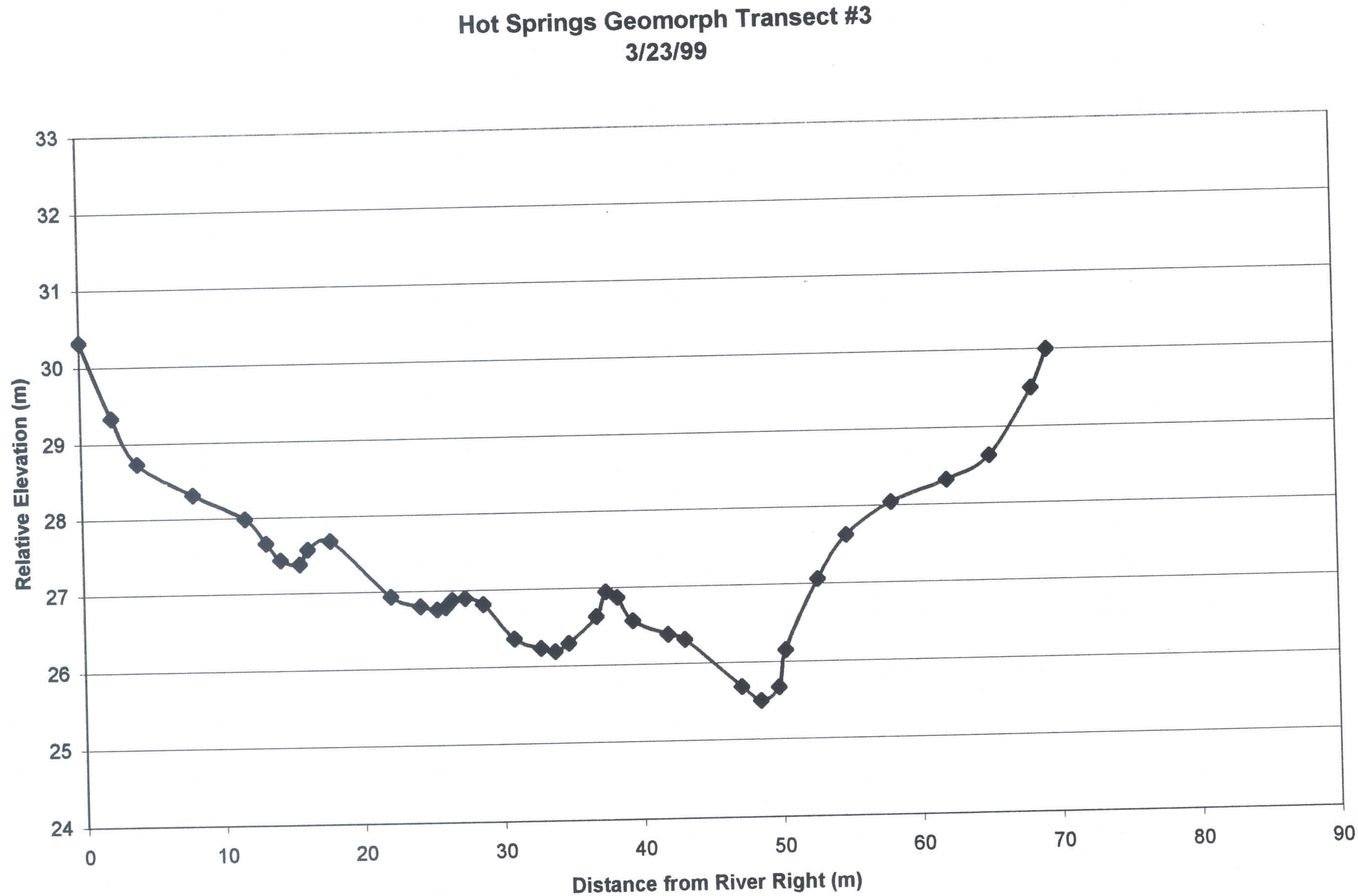

Bass Geomorph Transect #5
3/17/99
Relative Elevation (m)
33
32
31
30
29
28
27
26
25
24
23
22
0
10
20
30
40
50
60
70
80
90
100
110
120
Distance from River Right (m)

Hot Springs Geomorph Transect #1
3/22/99

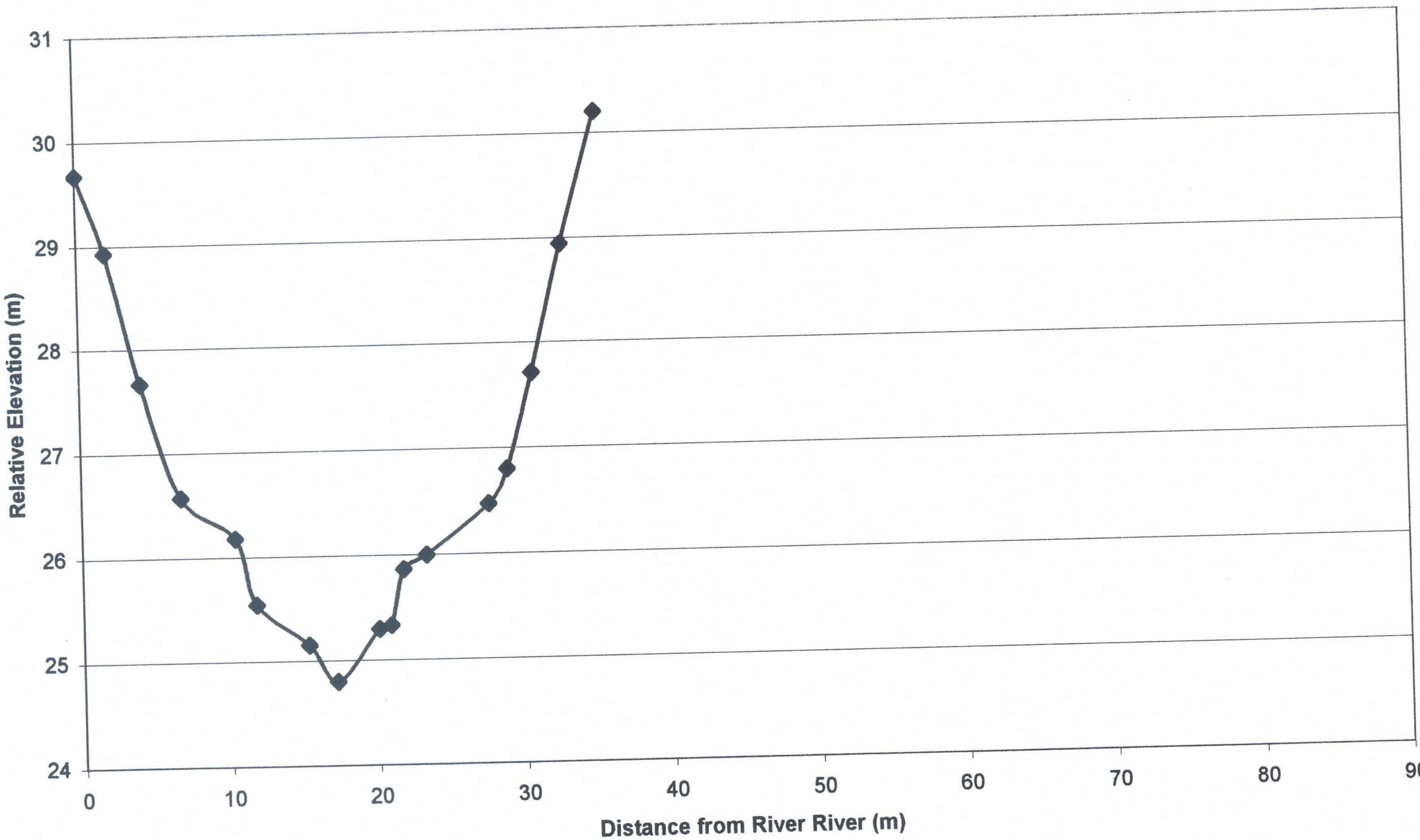


Hot Springs Geomorph Transect #2
3/23/99

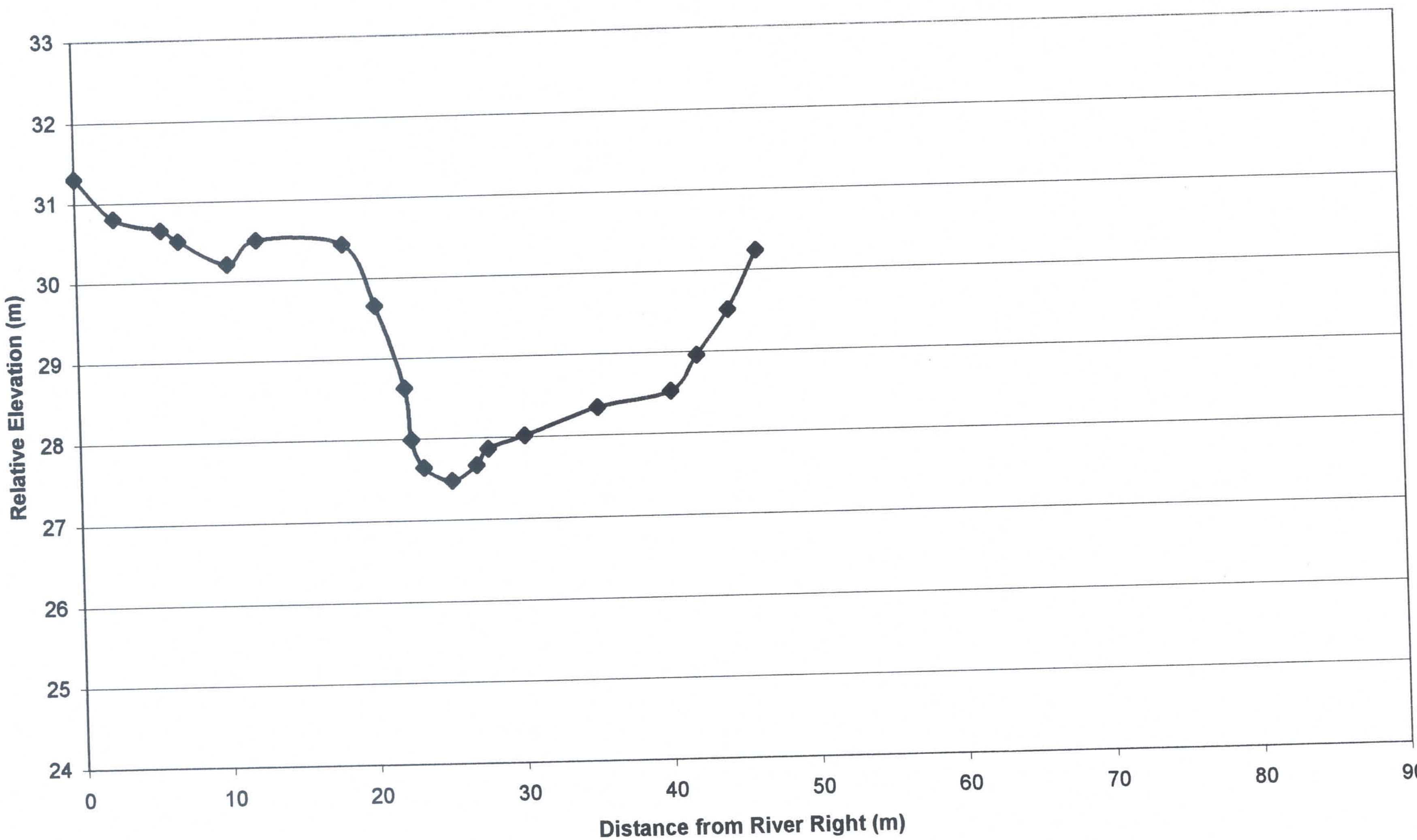



Hot Springs Geomorph Transect #3
3/23/99
Relative Elevation (m)
33
32
31
30
29
28
27
26
25
24
0
10
20
30
40
50
60
70
80
90
Distance from River Right (m)

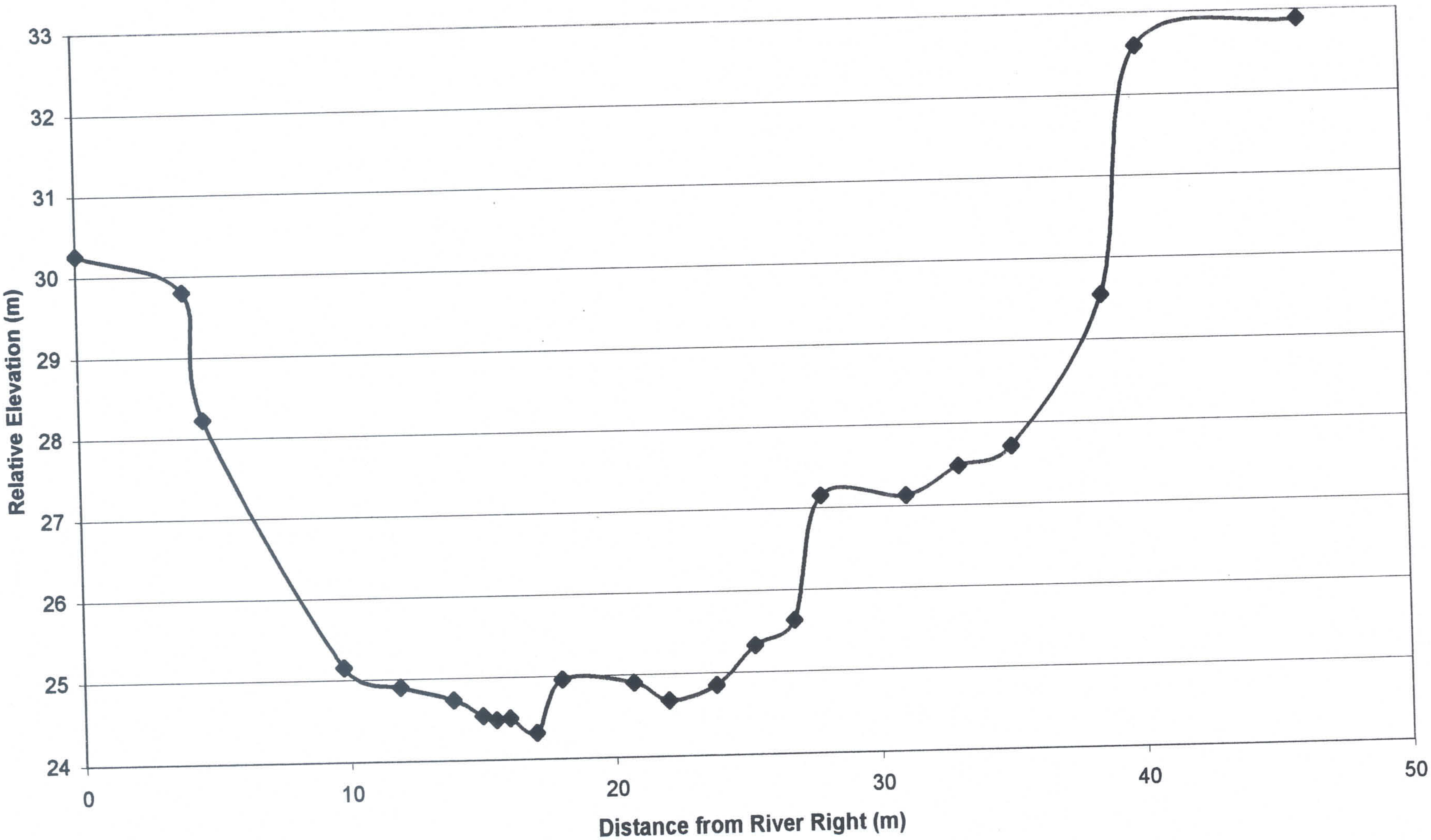
Hot Springs Geomorph Transect #4
3/30/99



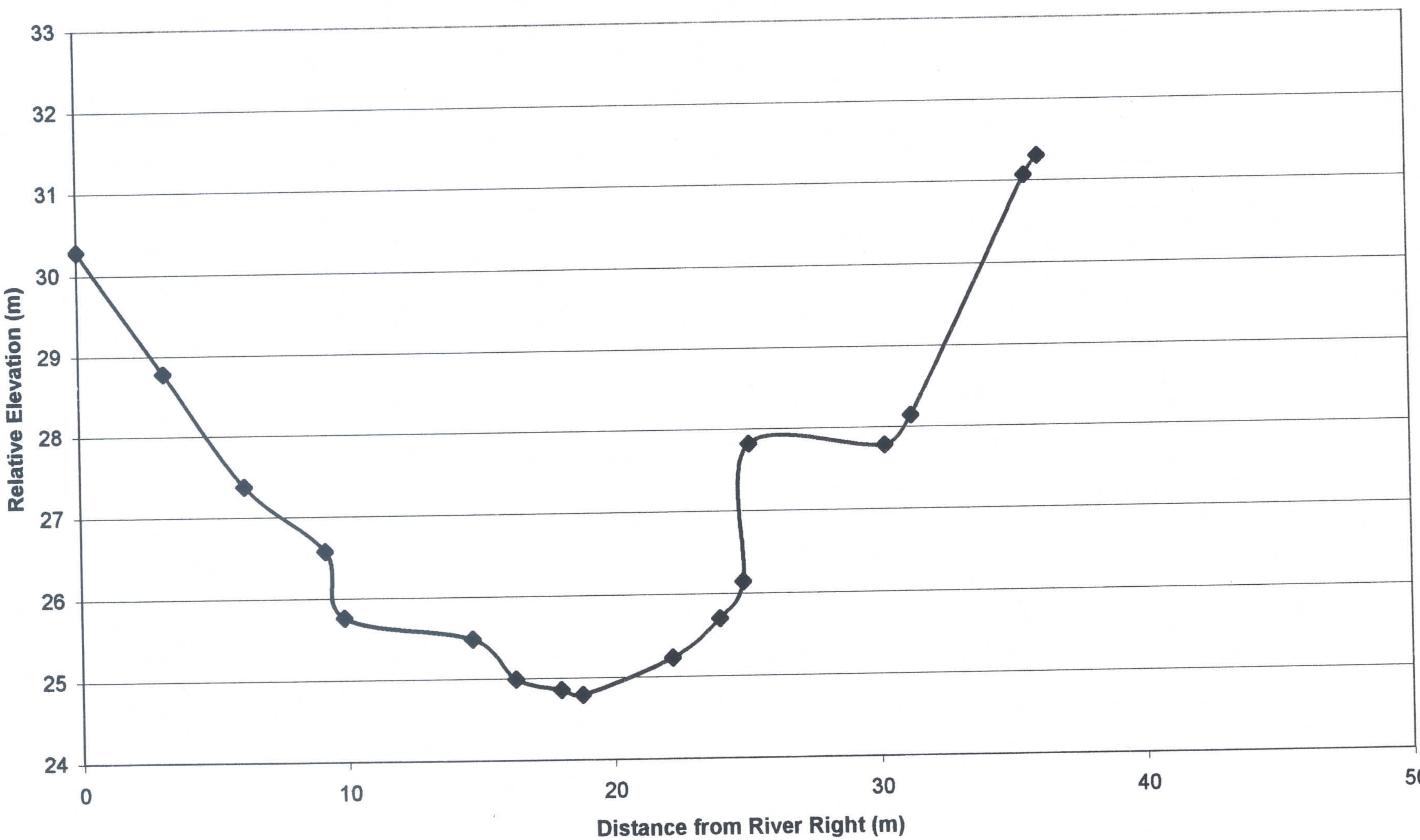
Hot Springs Geomorph Transect #5
3/25/99



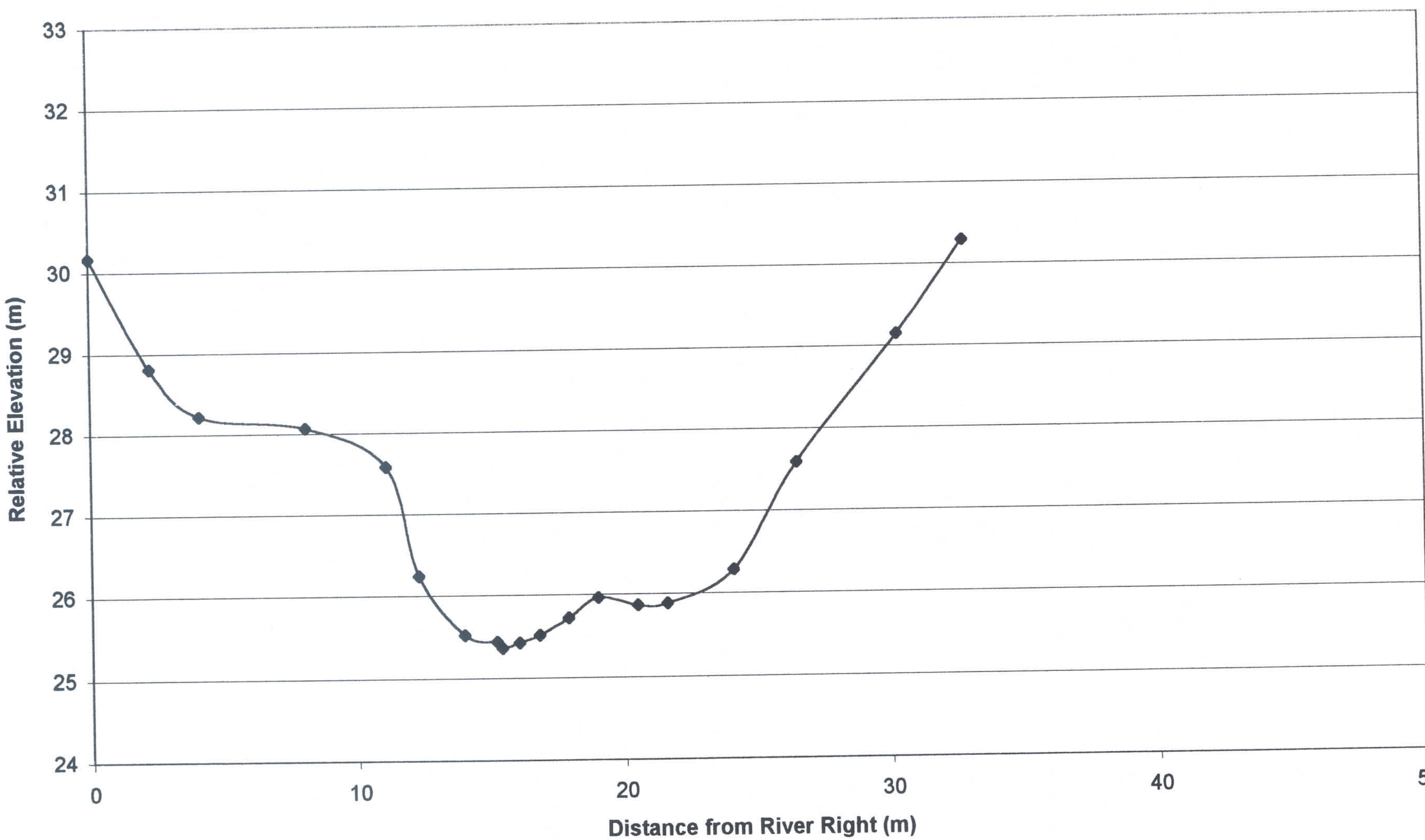
Double R Geomorph Transect #1
3/29/99



Double R Geomorph Transect #2
3/29/99



Double R Geomorph Transect #3
3/31/99



Appendix D

Examples of Photopoint Monitoring

Double R Burn (1998)
Upland Vegetation - Amole

Pre-burn 1996

1st year Post Burn 1998

2nd year Post Burn 1999

Double R Burn (1998)
Upland Vegetation - White Rocks

Pre-burn 1996

1st year Post Burn 1998

2nd year Post Burn 1999

Double R Burn (1998)
Upland Vegetation - Bear

Pre-Burn 1996

1st year Post Burn 1998

2nd year Post Burn 1999

Double R Burn (1998)
Upland Vegetation - Pride Ridge

Pre-Burn 1996

1st year Post Burn 1998

2nd year Post Burn 1999

Hot Springs Burn (1999)

Upland Vegetation - Jesus Tank

Pre Burn

Post Burn

Hot Springs Burn (1999)

Upland Vegetation - Bighorn

Pre Burn

Post Burn

Hot Springs Burn (1999)

Upland Vegetation - North Pole

Pre Burn

Post Burn

Hot Springs Burn (1999)

Upland Vegetation - Stone Cabin

Pre Burn

Post Burn

Hot Springs Burn (1999)

Upland Vegetation - Repeater View (Control Plot)

Pre Burn

Post Burn

Hot Springs Burn (1999)

Upland Vegetation - Ignition Rest (Control Plot)

Pre Burn

Post Burn

Hot Springs Burn (1999)

Upland Vegetation - Hooker's View (Control Plot)

Pre Burn

Post Burn

Fish Monitoring
Bass, Station #2
50 m point looking downstream

1997

1998

1999

2000

Fish Monitoring
Bass Station # 3
100 m point looking downstream

1996

1998

1999

2000

Fish Monitoring
Bass Station # 5
0 m point looking upstream

1996

1997

1999

2000

Fish Monitoring
Bass, station # 8
0 m point looking upstream

1996

1998

1999

2000

Fish Monitoring
RR Station # 2
50 m point looking downstream

1998

1999

2000

Fish Monitoring
Wildcat, Station # 1
0 m point looking upstream

1998

1999

2000

Riparian Transects

Bass Canyon

Upstream Portion of Transect
1994

Upstream Portion of Transect
2000

Fish Monitoring
Wildcat, Station # 2
0 m point looking upstream

1998

1999

2000

Riparian Transects

Double R, Downstream Portion of Transect
2000

Hot Springs, Upstream Portion of Transect
2000

Geomorphology Transect - Cross Section of Floodplain
Hot Springs, Established 1999

View 1

View 2

View 3

Geomorphology Transect - Cross Section of Floodplain
Bass Canyon, Established 1999

View 1

View 2

View 3

Appendix E

Summary Tables of Monitoring Data

Table 1: Percent Cover of Selected Shrubs and Total Shrub Cover for Plots in Double R Burn

	Pre-Burn						2 Year Post-Burn					
Plot	*Acacia constricta*	*Agave schottii*	*Gutierrezia sarothrea*	*Juniperus coahuilensis*	*Prosopis veluntina*	**Total Shrub Cover**	*Acacia constricta*	*Agave schottii*	*Gutierrezia sarothrea*	*Juniperus coahuilensis*	*Prosopis veluntina*	**Total Shrub Cover**
Amole	0.00	31.67	1.08	5.20	12.23	53.85	0.00	8.04	0.24	4.35	2.31	17.78
Bear	0.00	0.00	4.19	0.00	3.98	25.40	0.00	0.00	0.38	0.00	0.06	7.05
Benchmark	0.00	0.00	2.40	1.86	4.68	17.01	2.50	1.17	0.00	1.41	0.00	4.80
Black Waterfall	0.00	7.15	2.80	1.53	3.95	17.92	0.00	0.77	0.00	0.00	0.57	3.80
Old Pride Trap	0.00	21.03	4.50	0.00	15.73	46.09	0.00	0.00	0.00	0.00	0.00	5.18
Pride Ridge	0.00	0.00	9.15	0.20	9.39	26.79	0.00	0.00	2.72	0.00	3.13	11.73
Pride View	0.00	1.33	0.84	8.53	1.60	15.44	0.00	2.04	0.19	7.36	0.00	11.41
White Rocks	0.00	6.48	1.63	8.40	9.15	30.13	0.00	1.90	0.00	2.36	0.62	7.33

Acacia constricta (white thorn acacia)
Agave schottii (amole)
Gutierrezia sarothrea (snakeweed)
Juniperus coahuilensis (MX juniper)
Prosopis veluntina (mesquite)

Table 2: Frequency of occurrence of plant categories in nested quadrats, expressed as frequency percentage.

DOUBLE R BURN

		Pre-Burn		2 yr. Post-Burn			
PLOT	QUADRAT	Perennial Grass	Annual Grass	Perennial Grass	Annual Grass	Perennial Herb	Annual Herb
Amole	0.01	17.0	0.5	37.5	1.0	1.0	1.5
	0.16	70.0	3.0	87.5	13.5	17.0	19.0
	1.00	90.5	8.0	97.0	28.0	34.5	40.5
Bear	0.01	43.0	2.0	62.0	3.5	2.5	11.5
	0.16	85.0	7.5	90.0	32.0	24.0	56.0
	1.00	96.0	16.5	97.0	58.5	54.0	86.0
Benchmark	0.01	39.5	5.5	21.5	8.0	4.0	6.5
	0.16	80.5	29.0	68.0	34.0	16.5	39.5
	1.00	96.5	54.0	88.5	66.0	32.5	73.0
Black Waterfall	0.01	31.0	15.5	45.0	8.0	8.0	36.5
	0.16	80.0	33.5	88.5	31.0	30.0	84.0
	1.00	94.5	50.5	98.0	57.5	54.5	97.5
Old Pride Trap	0.01	30.0	4.5	38.5	13.0	9.0	11.0
	0.16	67.5	12.5	76.0	39.0	33.0	42.0
	1.00	91.0	26.5	92.5	64.0	60.0	65.0
Pride Ridge	0.01	32.5	33.0	43.0	31.5	13.0	33.0
	0.16	69.5	65.0	79.5	70.0	57.5	80.0
	1.00	93.0	82.5	95.5	88.0	85.0	95.5
Pride View	0.01	44.5	0.0	59.5	7.5	9.0	9.5
	0.16	90.5	11.5	92.0	27.0	40.0	45.0
	1.00	95.5	21.5	97.0	52.5	70.5	75.5
White Rocks	0.01	35.0	3.0	48.0	2.0	10.5	7.0
	0.16	85.0	11.5	86.0	6.5	40.0	50.0
	1.00	96.0	26.0	99.0	24.0	72.0	83.5

Annual and Perennial Herbs not recorded on frequency transects in 1996.

Table 3: Basal Cover of Different Substrate Categories in Monitoring Plots Double R Burn

	PRE-BURN				ONE GROWING SEASON POST-BURN				TWO GROWING SEASONS POST-BURN			
PLOT	Soil/Gravel Basal (%)	Rock Basal (%)	Litter Basal (%)	Live Basal (%)	Soil/Gravel Basal (%)	Rock Basal (%)	Litter Basal (%)	Live Basal (%)	Soil/Gravel Basal (%)	Rock Basal (%)	Litter Basal (%)	Live Basal (%)
Amole	61.45	14.25	18.68	5.63	48.25	17.38	23.63	10.75	41.75	8.88	29.88	19.50
Bear	39.70	28.10	21.60	10.60	58.38	23.75	7.00	10.88	51.00	7.50	8.25	33.25
Benchmark	48.62	21.73	21.11	8.54	39.75	30.63	27.13	2.50	44.00	21.00	20.25	14.75
Black Waterfall	50.45	11.63	27.18	10.75	63.38	18.50	8.13	10.00	58.13	6.38	13.38	22.13
Old Pride	33.46	13.23	42.11	11.20	42.38	17.00	20.75	19.88	56.38	3.75	20.38	19.50
Pride Ridge	29.75	33.59	29.56	7.10	62.75	2.88	21.63	12.75	55.13	0.25	22.13	22.50
Pride View	44.45	25.88	20.80	8.88	51.25	27.13	11.88	9.75	41.00	17.75	13.75	27.50
White Rocks	42.38	18.75	30.63	8.25	53.25	21.63	16.13	9.00	58.13	6.38	13.38	22.13

Table 4: Percent Composition by (Dry) Weight of Vegetation by Functional Group in Double R Burn

	Pre-Burn				2 Year Post-Burn			
PLOT	Perennial Grass	Annual Grass	Perennial Herb	Annual Herb	Perennial Grass	Annual Grass	Perennial Herb	Annual Herb
Amole	95.6	2.5	1.9	0.0	81.0	3.6	2.9	12.5
Bear	91.1	4.9	1.9	2.1	77.4	4.3	4.3	14.0
Benchmark	N/A	N/A	N/A	N/A	54.5	6.9	5.0	33.5
Black Waterfall	77.1	11.0	2.0	9.9	69.4	4.6	4.4	21.7
Old Pride Trap	60.9	36.3	2.5	0.3	66.3	7.7	3.9	22.2
Pride Ridge	48.8	23.9	20.9	6.5	59.3	19.9	5.4	15.4
Pride View	N/A	N/A	N/A	N/A	83.7	3.5	4.5	8.4
White Rocks	N/A	N/A	N/A	N/A	75.6	1.7	5.8	16.7

Table 5: Percent Cover of Selected Shrubs and Total Shrub Cover for Plots in Hot Springs Burn

		Pre-Burn							Post-Burn						
Plot	**Treatment**	*Acacia constricta*	*Agave schottii*	*Gutierrezia sarothrea*	*Isocoma coronopifolia*	*Juniperus coahuilensis*	*Prosopis veluntina*	**Total Shrub Cover**	*Acacia constricta*	*Agave schottii*	*Gutierrezia sarothrea*	*Isocoma coronopifolia*	*Juniperus coahuilensis*	*Prosopis veluntina*	**Total Shrub Cover**
Breakdown	Repeat	1.1	0.0	3.1	0.0	2.3	0.7	10.1	0.8	0.0	0.5	0.0	3.9	0.0	8.2
Big Horn	Burn	0.0	0.0	36.8	1.1	13.1	22.3	77.9	0.0	0.0	0.1	0.3	6.5	4.0	12.8
Fenceline	Repeat	1.1	0.0	8.3	0.0	0.0	0.9	11.8	1.1	0.0	1.0	0.0	0.0	2.5	9.7
Green Acres	Repeat	1.7	2.7	0.7	0.0	0.7	3.2	16.0	0.5	2.3	0.0	0.1	0.0	1.5	6.2
Grants	Burn	0.0	9.5	3.1	0.0	2.8	3.9	20.5	0.0	2.4	0.0	0.0	2.3	0.0	5.0
Jesus Tank	Burn	0.0	0.0	11.2	8.7	0.0	10.7	31.1	0.0	0.0	0.0	0.0	0.0	3.0	3.1
Lil' Rattler	Burn	0.0	22.2	0.0	0.0	0.0	1.0	26.6	0.0	7.6	0.0	0.3	0.0	0.0	8.7
Muledeer	Burn	0.0	2.7	12.3	1.0	0.0	9.9	29.6	0.0	0.3	0.0	0.0	0.0	1.0	2.5
Marty's Mom	Burn	0.0	5.4	6.0	2.5	0.0	13.5	28.7	0.0	1.1	0.0	0.0	0.0	2.4	3.7
North Pole	Burn	0.0	0.0	12.5	17.6	0.2	17.8	48.8	0.0	0.0	1.4	0.0	0.5	3.2	10.1
Stone Cabin	Burn	0.0	0.0	12.6	9.9	5.1	11.2	41.7	0.0	0.0	0.0	0.0	4.2	0.6	5.4
Wildcat	Repeat	0.0	5.7	0.6	0.0	0.0	4.5	13.6	0.9	0.8	0.0	0.0	0.0	1.6	4.6
Before Browning	Control	0.0	35.2	0.5	0.0	3.7	3.5	47.8	0.0	21.6	0.0	0.0	1.9	0.5	27.9
Hookers View	Control	21.6	0.0	0.0	0.0	0.0	0.0	40.8	22.9	0.0	0.0	0.0	0.0	0.0	31.5
Ignition Rest	Control	21.3	12.4	1.9	0.0	1.6	1.5	40.1	21.1	8.2	0.0	0.0	1.4	6.4	37.6
Red Baron	Control	1.0	0.0	2.0	5.1	0.0	11.5	25.5	12.2	0.0	0.2	9.6	0.0	8.1	36.8
Repeater View	Control	8.5	0.0	0.8	0.0	0.0	0.5	13.3	6.8	0.0	0.0	0.0	0.0	1.5	13.1
South Elan	Control	0.0	0.0	5.0	0.0	0.2	17.8	28.2	0.0	0.0	1.6	0.0	2.2	10.4	17.6

Acacia constricta (white thorn acacia)
Agave schottii (amole)
Gutierrezia sarothrea (snakeweed)
Isocoma coronopifolia (burrow we)eed
Juniperus coahuilensis (MX juniper)
Prosopis veluntina (mesquite)

Table 6: Frequency of occurrence of plant categories in nested quadrats, expressed as frequency percentage.

HOT SPRINGS BURN

			Pre-Burn				Post-Burn			
PLOT	Treatment	QUADRAT	Perennial Grass	Annual Grass	Perennial Herb	Annual Herb	Perennial Grass	Annual Grass	Perennial Herb	Annual Herb
Big Horn	burn	0.01	16.0	7.0	0.00	0.00	29.5	1.5	1.00	0.50
		0.16	57.5	24.5	0.50	1.00	90.0	10.5	16.50	2.00
		1.00	82.0	43.5	5.00	11.00	98.5	27.5	43.50	5.00
Breakdown	repeat	0.01	52.0	4.5	0.00	2.00	46.0	13.5	1.00	24.50
		0.16	96.0	29.0	4.00	17.50	95.0	59.0	3.00	84.00
		1.00	99.5	46.0	22.00	50.00	99.0	84.0	9.50	98.00
Fenceline	repeat	0.01	40.0	16.5	3.50	6.00	29.0	10.0	0.50	0.00
		0.16	93.0	56.5	23.50	46.50	89.5	33.5	2.50	14.50
		1.00	98.0	79.0	39.50	71.50	97.5	62.5	7.50	36.00
Grants	burn	0.01	42.5	3.0	0.50	2.00	38.5	10.0	1.50	0.50
		0.16	82.5	12.5	7.50	15.50	83.5	30.0	16.50	6.00
		1.00	97.5	17.0	21.00	36.50	97.5	59.5	34.00	18.00
Green Acres	repeat	0.01	42.0	0.0	1.00	1.00	21.0	6.0	5.00	12.50
		0.16	91.5	2.5	6.00	8.00	77.5	40.0	20.50	51.00
		1.00	99.0	6.5	22.50	26.00	99.0	69.0	47.00	77.50
Jesus Tank	burn	0.01	50.0	14.5	1.00	7.50	51.5	4.0	3.00	5.00
		0.16	89.0	58.5	11.50	33.50	96.5	20.5	21.00	24.00
		1.00	99.0	77.0	27.50	60.00	99.5	49.0	40.50	51.50
Lil' Rattler	burn	0.01	38.0	6.0	0.00	0.50	23.0	1.0	1.00	0.00
		0.16	91.5	13.5	0.50	1.00	82.5	14.0	4.50	4.00
		1.00	99.5	28.5	4.00	1.50	99.5	34.0	13.00	15.50
Marty's Mom	burn	0.01	41.0	16.0	1.50	2.00	56.5	7.0	1.00	18.00
		0.16	89.5	44.0	5.00	24.50	95.5	26.5	10.50	41.50
		1.00	99.0	58.0	16.50	58.00	99.5	52.0	28.50	52.50
Muledeer	burn	0.01	62.5	1.0	1.50	5.00	38.0	9.5	0.50	0.00
		0.16	95.0	8.0	2.50	30.00	90.0	32.0	6.00	2.50
		1.00	100.0	22.0	7.00	48.00	98.5	58.0	18.00	7.00
North Pole	burn	0.01	26.5	7.5	0.50	0.50	36.0	14.0	4.00	3.00
		0.16	61.0	25.5	6.00	13.00	67.0	42.5	15.50	28.00
		1.00	82.5	55.0	22.50	35.00	88.0	64.0	27.50	50.50
Stone Cabin	burn	0.01	38.5	3.0	0.00	3.00	55.0	6.0	1.00	0.00
		0.16	86.5	17.0	0.50	20.50	94.5	24.0	6.50	2.00
		1.00	98.0	40.5	2.50	58.00	99.0	42.0	17.00	9.00
Wildcat	repeat	0.01	29.5	2.5	2.00	5.00	5.5	18.5	0.50	0.50
		0.16	73.5	15.0	13.50	35.00	37.0	68.0	9.50	6.50
		1.00	91.0	31.5	31.00	72.50	68.5	88.0	15.50	17.00
Before Browning	control	0.01	19.5	1.0	4.0	0.0	19.5	2	2.5	0
		0.16	76.0	11.0	23.0	1.0	74	8.5	9.5	0.5
		1.00	96.0	26.5	46.0	2.0	92.5	16.5	27.5	3
Hooker's View	control	0.01	34.5	0.0	0.0	0.0	19	0	0.5	0.5
		0.16	87.0	0.0	2.5	0.0	82.5	0	7	4.5
		1.00	99.0	1.5	5.5	1.5	97	2	26.5	10.5
Ignition Rest	control	0.01	15.5	8.0	2.0	7.5	4	5.5	2.5	1
		0.16	52.0	26.0	15.5	38.0	36.5	18.5	8.5	4
		1.00	86.0	47.0	40.0	67.0	77	33.5	13.5	11
Red Baron	control	0.01	59.5	44.5	0.0	45.5	25	24.5	1	0.5
		0.16	82.5	85.5	4.0	81.5	70.5	63	11.5	9
		1.00	94.5	94.5	15.5	90.0	92	78.5	27.5	34
Repeater View	control	0.01	56.5	7.0	7.0	3.5	12.5	11	3.5	9
		0.16	92.0	30.5	42.0	34.0	36	45.5	31.5	57
		1.00	98.0	52.0	81.5	67.0	69	75	66.5	80.5
South Elan	control	0.01	71.0	2.0	1.0	11.0	35	1.5	4	5.5
		0.16	92.5	7.5	18.0	50.5	86.5	3.5	25	46
		1.00	99.0	18.5	41.5	75.0	97	13	48	79

Table 7:Basal Percent Cover of Different Substrate Categories in Monitoring Plots, Pre-Burn Measurements, Hot Springs Burn

Plot	Treatment	Rock Basal (%)	Soil/Gravel Basal (%)	Litter Basal (%)	Herbs Basal (%)	Annual Grass Basal (%)	Perennial Grass Basal (%)	Total Live Basal (%)
Big Horn	Burn	6.57	63.03	26.80	0.00	0.13	3.47	3.60
Before Browning	Control	8.90	30.01	52.49	0.53	0.27	7.80	8.60
Breakdown	Repeat	29.76	40.36	18.41	0.67	0.93	9.87	11.47
Fenceline	Repeat	23.29	46.59	22.92	0.00	0.40	6.80	7.20
Grants	Burn	26.04	33.48	25.67	0.13	0.00	14.67	14.80
Green Acres	Repeat	10.81	68.36	7.50	0.67	0.00	12.67	13.33
Hooker's	Control	2.64	55.84	24.39	0.27	0.00	16.87	17.14
Ignition Rest	Control	11.29	30.42	51.42	2.93	0.27	3.67	6.87
Jesus Tank	Burn	5.91	65.49	15.13	0.93	0.53	12.00	13.47
Lil Rattler	Burn	20.61	40.48	25.58	0.00	0.13	13.20	13.33
Marty's Mom	Burn	28.41	27.43	35.76	0.67	0.13	7.60	8.40
Mule Deer	Burn	15.85	49.09	20.25	1.20	0.00	13.60	14.80
North Pole	Burn	9.89	61.65	19.79	0.53	0.27	7.87	8.67
Red Baron	Control	0.00	55.38	20.02	1.73	2.40	14.47	18.60
Repeater View	Control	4.92	50.35	19.06	2.80	2.13	20.73	25.66
South Elan	Control	5.43	31.83	32.14	0.93	0.40	29.27	30.60
Stone Cabin	Burn	4.58	68.25	18.11	0.00	0.00	9.07	9.07
Wildcat	Repeat	11.64	53.80	24.16	1.73	0.00	8.67	10.40

Table 8: Basal Percent Cover of Different Substrate Categories in Monitoring Plots, Post-Burn Measurements, Hot Springs Burr

Plot	Treatment	Rock Basal (%)	Soil/Gravel Basal (%)	Litter Basal (%)	Herbs Basal (%)	Annual Grass Basal (%)	Perennial Grass Basal (%)	Total Live Basal (%)
Big Horn	Burn	20.35	44.03	24.42	1.07	0.00	10.13	11.20
Before Browning	Control	19.27	23.97	53.29	0.00	0.13	3.33	3.47
Breakdown	Repeat	32.79	36.80	20.28	1.07	1.73	7.33	10.13
Fenceline	Repeat	12.16	56.38	19.73	0.13	0.80	10.80	11.73
Grants	Burn	31.01	36.82	22.04	0.27	0.53	9.33	10.13
Green Acres	Repeat	15.29	53.82	26.22	0.93	0.40	3.33	4.67
Hooker's	Control	10.60	61.68	25.46	0.13	0.00	2.13	2.27
Ignition Rest	Control	16.78	39.30	42.31	0.40	0.53	0.67	1.60
Jesus Tank	Burn	7.73	63.04	15.76	0.53	0.13	12.80	13.47
Lil Rattler	Burn	19.00	44.67	25.67	0.40	0.27	10.00	10.67
Marty's Mom	Burn	19.42	47.59	18.45	0.13	0.53	13.87	14.53
Mule Deer	Burn	19.45	53.16	16.86	0.80	0.40	9.33	10.53
North Pole	Burn	8.89	47.19	31.26	0.93	0.67	11.07	12.67
Red Baron	Control	14.53	48.87	27.93	1.87	2.93	3.87	8.67
Repeater View	Control	8.82	46.26	41.18	0.40	1.87	1.47	3.73
South Elan	Control	6.33	49.56	37.98	0.93	0.00	5.20	6.13
Stone Cabin	Burn	9.65	56.07	20.68	0.00	0.27	13.33	13.60
Wildcat	Repeat	11.59	59.56	21.12	3.33	2.67	1.73	7.73

Table 9: Percent Composition by (Dry) Weight of Vegetation by Functional Group in Hot Springs Burn

		Pre-Burn				Post-Burn			
PLOT	Treatment	Perennial Grass	Annual Grass	Perennial Herb	Annual Herb	Perennial Grass	Annual Grass	Perennial Herb	Annual Herb
Big Horn	burn	80.93	19.00	0.00	0.07	83.05	4.48	7.37	5.09
Breakdown	repeat	87.84	7.57	1.40	3.19	61.65	17.30	0.25	20.80
Fenceline	repeat	69.59	13.55	10.43	6.43	84.23	12.37	0.91	2.48
Grants	burn	88.16	4.92	2.41	4.50	80.35	14.55	2.83	2.28
Green Acres	repeat	95.31	0.76	1.47	2.46	63.64	15.42	5.74	15.20
Jesus Tank	burn	78.37	8.79	4.87	7.97	87.35	2.35	5.10	5.20
Lil' Rattler	burn	96.36	3.64	0.00	0.00	91.58	5.19	2.47	0.77
Marty's Mom	burn	87.40	1.07	2.84	8.69	82.20	12.68	2.07	3.06
Muledeer	burn	67.57	12.76	0.36	19.32	77.72	10.11	2.96	9.22
North Pole	burn	63.22	23.88	5.33	7.57	53.90	28.76	2.85	14.49
Stone Cabin	burn	90.96	5.08	3.41	0.56	91.35	6.10	1.01	1.53
Wildcat	repeat	69.97	10.77	7.81	11.44	33.99	58.60	5.20	2.21
Before Browning	control	86.30	6.27	4.43	3.01	88.26	6.52	0.79	4.43
Hooker's View	control	97.36	0.00	2.59	0.06	83.12	0.00	10.09	6.79
Ignition Rest	control	44.37	13.77	4.97	36.89	58.63	19.59	2.29	19.49
Red Baron	control	56.55	26.38	1.01	16.06	42.57	35.54	1.89	20.00
Repeater View	control	73.61	7.40	4.73	14.25	18.31	25.67	10.37	45.65
South Elan	control	84.76	3.11	3.41	8.73	67.17	1.12	10.22	21.49

Table 10: Proportion and Length of Macroaquatic Habitat by Type in 3 Muleshoe Streams, 1998-2000.

Stream	Year	RIFFLE	RUN	GLIDE	POOL	OTHER	Total Length (m)
Hot Springs	**2000**	0.29	0.45	0.20	0.03	0.03	1.0
	length (m)	202.2	320.4	143.3	19.5	20.5	705.9
	1999	0.16	0.39	0.39	0.06		1.0
	length(m)	127.5	307.0	309.5	46.0		790.0
	1998	0.07	0.54	0.26	0.13		1.0
	length (m)	46.2	397.2	191.7	90.9		726.0
Bass Canyon	**2000**	0.06	0.47	0.29	0.15	0.04	1.0
	length (m)	39.5	315.0	193.8	101.2	26.8	676.3
	1999	0.03	0.52	0.40	0.05		1.0
	length (m)	19.0	360.0	282.0	38.0		699.0
	1998		0.46	0.30	0.13	0.11	1.0
	length (m)		258.0	158.0	89.5	89	594.5
Double R	**2000**		0.56	0.27	0.17		1.0
	length (m)		55.6	27.4	17.0		100.0
	1999		0.23	0.75	0.02		1.0
	length (m)		26.7	87.5	2.3		116.5
	1998	0.02	0.44	0.48	0.07		1.0
	length (m)	1.5	47.3	50.2	8.0		107.0

Table 11: Pool Habitat Characteristics in 3 Muleshoe Streams, 1998-2000

		On Transects						Between Transects
	YEAR	Proportion of Pool Habitat	Number Pools/Mile	Number pools/mile w/ max. depth > 0.6m	Mean Depth of Pool Habitat (m)	Mean Max. Depth of Pool Habitat (m)	Proportion of Pools with Gila Chub captured	Number of pools with Gila Chub
HOT SPRINGS								
	2000	0.03	9.5	2.38	0.31	0.53	0	34
	1999	0.06	16.1	9.20	0.29	0.55	0.43	59
	1998	0.13	20.7	9.20	0.31	0.61	0.44	34
BASS CANYON								
	2000	0.15	30.8	3.17	0.28	0.61	0.92	50
	1999	0.05	19.8	0.99	0.29	0.55	0.88	41
	1998	0.13	26.8	4.31	0.31	0.61	0.90	36
DOUBLE R								
	2000	0.17	16.7	0.0	0.16	0.59	0	0
	1999	0.02	16.7	0.0	0.19	0.33	0	0
	1998	0.07	10.0	0.0	0.20	0.38	0	0

Table 12: Native Fish Captures, Relative Percent and Densities for 4 Muleshoe Streams, 1998-2000

	AGCH ADULT	AGCH JUV	CAIN ADULT	CAIN JUV	GIIN ADULT	GIIN JUV	PACL ADULT	PACL JUV	RHOS ADULT	RHOS JUV	UNK FRY	FISH DENSITY (# fish/m)	TOTAL FISH per year	GIIN DENSITY (# fish/m)	AGCH DENSITY (# fish/m)
HOT SPRINGS															
2000	757	192	46	30	40	26	46	261	236	74	4	2.03	1712	0.08	1.13
Relative Percent by Species	55.4		4.4		3.9		17.9		18.2		0.2				
1999	1282	271	27	83	3	31	47	336	522	178	5	3.27	2785	0.04	1.83
Relative Percent	55.8		3.9		1.2		13.8		25.1		0.2				
1998	1258	611	5	48	13	13	132	326	284	556		5.44	3246	0.04	3.13
Relative Percent	57.6		1.6		0.8		14.1		25.9						
BASS CANYON															
2000	555	352	14	2	32	239	38	44	211	225	25	2.45	1737	0.38	1.28
Relative Percent	52.2		0.9		15.6		4.7		25.1		1.4				
1999	674	1648	15	4	19	100	53	86	346	188	76	3.51	3209	0.13	2.54
Relative Percent	72.4		0.6		3.7		4.3		16.6		2.4				
1998	548	392	3	12	27	63	51	174	324	506		4.58	2100	0.20	2.05
Relative Percent	44.8		0.7		4.3		10.7		39.5						
DOUBLE R												# fish/second			
2000	64	27							75	16	3	0.05	185		0.03
Relative Percent	49.2								49.2		1.6				
1999	129	102							77	76	7	0.12	391		0.07
Relative Percent	59.1								39.1		1.8				
1998	85	41							136	105	0	0.09	367		0.03
Relative Percent	34.3								65.7						
WILDCAT CANYON												# fish/second			
2000	80				1		2		28	4		0.06	115	0.0005	0.04
Relative Percent	69.6				0.9		1.7		27.8						
1999	146	32			1		9	5	46	13		0.12	252	0.0005	0.09
Relative Percent	70.6				0.4		5.6		23.5						
1998	86	72							70	98		0.07	326		0.03
Relative Percent	48.5								55.2						

	Scientific Name	Common Name
AGCH=	*Agosia chrysogaster*	Longfin Dace
CAIN=	*Catostomus insignis*	Sonoran Sucker
GIIN=	*Gila intermedia*	Gila Chub
PACL=	*Pantosteus clarki*	Desert Sucker
RHOS=	*Rhinichthys osculus*	Speckled Dace

Table 13: Instream flow (measured in cubic feet per second) at Muleshoe Ranch Preserve CMA

WATER YEAR	OCT	NOV	DEC	JAN	FEB	MARCH	APRIL	MAY	JUNE	JULY	AUG	SEPT
Upper Hot Springs												
1997-98	na	2.25	4.12	4.06	3.29	2.99	1.78	1.01	0.58	0.45	1.31	2
1998-99	1.89	2.85	3.35	2.67	2.13	2.22	1.86		0.63	4.1		1.39
1999-00	1.6	2.01	2.3	0.89	na	na	1.2	0.8	0.56	0.68	1.99	0.98
2000-01	10.8	10.5	9.4									
Lower Bass Creek												
1997-98	na	0.75	2.67	2.67	2.46	2.42	1.24	0.33	0	0.14	0.64	0.61
1998-99	0.6	0.94	1.5	1.06	0.83	0.83	0.51	0	0	2.1		0.76
1999-00	0.69	0.9	1.02	0.68	na	na	0.42	0.34	0	0.11	1.3	0.2
2000-01	7.4	6.8	6.9									
Wildcat Creek												
1997-98	0	0.07	0.17	0.16	0.15	0.013	0.113	0.04	0	0.03	0.08	0.07
1998-99	0.13	0.15	0.1	0.12	0.11	0.06	0.07	0	0	0.05	0	0.03
1999-00	0.08	0.11	0.18	0.09	na	na	0.08	0	0	0	0.024	0.014
2000-01	0.03	0.02	0.017									

zero values were recorded when there was no flow
na = no data collected

Appendix F

Prescribed Burning and Its Effects On Water Quality and Fish Populations of a Perennial Stream

Prescribed Burning and Its Effects on Water Quality and Fish Populations of a Perennial Stream

by

Lisa Marie Mooney

A Thesis Submitted to the Faculty of the

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2000

STATEMENT BY AUTHOR

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Lisa Mooney

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ABSTRACT

The effects of a prescribed burn on water quality, aquatic habitat features, and native fish populations were monitored in a perennial stream in Arizona. I compared pre-burn and post-burn levels of dissolved oxygen, carbon dioxide, temperature, hardness, alkalinity, nitrate-nitrogen, ammonia-nitrogen, chloride and pH, at permanent stations established in a stream, control (downstream) and experimental (upstream) of a prescribed burn. Increases in some nutrients were detected, but the differences between stations were not statisically significant, or large enough to adversely affect water quality. Aquatic microhabitat features, such as runs, glides, riffles and pools, changed significantly in the treatment stations after the prescribed burn. The mean percent composition of pools within the stream declined due to an increase in sediment fill-in. Mean volume of pools in the treatment stations decreased by an average of 96% in total volume. The mean number of individuals captured for longfin dace (*Agosia chrysogaster)* increased significantly, almost doubling after the burn in treatment stations, compared to no change from pre-burn levels in control stations. This increase in longfin dace abundance may be due to observed increases in preferred aquatic habitat: shallow, sandy-bottomed runs and glides, for this species. The abundance of speckled dace (*Rhinycthys osculus*), desert sucker (*Pantosteus clarki*), Sonora sucker (*Catostomus insignis*), and Gila chub (*Gila intermedia*) were not significantly different in treatment compared to control stations after the prescribed burn.

INTRODUCTION

Water is a valuable resource derived from forests and rangelands; it is the principal carrier of nutrients through the soil-plant-water-atmospheric continuum. Of all natural resources, water is probably the most sensitive to a disturbance of vegetation and soils on the land surface. Water responses to disturbances include changes in (1) timing of flow, (2) physical parameters, such as temperature, sediment content, dissolved oxygen, and (3) biological constituents.

Water yield and stormflow in the short term may be increased by burning semi-desert grasslands and rangelands (Simanton 1981). The amount of increase depends upon the intensity and severity of burning and the proportion of the watershed burned. Where vegetation is destroyed, interception and evapotranspiration are reduced. Where the organic layers of rangelands are consumed and mineral soil exposed, infiltration and water storage capacities are reduced (Baker 1990). The duration of post-burn effects range from days or months to many decades, depending on the intensity of the burn, type of habitat burned, the amount of area burned, and climatic factors all of which affect habitat recovery.

The long-term benefits of prescribed burns include: (1) improved watershed condition by increasing the abundance and cover of perennial grasses and reducing shrubs, (2) decreased frequency and intensity of scouring floods, (3) reduced soil loss from the uplands, (4) increased amount and extent of baseflow, (5) increased quality and diversity of aquatic habitats, especially the frequency of pools which will benefit fish, and (6) increased density of riparian trees and recruitment of younger age classes (Debano and Schmidt 1990).

Prescribed burns generally are administered during periods of less intense burning conditions so damage to grasslands and rangelands is less severe than during intense wildfires. Conditions needed for prescribed burning to achieve desired management objectives (without also causing adverse effects to watersheds) can be difficult to obtain for the various vegetation and weather conditions found in the Southwest. Large areas cleared by prescribed burns can yield substantial amounts of eroded material if subjected to large, high-intensity summer storms. Large yields of eroded material may lead to substantial transport of sediments, altering aquatic habitats and causing direct mortality to fish and other aquatic organisms (Simanton 1981). These immediate effects are short-term consequences of prescribed burns.

Unfortunately, little is known about recovery of aquatic ecosystems following a prescribed burn. I examined the short term, immediate effects of a prescribed burn on water quality, aquatic habitat, and fish populations of a perennial stream in southern Arizona.

Water Quality and Nutrients

Plant communities accumulate and cycle substantial quantities of nutrients. During a fire, nutrients incorporated in vegetation, litter, and soil can be volatilized during combustion, removed from the system, mineralized during oxidation, or lost by ash convection (Grier 1975). After a fire, nutrients in ash can be redistributed by wind or leached by water. Changes in the water chemistry of streams following a burn can vary among watersheds because of differences in amounts of plant biomass and litter, fire severity, ion exchange/retention capacity of humus and soil, and moisture flux. Where debris torrents occur, large amounts of nutrients may be transported out of a watershed to be deposited elsewhere (Helvey 1972). However, most studies have shown relatively small increases, if any, in nutrient concentrations and export following fire (Tiedemann 1979, Richter 1982). Because many streams have relatively low nutrient levels, additional nutrient inputs may provide a basis for increased aquatic productivity (Table 1).

Nitrogen

Several forms of nitrogen occur naturally in streams, but nitrate-nitrogen has typically been studied because it is one of the most mobile ions in soil-water systems and is one of two forms of nitrogen commonly used by plants (Tiedemann 1979). Nitrate usually moves with moisture through the soil profile to streams. Nitrate concentrations are normally low in streams that drain undisturbed forested watersheds (Table 12).

Maximum reported nitrate-nitrogen concentrations range from less than 0.1 mg/l to a high of 4.9 mg/l for forested watersheds in the western United States. Most reported maximum concentrations are less than 1 mg/l (Sandberg 1990). A substantial increase (from 0.8 to 7.6 mg/l) in maximum nitrate-nitrogen concentrations were reported following a burn in northern Idaho (Snyder 1975), but most studies have shown no change or relatively small increases in the export of nitrogen from a burned area.

Metallic Nutrients

Metallic nutrient elements such as Ca, Mg, and K are converted to oxides and deposited as ash on the soil surface during a burn. These oxides are relatively insoluble until they react with CO_2 and H_2O and are converted to bicarbonate salts. These salts are substantially more soluble and vulnerable to loss by surface runoff (Gregory 1987). Although total cation export may increase following burning, these increases do not necessarily translate directly into higher concentrations in streams. Studies typically have not found major changes in cation concentrations in streams following burning (Gregory 1987).

pH

At a given temperature, pH (or hydrogen ion activity) indicates the intensity of the acidic or basic character of a solution and is controlled by dissolved chemical compounds.

The pH of most natural waters falls in the range of 6 to 8. This is also the acceptable living range for most freshwater fish (Larson 1982). Deviation from neutral (pH 7) is primarily the result of hydrolysis of salts, strong bases, and weak acids. However, dissolved gases such as CO_2, H_2S, and NH_3 also have a significant effect (APHA 1989). Differences in pH can reveal changes in biological activity in natural water chemistry, as well as pollution.

Dissolved Gases

Dissolved gases are those in solution in water. The most common gases are oxygen, carbon dioxide, nitrogen, and ammonia.

Oxygen

Dissolved oxygen (DO) is by far one of the most important chemical parameters in aquatic ecosystems. Low dissolved oxygen levels are responsible for more fish kills, either directly or indirectly, than all other water problems combined (Swann 1990). Like humans, fish require oxygen for respiration. The amount of oxygen consumed by a fish is a function of its size, feeding rate, activity level, and temperature. The amount of oxygen that can be dissolved in water decreases as temperature increases. This explains why oxygen depletion is more commonly seen in summer with higher water temperatures. Dissolved oxygen levels lower than 3 ppm are stressful to most aquatic organisms. Most fish cannot live in water with levels below 2 ppm (Larson 1982). Fish growth and activity require 5 to 6 ppm of dissolved oxygen (Larson 1982).

During the day, aquatic plants contribute to increases in DO in the water. In the dark there usually is a drop in DO levels. Flowing water tends to have higher dissolved oxygen levels than standing water because of turbulence and mixing at the air-water surface.

Organic matter may cause dissolved oxygen levels to decline primarily because organic matter is decomposed by bacteria which take oxygen out of the water. Following a burn, there may be a substantial increase in organic debris, resulting in an increase in decomposition within the stream. This increase in decomposition could result in a decrease in DO levels, because of bacterial consumption of oxygen.

CO_2

Carbon dioxide is an odorless, colorless gas produced during the respiration cycle of animals, plants, and bacteria. Green plants, in turn, absorb carbon dioxide by the process of photosynthesis, produce oxygen and reduced carbon compounds. The general formula for photosynthesis and respiration are summarized below.

Photosynthesis (in the presence of light and chlorophyll):

Carbon dioxide + Water → Oxygen + Sugars

$$CO_2 \quad H_2O \quad O_2 \quad C_6H_{12}O_6$$

Respiration:

Reduced Compounds + O_2 → CO_2 + H_2O

Animals and plants respire at night. Consequently, more oxygen is used and more carbon dioxide enters waterways at night than during the daytime. When carbon dioxide levels are high and oxygen levels are low, fish may have trouble respiring, this problem increases as water temperature rises. Most fish can tolerate CO_2 up to 10 ppm without experiencing any negative effects (Table 2). Carbon dioxide quickly combines in water to form carbonic acid, a weak acid. Carbonic acid may cause water to become more acidic.

A burn may affect carbon dioxide levels. After a burn, run-off from the burn site may significantly increase turbidity in streams. This would reduce light penetration to plants, and reduce photosynthesis.

Table 2. Effects of CO_2 on fish (Larson 1982)

Amount of CO_2 (ppm)	Effects on Fish
1.0-10.0	Fish can tolerate these amounts.
≥12.0	Few freshwater fish can survive for long periods of time.
≥30.0	Kills fish immediately

Ammonia

Fish excrete ammonia and lesser amounts of urea into water. Two forms of ammonia occur in water, ionized and un-ionized. Un-ionized ammonia (NH_3) is extremely toxic while the ionized form (NH_4^+) is not. Both forms are grouped together as "total ammonia." Through biological processes, ammonia can be degraded to harmless nitrates.

The toxicity of ammonia to fish depends on water temperature and pH, along with dissolved oxygen and carbon dioxide levels (Table 3). The higher the pH and the warmer the water temperature, the higher the un-ionized proportion of "total ammonia" . Ammonia levels below 0.02 ppm are considered safe for fish (Larson 1982). In natural water bodies, densities of fish are too low to cause ammonia to reach toxic levels (Table 12).

Table 3. Percentage of total ammonia that is un-ionized at various temperatures and pH (Larson 1982).

pH	12° C	17° C	20 °C	24° C	28° C	32° C
7	0.2	0.3	0.4	0.5	0.7	1
7.4	0.5	0.7	1	1.3	1.7	2.4
7.8	1.4	1.8	2.5	3.2	4.2	5.7
8.2	3.3	4.5	5.9	7.7	11	13.2
8.6	7.9	10.6	13.7	17.3	21.8	27.7
9	17.8	22.9	28.5	34.4	41.2	49
9.2	35.2	42.7	50	56.9	63.8	70.8
9.6	57.7	65.2	71.5	76.8	81.6	85.9
10	68.4	74.8	79.9	84	87.5	90.6

STUDY AREA

I chose to study Bass Creek located in the Muleshoe Ranch Cooperative Management Area (CMA). Muleshoe Ranch consists of over 20,243 ha of high desert grasslands which are watersheds for seven perennial streams. Bass Creek is an ideal choice for monitoring the effects of a prescribed burn because of the physical layout of the stream in relation to the burn area. Also, Bass Creek contains five native species of fish: longfin dace (*Agosia chrysogaster*), speckled dace (*Rhinycthys osculus*), desert sucker (*Pantosteus clarki*), Sonora sucker (*Catostomus insignis*), and Gila chub (*Gila intermedia*). Two canyons were included in the study area: Double R Canyon and Bass Canyon (Figure 1).

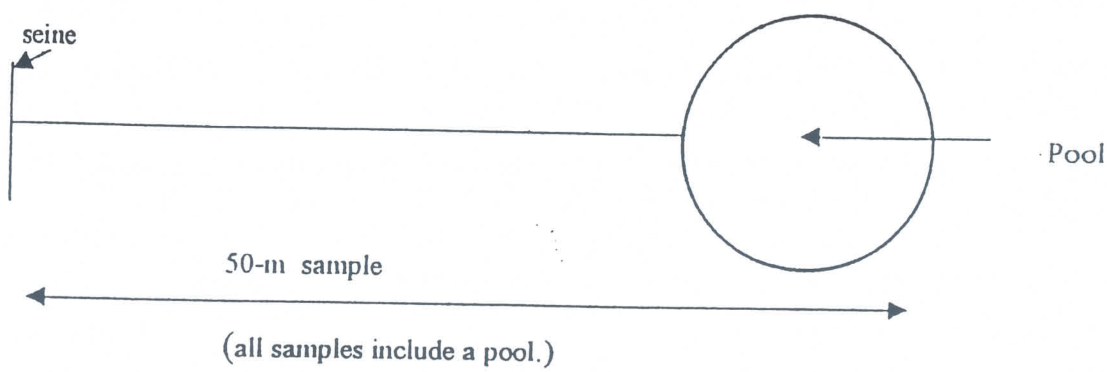
In 1994, the Bureau of Land Management and The Nature Conservancy began work on a Cooperative Resource Management Plan for the Muleshoe CMA, and enlisted the help of neighboring ranchers, the Arizona Game and Fish Department, and wildlife biologists and range specialists from the University of Arizona, and Arizona State University. The plan sets a series of goals for the recovery and restoration of watershed and riparian vegetation and native fish populations. The most effective way to manage native fish populations is to improve the conditions of watershed vegetation, thereby restoring natural hydrological processes to the watershed. Prescribed burns are needed throughout the CMA to reduce shrub density and cover. This change will provide additional soil moisture for growth and spread of perennial grasses.

On June 23, 1998, a prescribed burn was conducted in the Double R Creek watershed. The burn extended for two days. The area burned was about 1,862 ha. Most, but not all of the burned area was contained within the Double R watershed (Figure 1). The Double R watershed is approximately 2,591 ha, and 954 ha or approximately 36% of the watershed was burned. The Double R watershed is a significant part of the Bass watershed downstream of the confluence, making up approximately 11.3% of the total watershed area. A small portion of the burn extended into Bass Canyon watershed upstream of confluence (Figure 1). The Bass Canyon watershed upstream of the Double R confluence is approximately 20,243 ha and the amount burned was approximately 770 ha or 3.8% of the watershed upstream of the Double R confluence. The acreage of the Bass Canyon portion of the burn was an insignificant part of the entire Bass Canyon watershed upstream of the Double R-Bass Canyon confluence. However, the burn area was a significant portion of the Double R watershed, which contributes significantly to the Bass Canyon's watershed downstream of the Double R-Bass Canyon confluence. Based on these circumstances I identified two reaches of Bass Creek, in terms of burn influence: more strongly influenced (lower Bass, downstream of the confluence) and less influenced (upper Bass, upstream of the confluence). I began monitoring water quality, aquatic microhabitats, and fish populations the first week of May 1998 (before the burn), and concluded the last week of October 1999 (after the burn).

METHODS

I selected four stations along Bass Creek (Figure 2). Stations were selected first by locating well established pools within the stream, and second, by similarities in other stream features. Stations #1 and #2, were control stations less influenced by the burn (located in upper Bass Creek, upstream of the Double R-Bass confluence). Stations #3 and #4 were treatment stations strongly influenced by the burn (located in lower Bass Creek, downstream of the Double R-Bass confluence). Pools were chosen, and 50-m reaches established, starting from the upstream edge of a pool and continuing 50 m downstream. Glides, riffles, runs, and pools (microhabitats) were identified and fish were counted within each of these settings. An electro-shocker was used to briefly stun fish. Electro-shocking permitted only two counts per year. A seine was placed across the stream at the 50-m mark to prevent fish from moving downstream (Figure 3).

Figure 3. An illustration of station set-up and seine placement for fish captures.



Teams of three people lined up perpendicular to the stream flow with the electro-shocking device in the middle and one person on each side with nets. Disabled fish were removed from the stream and placed in a large bucket of water. Approximately 10-m sections of stream were sampled at a time, the length of capture area depended on the length of each microhabitat, since microhabitats were sampled separately along the station. For example, if a glide ran for 12 m, then the entire 12-m area was shocked. After the first run of the electro-shock, the initial catch of fish were counted. Additional sample runs were conducted until a sample yielded less then 10% of the initial number of fish captured. I then, operationally defined fish depletion to have occurred for that sample. The seine was then moved to the downstream end of the next microhabitat, to insure fish didn't travel to the sampling area already shocked. Fish were counted and recorded by species. Fish were then returned to the microhabitat from which they were captured. The team then moved to the next microhabitat upstream and followed the same procedure.

Depth and width for each microhabitat within that stream transect were taken at all four stations. These measurements were taken at random for each successive microhabitat in the station. The depth measurements were made along channel cross-sections with 4-5 measurements taken per cross-section, starting and ending approximately 10 cm from the waters edge. Maximum depths also were recorded. In addition to the established stations, three random pools were also monitored in lower Bass Creek, for mean depth, maximum depth, length, and width.

Water quality testing was performed with a LaMotte Limnology water test kit. Testing included: dissolved oxygen, carbon dioxide, ammonia nitrogen, turbidity, alkalinity, hardness, pH, temperature, and nitrite nitrogen. Water quality was tested weekly beginning the first week of May 1998, prior to the burn, and concluded the last week of October 1998, post burn. Water quality measurements were taken from the pools within each station. Water quality data were not monitored in 1999.

Results

Water Quality

I performed a repeated measures analysis of variance (ANOVA) on water quality data, with factors being time, and treatment (control vs treatment). The stream water showed no significant differences after the prescribed burn (Table 4). There was however, significant changes in water quality over time (Table 4B, 4C, 4D, 4E, and 4F). These differences over time were independent of the prescribed burn (Figure 4, 5, 6, 7, and 8) because they were observed both in the control stations and treatment stations. Ammonia nitrogen remained unchanged at 0.2 ppm, pH remained unchanged at 7.5, and nitrite-nitrogen remained undetectable at all four stations.

Habitat Conditions

To analyze microhabitat data I used a repeated measures analysis ANOVA for each microhabitat (runs, glides, riffles and pools), with factors being time, and treatment (control and treatment) [Table 5, 6, and 7].

Mean depth for runs, glides, and pools did not differ in the control stations versus treatment stations post-burn, but the mean depth of riffles was significantly less in treatment stations compared to control stations. (Table 6, Figure 9). This difference was observed in the spring of 1998, pre-burn (Table 8) indicating that it was not a result of the burn. Maximum depth for runs, glides, and pools also did not differ in the control versus treatment, but the maximum depth of riffles was significantly different between control and treatment stations (Table 7, Figure 10). Again, this difference in maximum depth of riffles between control and treatment stations was independent of the burn because the difference existed in the spring of 1998, pre-burn (Table 8). The percent composition of runs, glides, and riffles did not differ significantly in control versus treatment stations post-burn, but percent pool composition was significantly lower in the treatment stations post-burn (Table 5, Figure 11, 12, and 13). Pool volume in cm^3 was determined for all pools in all stations, including the three random pools pre-burn and post-burn. I compared pre-burn (spring 1998) to post-burn (Fall 1999) data to establish percent decrease or increase in pool volume (Table 9). Pools in the control stations (pools 1 & 2), increased in volume by 27%. Pools in the treatment stations (pools 3 - 7), decreased in volume by 94%, due to sediment fill-in.

Table 9. Pool volume in cm^3 for pools 1 - 7, and percent increase or decrease post-burn. Pools 1 & 2 located in control stations. Pools 3 - 7 located in treatment stations.

Pool Volume in cm^3			
Pool #	Pre-burn	Post-burn	% gain (+) or loss (-)
1	1190.7	1549.8	(+) 30
2	1362.8	1681.3	(+) 23
3	1165.4	26.68	(-) 97
4	1701	25.5	(-) 98
5	1118.3	6.6	(-) 99
6	436.5	5.3	(-) 98
7	2450	303.5	(-) 88

Fish Population

I performed a three-way analysis of variance (ANOVA) on the fish abundance data, with the three factors being 1) treatment (control vs treatment), 2) season (spring vs fall), and 3) year (1998 vs 1999). Of the five species sampled, longfin dace was the only fish that was significantly affected by the burn (Table 10E, Figure 14): lonfin dace were significantly more abundant in treatment compared to burn stations after compared to before the burn (C vs T effect); and in fall of 1999 increased in abundance in treatment stations compared to a decrease in abundance in control stations (CT x season interaction effect, Figure 15). Speckled dace were significantly more abundant in fall compared to spring across treatment sites (Table 10A, Figure 16). Gila chub were significantly more abundant in 1999 than 1998 across treatment stations (Table 10D, Figure 17). The increase in abundance of some of the fish species in fall compared to the previous spring is presumably due to breeding in spring and summer, known to occur with these fish (Figure 16, Figure 18) (Mueller 1984). The remaining two species of fish that I sampled, desert sucker and Sonora sucker, did not differ by treatment, season, or year.

Conclusion

The prescribed burn in the Double R watershed did not result in significant changes to water chemistry post-burn. Runoff and sediment yield immediately following the burn may have increased, but this increase had a negligible effect on water chemistry. Water chemistry also had a negligible effect on fish populations because fish abundance continued to increase or remain stable for all five species.

Prescribed burns may lead to increased sensitivity to forces of erosion immediately following a burn. Fire often causes an increase in sediment transportation after rainfall. The burn was administered in summer of 1998. The fall 1998 monsoon rain season was the fourth driest on record. Annual rainfall for 1998-99 was 17.66 cm (normal 32.45 cm). Sediment transportation probably was delayed due to lack of rainfall until the fall of 1999 (Figure 13). This delay in sediment runoff may also explain why water chemistry showed no difference post-burn in 1998. Annual rainfall for 1999-00 was 53.32 cm. Microhabitat loss due to sedimentation is best observed by comparing pool volume pre-burn to pool volume of the last post-burn sampling (Table 9). Maximum depth and mean depth did not show this decrease because pools may have decreased in volume but not in depth. Prescribed burns have short-term immediate effects on pools in streams due to increased sedimentation. The volume of pools in the treatment stations decreased an average of 96%.

Bass Creek contains five native fish species, the abundance of four species was not significantly different in the treatment versus control stations post-burn. The abundance of longfin dace increased significantly post-burn in the treatment stations (Table 11E, Figure 14). This increase in numbers may be due to an increase in preferred microhabitat type post-burn. Longfin dace have been called the "commonest and most adaptable" cyprinid native to the American Southwest (Minckley and Barber 1971). This species is known to persist in the dwindling waters of sandy streams and are suited to survive and flourish under these circumstances. Longfin dace prefer shallow, sandy-bottomed desert streams. The stream microhabitat structure in the treatment stations changed pre-burn (spring 1998) to post-burn (Fall 1999), with percent pool composition decreasing by 87 percent and the combined percent of shallower microhabitats runs, glides, and riffles increasing by 40 percent (Figure 19). These changes in stream microhabitats may have benefited longfin dace. Gila chub are highly secretive fish that prefer deeper water with cover, a pool specialist (Minckley 1985). The preferred microhabitat for this species (pools) was reduced significantly in the treatment stations (Table 9), and the mean abundance of Gila chub declined in Fall 1999, but not significantly (Table 10D). Gila chub were significantly more abundant in 1999 than in 1998, (year effect). This significant increase in abundance between year 1998 and 1999 was due to the high number of captures in the control stations while the number of captures in the treatment stations did not show a decrease until the last sampling in Fall 1999 (Figure 17).

Future studies on post-burn effects on native fish species should show any delayed effects on populations, especially Gila chub in the treatment stations of the stream.

Prescribed burns may be beneficial in restoring rangelands long-term, but they also have immediate short-term effects on streams within the area of the burn. There is a cost and benefit interaction with prescribed burns. Land managers need to be aware of the delicate balance that exists within the soil-plant-water-atmosphere system and how easily it can be either positively or negatively influenced by fire.

Table 1. Measured maximum limits of continuous exposure or tolerance ranges for fish to selected chemicals in natural waters (Larson 1982). An asterisk means these chemicals were monitored in my study. Units are parts per million (ppm), parts per billion (ppb), and Jackson Turbidity Units (JTU).

Chemical	**Maximum Limit of Exposure and/or Tolerance Range**
*Ammonia (NH_3)	0.0125 ppm (un-ionized form)
Cadmium[a]	0.004 ppm
Cadmium[b]	0.003 ppm
Calcium	4.0 to 160 ppm
*Carbon Dioxide	0.0 to 10 ppm
Chlorine	0.03 ppm
Copper[c]	0.006 ppm
Hydrogen sulfide	0.0 ppm
Iron (total)	0.0 to 0.15 ppm
Ferrous ion	0.0 ppm
Ferric ion	0.5 ppm
Lead	0.03 ppm
Manganese	0.0 to 0.01 ppm
Mercury	0.002 ppb
Nitrate (NO_3^-)	0.0 to 3.0 ppm
Nitrite (NO_2^-)	0.2ppm
*Nitrite-Nitrogen	0.03 to 0.06 ppm
Nitrogen	Maximum total gas pressure 110% of saturation
*Oxygen	3.0 ppm to saturation
Ozone	0.005 ppm
*pH	6.5 to 8.0
Phosphorus	0.01 to 3.0 ppm
PCB"s	0.002 ppb
*Total Hardness ($CaCO_3$)	10.0 to 400 ppm
*Total Alkalinity ($CaCO_3$)	10.0 to 400 ppm
*Turbidity	100 JTU's or greater
Zinc	0.03 to 0.05 ppm

Figure 1. Area of Muleshoe Ranch Cooperative Management Area, Arizona, burned on June 23, 1998. (A = Bass watershed; B = Double R watershed; C = burn outside planned area in Bass watershed); D = planned burn within Bass watershed. The crossed line indicates the boundary between Double R Canyon's watershed and Bass Canyon's watershed.

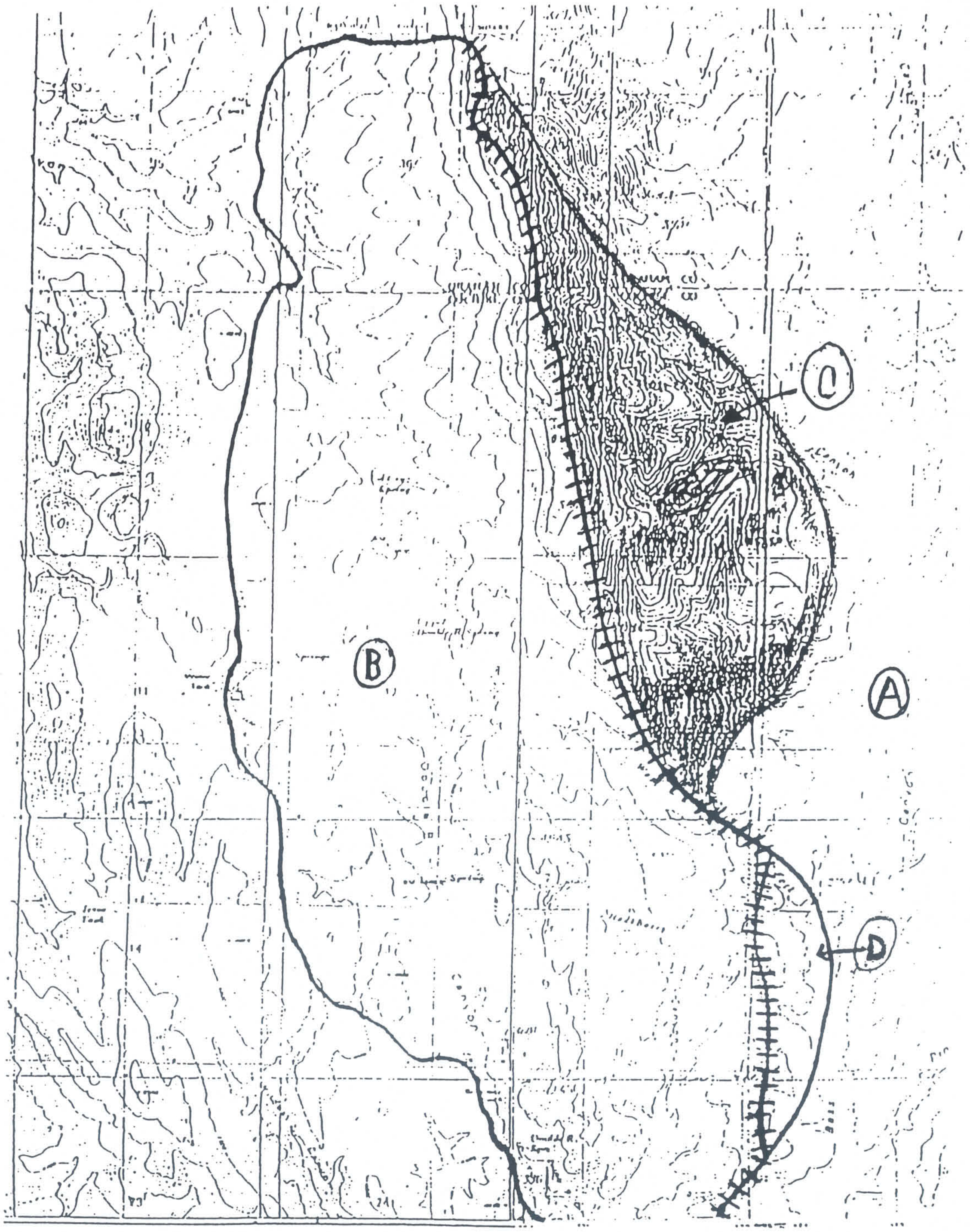


Figure 2. Monitoring stations along Bass Creek, Arizona

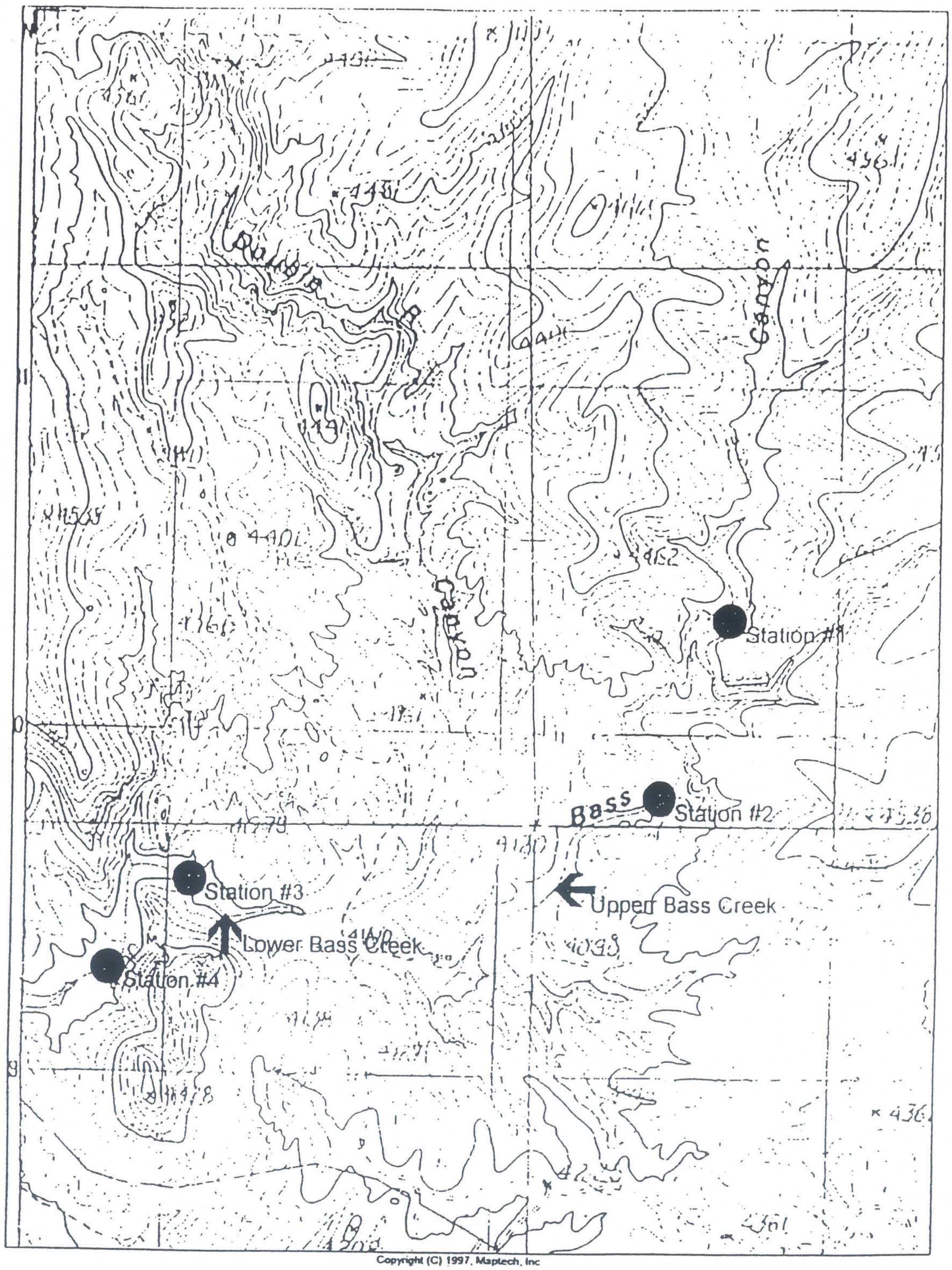


Table 4: Repeated measures of analysis of variance (ANOVA) for water quality results:

A. Chloride

Between Subjects

Source	SS	DF	MS	F	P
Treatment	338.000	1	338.000	5.200	0.150
Error	130.000	2	65.000		

Within Subjects

Source	SS	DF	MS	F	P
Time	36.000	17	2.118	1.500	0.154
Time*Treatment	20.000	17	1.176		
Error	48.000	34	1.412		

B. Alkalinity

Between Subjects

Source	SS	DF	MS	F	P
Treatment	210.125	1	210.125	3.343	0.209
Error	125.694	2	62.847		

Within Subjects

Source	SS	DF	MS	F	P
Time	1233.736	17	72.573	3.763	0.000*
Time*Treatment	135.625	17	7.978	0.414	0.972
Error	655.806	34	19.288		

C. Carbon dioxide

Between Subjects

Source	SS	DF	MS	F	P
Treatment	56.711	1	56.711	0.940	0.435
Error	120.661	2	60.331		

Table 4: Water quality results continued.

Carbon dioxide
Within subjects

Source	SS	DF	MS	F	P
Time	97.096	17	5.712	9.281	0.000*
Time*Treatment	245.901	17	14.465	23.505	0.000*
Error	20.924	34	0.615		

D. Dissolved oxygen
Between Subjects

Source	SS	DF	MS	F	P
Treatment	34.031	1	34.031	4.023	0.183
Error	16.918	2	8.459		

Within Subjects

Source	SS	DF	MS	F	P
Time	106.346	17	6.256	13.363	0.000*
Time*Treatment	6.771	17	0.398	0.851	0.629
Error	15.917	34	0.468		

E. Hardness
Between Subjects

Source	SS	DF	MS	F	P
Treatment	112.500	1	112.500	0.723	0.485
Error	311.222	2	155.611		

Within Subjects

Source	SS	DF	MS	F	P
Time	1589.611	17	93.507	3.084	0.000*
Time*Treatment	290.500	17	17.088	0.564	0.895
Error	1030.778	34	30.317		

Table 4: Water quality results continued

F. Temperature

Between Subjects

Source	SS	DF	MS	F	P
Treatment	25.681	1	25.681	0.657	0.503
Error	78.139	2	39.069		

Within Subjects

Source	SS	DF	MS	F	P
Time	34.236	17	2.014	20.372	0.000*
Time*Treatment	10.569	17	0.622	6.289	0.000*
Error	3.361	34	0.099		

Figure 4. Alkalinity levels over time in control and treatment stations (n = 2).

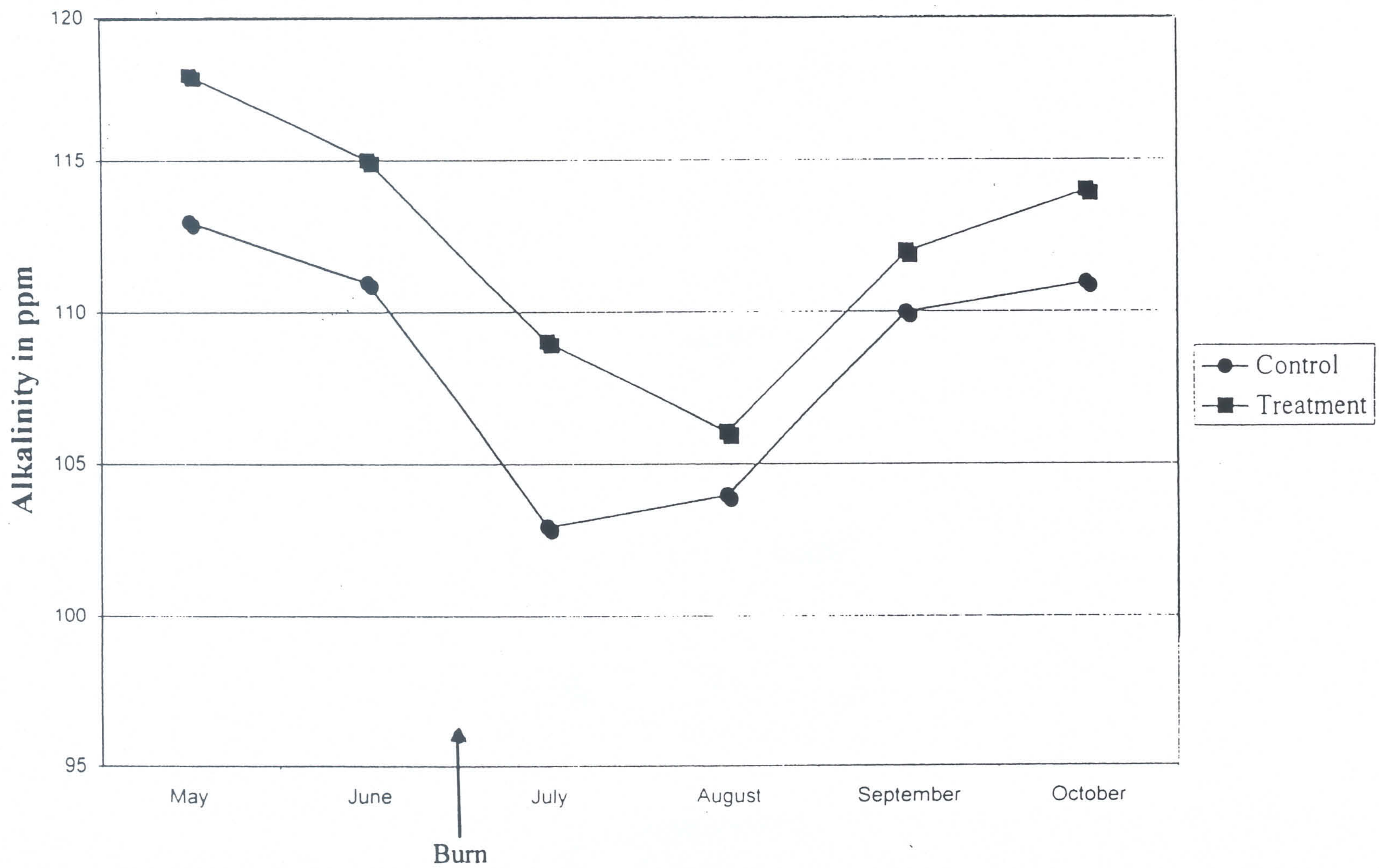


Figure 5. CO_2 levels over time in control and treatment stations (n = 2).

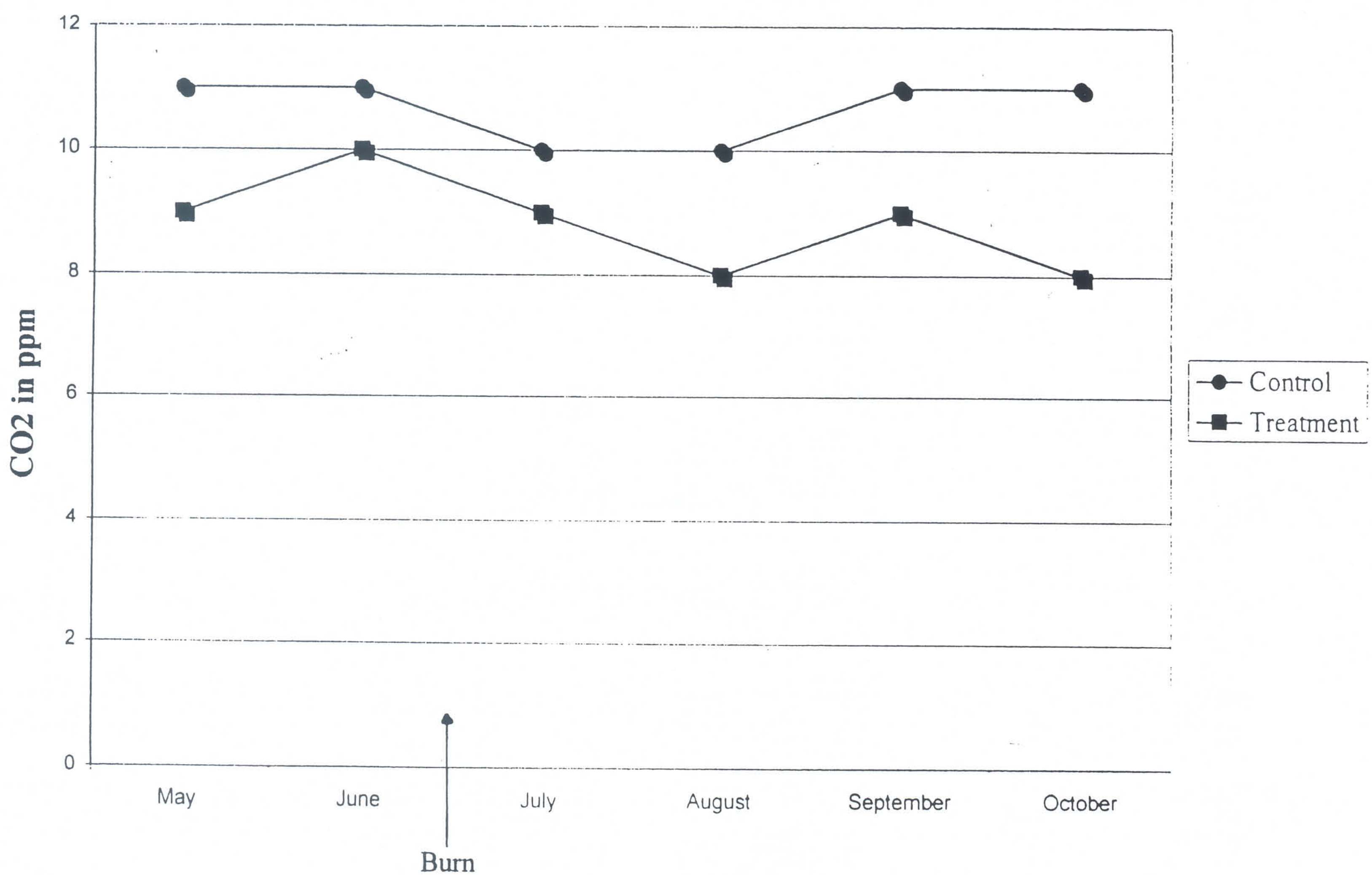


Figure 6. DO levels over time in control and treatment stations (n = 2).

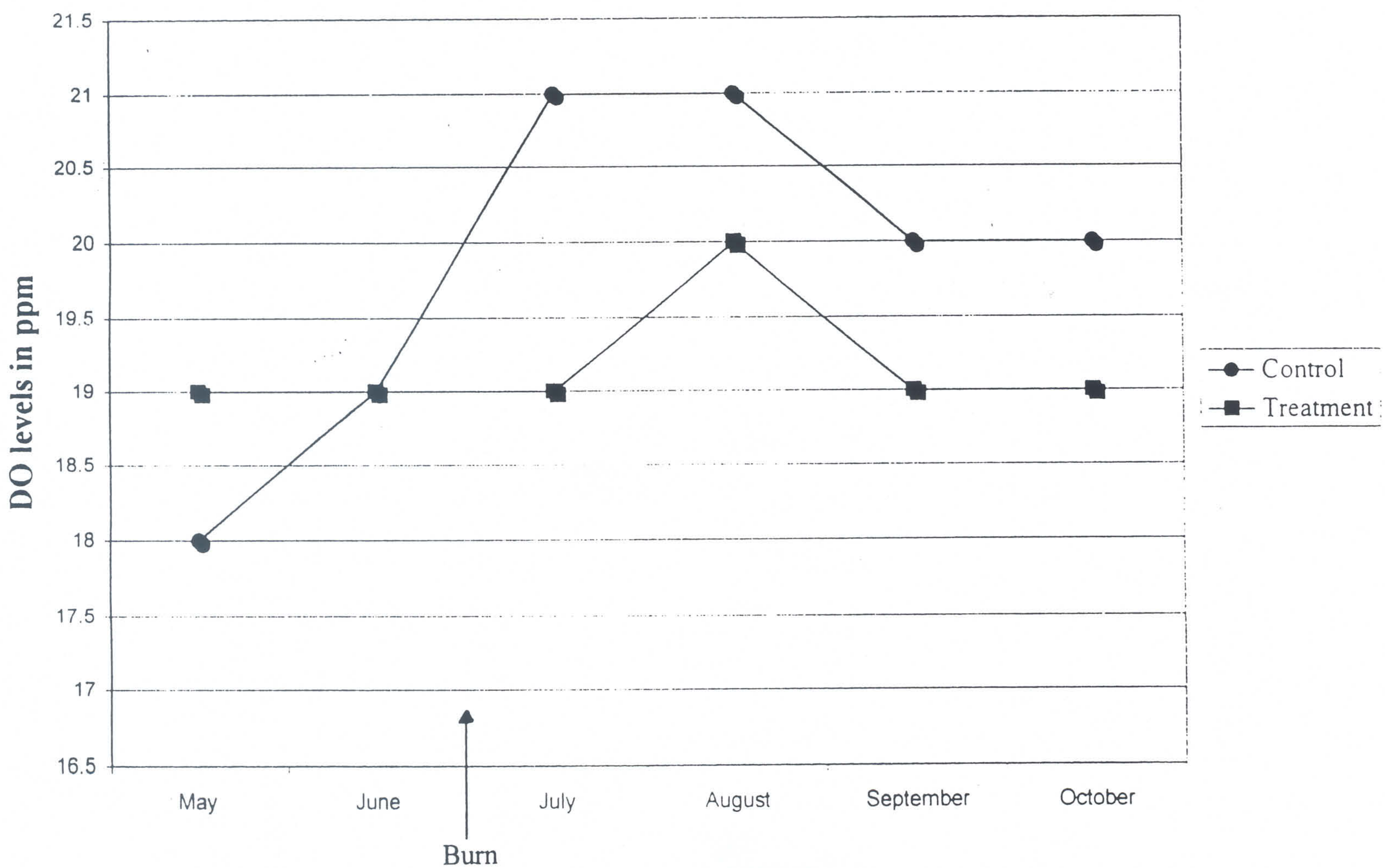


Figure 7. Water hardness levels over time in control and treatment stations (n = 2).

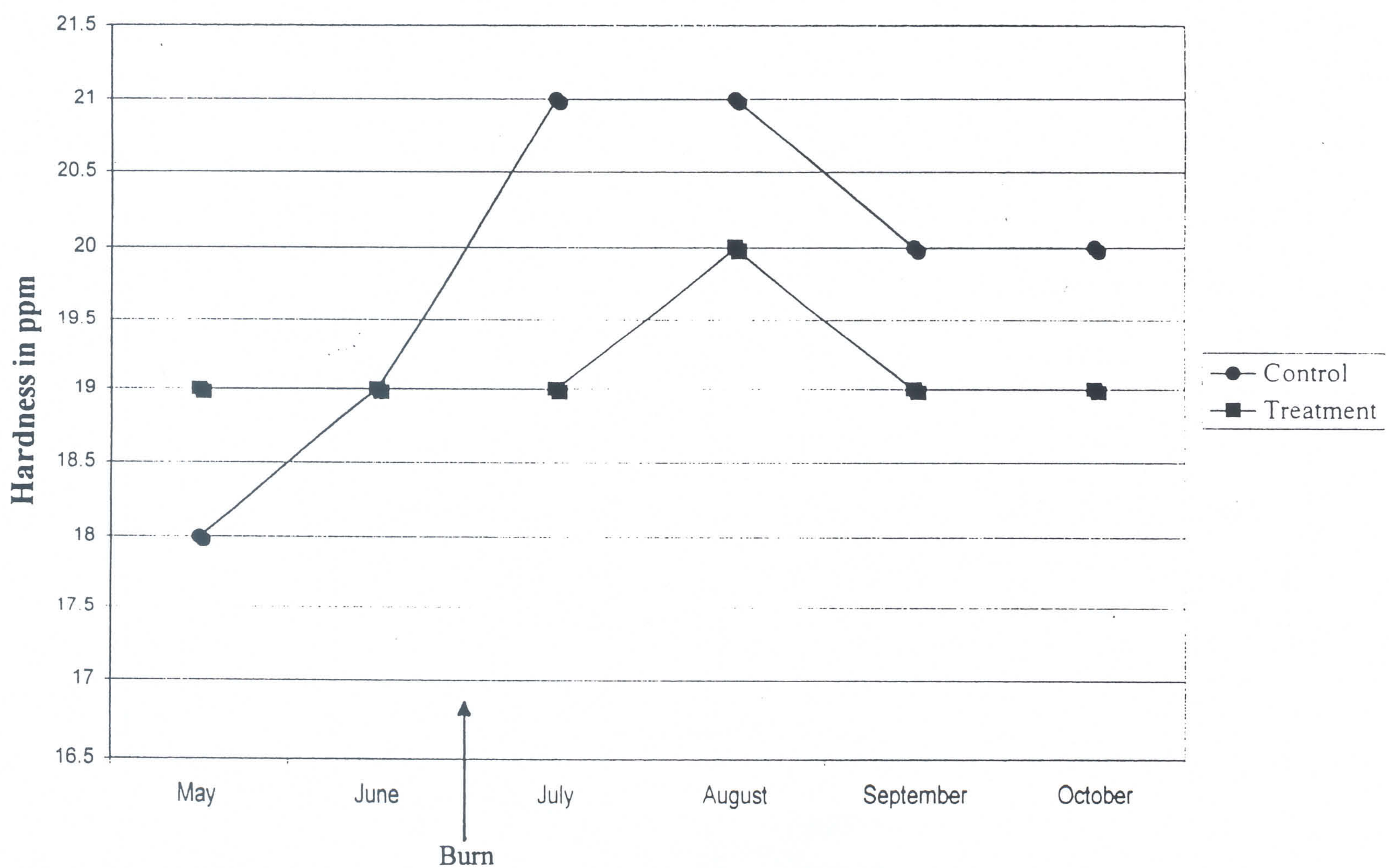


Figure 8. Water temperature in °C over time in control and treatment stations (n = 2).

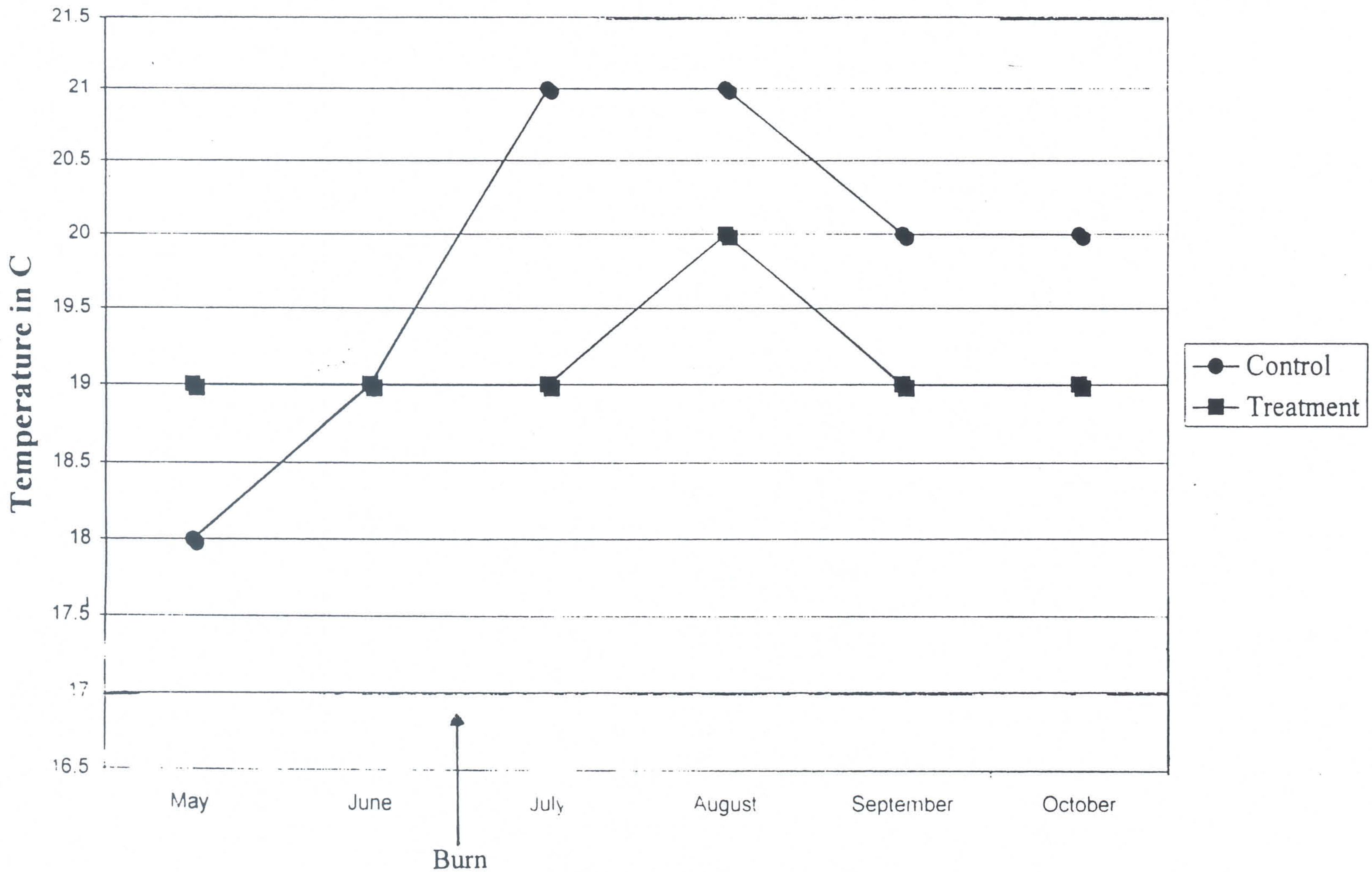


Table 5. Stream microhabitat results of a one-way ANOVA for percent composition, factors being time (1, 2, 3, 4) control (stations 1, 2), and treatment (stations 3, 4). A = Runs, B = Riffles, C = Glides, and D = Pools. An asterisk denotes significance.

A.

Percent composition runs
Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	7	2956.7500	422.393	1.2248
Error	8	2759.0000	344.875	Prob>F
C Total	15	5715.7500		0.3879

Effect Test

Source	Nparm	DF	Sum of Squares	F Ratio	Prob>F
Time	3	3	1740.2500	1.6820	0.2472
C or T	1	1	1122.2500	3.2541	0.1089
C or T*Time	3	3	94.2500	0.0911	0.9629

B.

Percent composition riffles
Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	7	962.4375	137.491	0.8537
Error	8	1288.5000	161.063	Prob>F
C Total	15	2250.9375		0.5762

Effect Test

Source	Nparm	DF	Sum of Squares	F Ratio	Prob>F
Time	3	3	572.18750	1.1842	0.3751
C or T	1	1	203.06250	1.2608	0.2941
C or T*Time	3	3	187.18750	0.3874	0.7653

Table 5. Percent composition results continued.
A = Runs, B = Riffles, C = Glides, D = Pools

C.

Percent composition glides
Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	7	787.4375	112.491	0.3485
Error	8	2582.5000	322.813	Prob>F
C Total	15	3369.9375		0.9087

Effect Test

Source	Nparm	DF	Sum of Squares	F Ratio	Prob>F
Time	3	3	398.18750	0.4112	0.7495
C or T	1	1	0.56250	0.0017	0.9677
C or T*Time	3	3	388.68750	0.4014	0.7560

D.

Percent composition pools
Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	7	1476.0000	210.857	14.5419
Error	8	116.0000	14.500	Prob>F
C Total	15	1592.0000		0.0006 *

Effect Test

Source	Nparm	DF	Sum of Squares	F Ratio	Prob>F
Time	3	3	590.00000	13.5632	0.0017 *
C or T	1	1	400.00000	27.5862	0.0008 *
C or T*Time	3	3	486.00000	11.1724	0.0031 *

Table 6. Stream microhabitat results of a one-way ANOVA for mean depth, factors being time (1, 2, 3, 4) control (stations 1, 2), and treatment (stations 1, 2). A = Runs, B = Riffles, C = Glides, and D = Pools. An asterisk denotes significance.

A.

Mean depth runs

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	7	239.65638	34.2366	4.4784
Error	8	61.15900	7.6449	Prob>F
C Total	15	300.81538		0.0258*

Effect Test

Source	Nparm	DF	Sum of Squares	F Ratio	Prob>F
Time	3	3	213.37608	9.3037	0.0055*
C or T	1	1	10.17610	1.3311	0.2819
C or T*Time	3	3	16.10420	0.7022	0.5768

B.

Mean depth riffles

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	7	138.69359	19.8134	1.1295
Error	8	140.33375	17.5417	Prob>F
C Total	15	279.02734		0.4295

Effect Test

Source	Nparm	DF	Sum of Squares	F Ratio	Prob>F
Time	3	3	16.04672	0.3049	0.8213
C or T	1	1	112.09516	6.3902	0.0354*
C or T*Time	3	3	10.55172	0.2005	0.8932

Table 6. Mean depth results continued.
A = Runs, B = Riffles, C = Glides, D = Pools

C.

Mean depth glides
Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	7	164.06664	23.4381	0.8217
Error	8	228.19055	28.5238	Prob>F
C Total	15	392.25719		0.5957

Effect Test

Source	Nparm	DF	Sum of Squares	F Ratio	Prob>F
Time	3	3	45.383869	0.5304	0.6740
C or T	1	1	46.751406	1.6390	0.2363
C or T*Time	3	3	71.931369	0.8406	0.5088

D.

Mean depth pools
Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	7	1012.4719	44.639	2.3176
Error	8	499.2625	62.408	Prob>F
C Total	15	1511.7344		0.1309

Effect Test

Source	Nparm	DF	Sum of Squares	F Ratio	Prob>F
Time	3	3	459.89562	2.4564	0.1377
C or T	1	1	16.20062	0.2596	0.6242
C or T*Time	3	3	536.37562	2.8649	0.1040

Table 7. Stream microhabitat results of a one-way ANOVA for maximum depth, factors being time (1, 2, 3, 4) control (stations 1, 2),and treatment (stations 3, 4). A = Runs, B = Riffles, C = Glides, and D = Pools. An asterisk denotes significance.

A.

Maximum depth runs
Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	7	873.5158	124.788	6.4186
Error	8	155.5334	19.442	Prob>F
C Total	15	1029.0492		0.0089 *

Effect Test

Source	Nparm	DF	Sum of Squares	F Ratio	Prob>F
Time	3	3	691.09347	11.8490	0.0026 *
C or T	1	1	78.58823	4.0423	0.0792
C or T*Time	3	3	103.83407	1.7803	0.2286

B.

Maximum depth riffles
Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	7	726.2675	103.752	1.6661
Error	8	498.1900	62.274	Prob>F
C Total	15	1224.4575		0.2447

Effect Test

Source	Nparm	DF	Sum of Squares	F Ratio	Prob>F
Time	3	3	360.07250	1.9274	0.2037
C or T	1	1	329.42250	5.2899	0.0505 *
C or T*Time	3	3	36.77250	0.1968	0.8957

Table 7. Maximum depth results continued.
A = Runs, B = Riffles, C = Glides, D = Pools

C.

Maximum depth glides
Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	7	585.2747	83.611	0.7900
Error	8	846.7356	105.842	Prob>F
C Total	15	1432.0103		0.6156

Effect Test

Source	Nparm	DF	Sum of Squares	F Ratio	Prob>F
Time	3	3	257.21690	0.8101	0.5231
C or T	1	1	137.35840	1.2978	0.2876
C or T*Time	3	3	190.69940	0.6006	0.6325

D.

Maximum depth pools
Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	7	4304.0000	614.857	1.7719
Error	8	2776.0000	347.000	Prob>F
C Total	15	7080.0000		0.2200

Effect Test

Source	Nparm	DF	Sum of Squares	F Ratio	Prob>F
Time	3	3	1552.5000	1.4914	0.2890
C or T	1	1	156.2500	0.4503	0.5211
C or T*Time	3	3	2595.2500	2.4930	0.1341

Figure 9. Mean depth for riffles in control and treatment stations (n = 2).

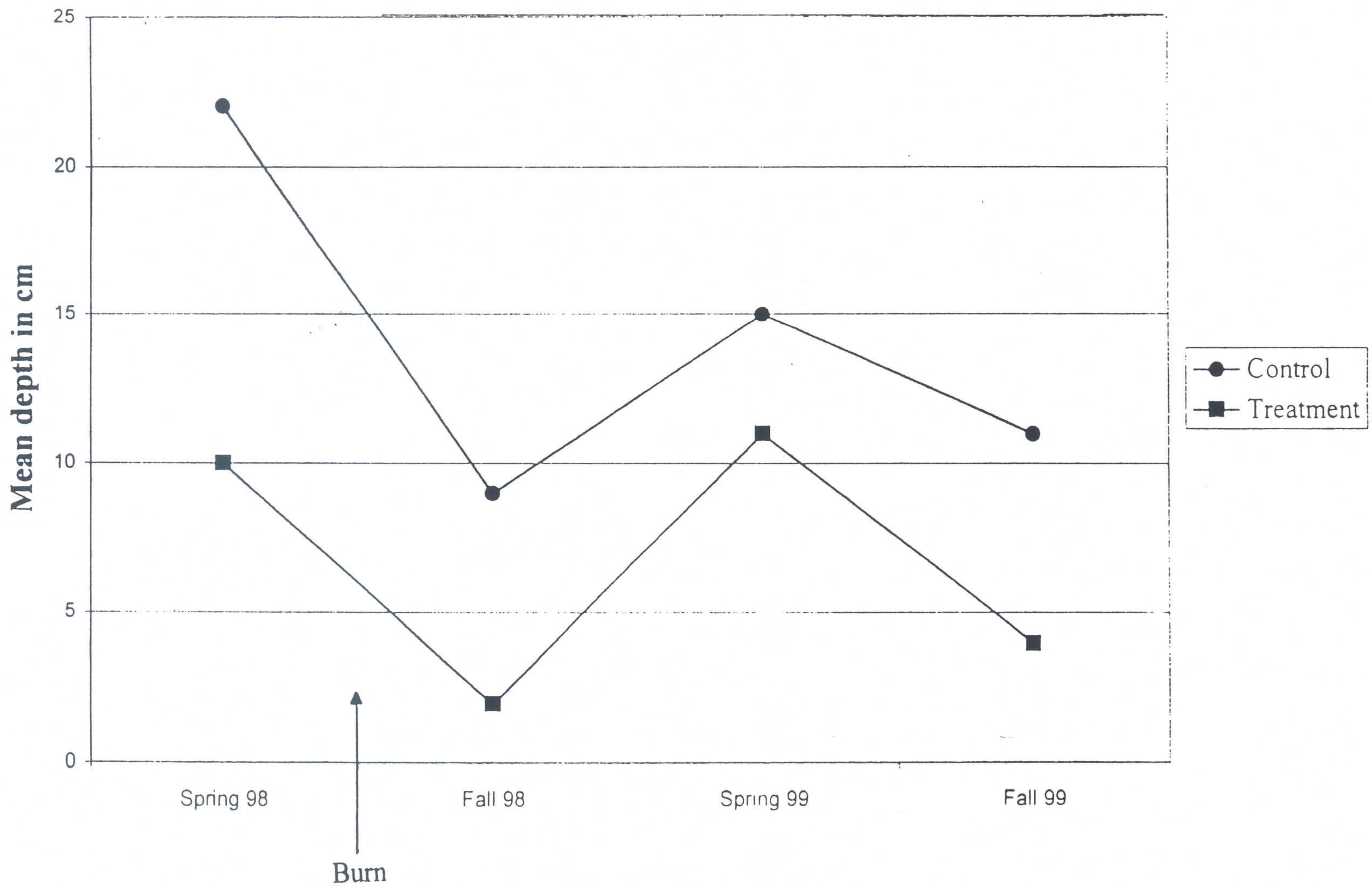


Figure 10. Maximum depth for riffles in control and treatment stations (n = 2).

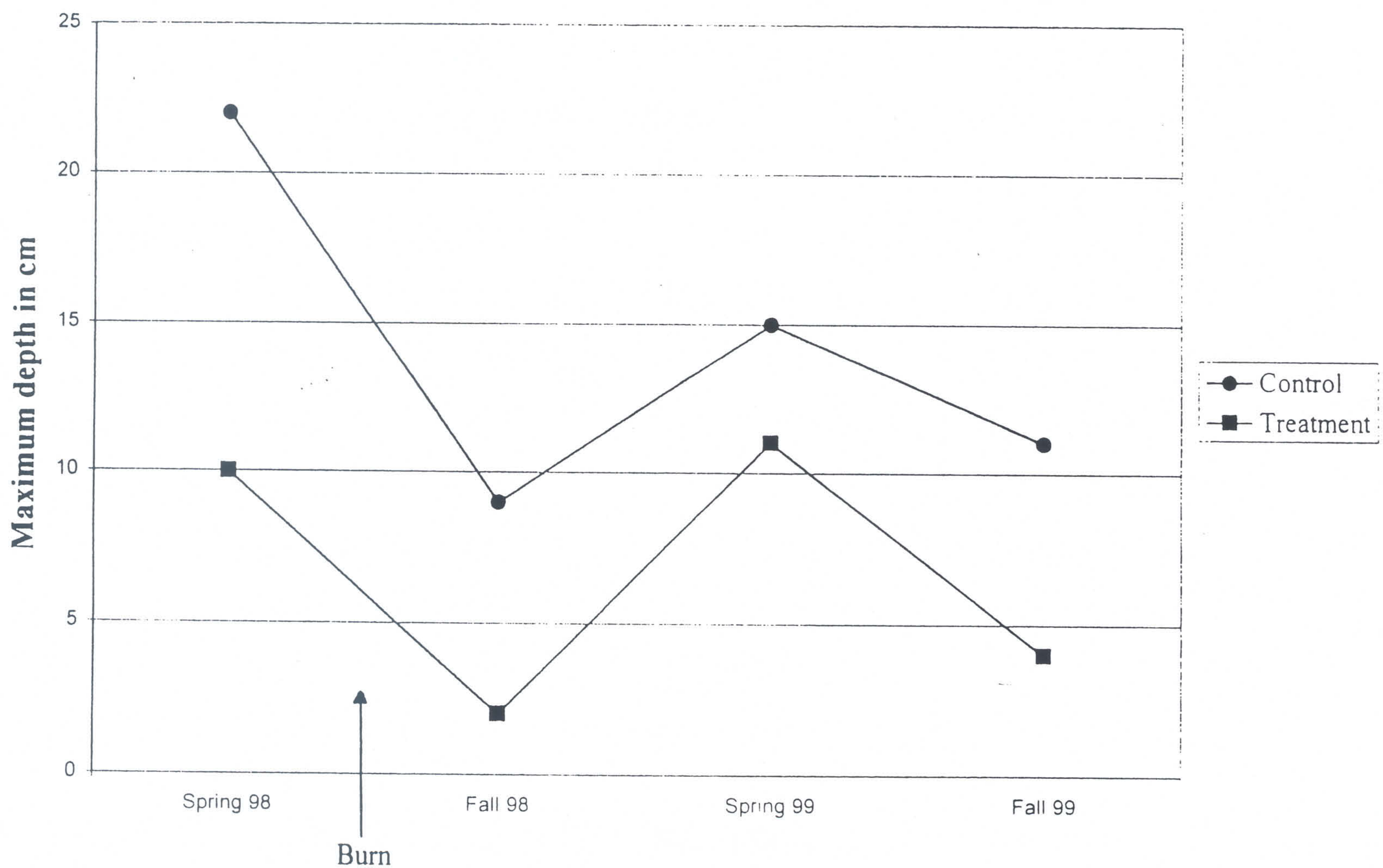


Table 8. Means and S.E. for ANOVA results: A = percent composition of microhabitats, B = mean depth for microhabitats, C = maximum depth for microhabitats; station (t = treatment, c = control); season (1 = spring, 2 = fall).

A.

Date	Season	Station	N	(Mean) Runs	S.E.	(Mean) Riffles	S.E.	(Mean) Glides	S.E.	(Mean) Pools	S.E.
5/23/98	1	c	2	38	10	17	17	12	4	33	3
5/23/98	1	t	2	57	13	8	8	4	4	31	1
10/10/98	2	c	2	41.5	5.5	9	9	14.5	0.5	35	3
10/10/98	2	t	2	60	10	9	9	0	0	31	1
6/5/99	1	c	2	14	14	24	24	27	5	35	5
6/5/99	1	t	2	35	15	18	2	17	17	30	0
10/2/99	2	c	2	42.5	5.5	11.5	11.5	13	3	33	3
10/2/99	2	t	2	51	23	28	8	17	17	4	2

B.

Date	Season	Station	N	(Mean) Runs	S.E.	(Mean) Riffles	S.E.	(Mean) Glides	S.E.	(Mean) Pools	S.E.
5/23/98	1	c	2	10.75	1.55	8.975	2.025	4.98	4.98	38.125	1.375
5/23/98	1	t	2	11.695	1.135	2	2	5.525	5.525	39.05	6.65
10/10/98	2	c	2	9.3	2	8.675	0.225	2.3	2.3	42.725	6.775
10/10/98	2	t	2	6.455	1.505	5.85	5.85	3.125	3.125	54.45	7.55
6/5/99	1	c	2	1.5	1.5	7.225	3.025	5.48	5.48	37.05	5.25
6/5/99	1	t	2	1.165	1.165	2.35	2.35	7.05	0.95	36.7	3.3
10/2/99	2	c	2	6.975	4.125	10.1	0.4	1.865	1.865	44.7	7.8
10/2/99	2	t	2	2.83	0.03	3.6	3.6	12.6	3.05	24.35	1.15

Table 8. ANOVA means continued.

C.

Date	Season	Station	N	(Mean) Runs	S.E.	(Mean) Riffles	S.E.	(Mean) Glides	S.E.	(Mean) Pools	S.E.
5/23/98	1	c	2	20.65	1.65	21.5	8.5	8.83	8.83	95	0
5/23/98	1	t	2	21.315	2.985	10	10	10	10	72.5	27.5
10/10/98	2	c	2	15.225	3.475	9	3	3.33	3.33	75.5	7.5
10/10/98	2	t	2	11.5	3.5	0	0	4.75	4.75	102.5	15.5
6/5/99	1	c	2	3.5	3.5	15.15	5.15	12.15	12.15	78	7
6/5/99	1	t	2	1.665	1.665	11	1	15.25	0.25	86.5	13.5
10/2/99	2	c	2	17.165	5.165	11.65	6.35	5	5	82	10
10/2/99	2	t	2	4.33	0.33	0	0	22.75	6.25	44	2

Figure 11. Mean percent composition of different microhabitat types (± S.E.) in treatment and control stations for Bass Creek in June 1998, before the burn.

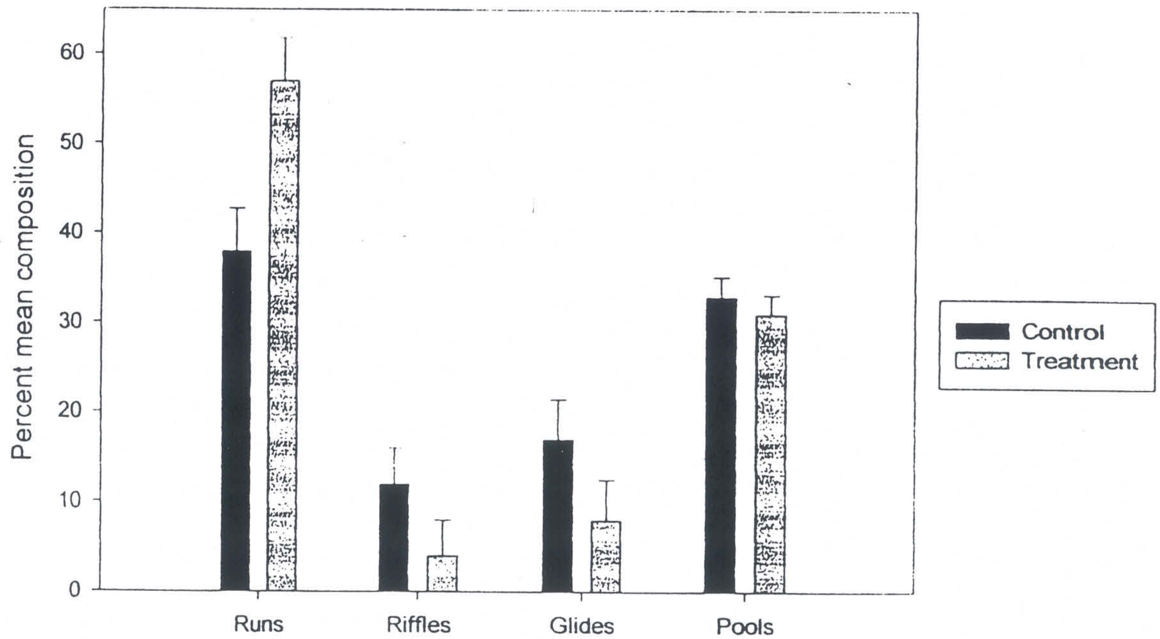


Figure 12. Mean percent composition of different microhabitat types (± S.E.) in treatment and control stations for Bass Creek in October 1999, after the burn.

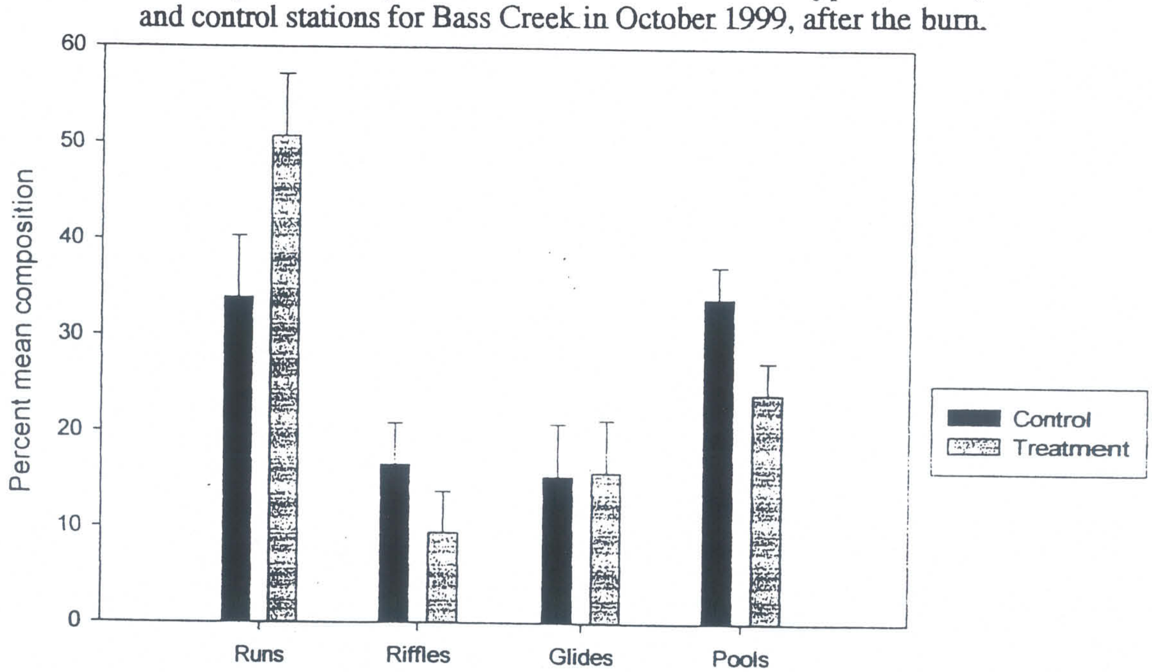


Figure 13. Percent pool composition over sampling periods for control and treatment stations.

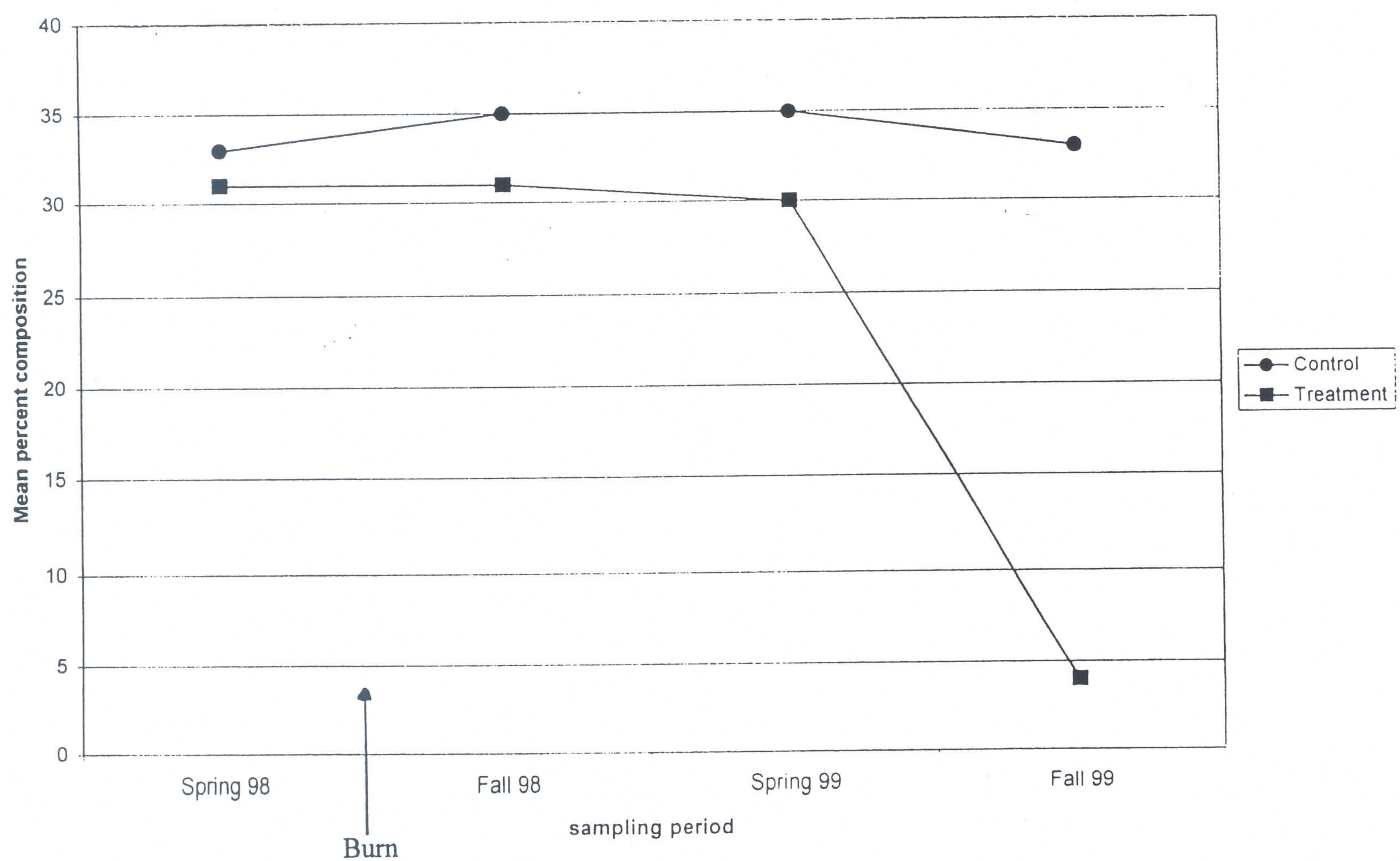


Table 10. ANOVA results of data for five fish species. Factors season (fall, spring) and C or T (control = stations 1,2; treatment = stations 3,4) and year (1998, 1999). A = speckled dace, B = desert sucker, C = Sonora sucker, D = Gila chub, and E = longfin dace. An asterisk denotes significance.

A. Speckled dace ANOVA results.

Effect Test

Source	Nparm	DF	Sum of Squares	F Ratio	Prob>F
year	1	1	930.250	0.4028	0.5434
season	1	1	39006.250	16.8886	0.0034*
C or T	1	1	3364.000	1.4565	0.2620
C or T*year	1	1	110.250	0.0477	0.8325
C or T*season	1	1	2070.250	0.8964	0.3715
season*year	1	1	47089.000	20.3882	0.0020*
C or T*year*season	1	1	7744.000	3.3529	0.1045

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	7	100314.00	14330.6	6.2047
Error	8	18477.00	2309.6	Prob>F
C Total	15	118791.00		0.0099

B. Sonoran sucker ANOVA results.

Effect Test

Source	Nparm	DF	Sum of Squares	F Ratio	Prob>F
year	1	1	14.062500	1.2295	0.2997
season	1	1	27.562500	2.4098	0.1592
C or T	1	1	14.062500	1.2295	0.2997
C or T*year	1	1	0.062500	0.0055	0.9429
C or T*season	1	1	45.562500	3.9836	0.0810
season*year	1	1	52.562500	4.5956	0.0644
C or T*year*season	1	1	27.562500	2.4098	0.1592

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	7	181.43750	25.9196	2.2662
Error	8	91.50000	11.4375	Prob>F
C Total	15	272.93750		0.1372

Table 10. ANOVA results of data for five fish species continued.

C. Desert sucker ANOVA results.

Effect Test

Source	Nparm	DF	Sum of Squares	F Ratio	Prob>F
year	1	1	3.0625	0.0012	0.9736
season	1	1	2943.0625	1.1197	0.3209
C or T	1	1	1072.5625	0.4081	0.5408
C or T*year	1	1	1008.0625	0.3835	0.5529
C or T*season	1	1	2782.5625	1.0586	0.3336
season*year	1	1	7014.0625	2.6685	0.1410
C or T*year*season	1	1	115.5625	0.0440	0.8392

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	7	14938.938	2134.13	0.8119
Error	8	21027.500	2628.44	Prob>F
C Total	15	35966.438		0.6018

D. Gila chub ANOVA results.

Effect Test

Source	Nparm	DF	Sum of Squares	F Ratio	Prob>F
year	1	1	473.06250	5.5047	0.0470*
season	1	1	5.06250	0.0589	0.8143
C or T	1	1	126.56250	1.4727	0.2595
C or T*year	1	1	10.56250	0.1229	0.7350
C or T*season	1	1	95.06250	1.1062	0.3236
season*year	1	1	95.06250	1.1062	0.3236
C or T*year*season	1	1	76.56250	0.8909	0.3729

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	7	881.9375	125.991	1.4661
Error	8	687.5000	85.938	Prob>F
C Total	15	1569.4375		0.3006

Table 10. ANOVA results of data for five fish species continued.

E. Longfin dace ANOVA results.

Effect Test

Source	Nparm	DF	Sum of Squares	F Ratio	Prob>F
year	1	1	100.000	0.1073	0.7516
season	1	1	8464.000	9.0852	0.0167 *
C or T	1	1	36672.250	39.3637	0.0002 *
C or T*year	1	1	3969.000	4.2603	0.0729
C or T*season	1	1	14641.000	15.7156	0.0042 *
season*year	1	1	6006.250	6.4471	0.0348 *
C or T*year*season	1	1	306.250	0.3287	0.5822

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	7	70158.750	10022.7	10.7583
Error	8	7453.000	931.6	Prob>F
C Total	15	77611.750		0.0016*

Table 11. Means and standard errors, number of fish caught in control (c) and treatment (t) stations.

Date	Season	Station	N	(Mean) longfin dace	S.E.	(Mean) speckled dace	S.E.	(Mean) desert sucker	S.E.	(Mean) sonoran sucker	S.E.	(Mean) gila chub	S.E.
5/23/98	Spring	c	2	102.5	24.5	16.5	6.5	55	5	1.5	1.5	8	4
5/23/98	Spring	t	2	105	21	74.5	28.5	33.5	22.5	0.5	0.5	4.5	0.5
10/10/98	Fall	c	2	288.5	68.5	32	26	103	24	8.5	3.5	14.5	2.5
10/10/98	Fall	t	2	333.5	41.5	228.5	9.5	123.5	75.5	6	2	10	5
6/5/99	Spring	c	2	146.5	0.5	83	23	119	1	4.5	2.5	21	2
6/5/99	Spring	t	2	247.5	31.5	95.5	33.5	55	27	8.5	0.5	23	17
10/2/99	Fall	c	2	203.5	17.5	38.5	13.5	72.5	16.5	9.5	4.5	26.5	1.5
10/2/99	Fall	t	2	171	22	154.5	16.5	72	52	1.5	0.5	10	1

Table 10. Means and standard errors for proportions of fish captured in control (c) and treatment (t) stations.

Date	Season	Station	N	(Mean) longfin dace	S.E.	(Mean) speckled dace	S.E.	(Mean) desert sucker	S.E.	(Mean) sonoran sucker	S.E.	(Mean) gila chub	S.E.
5/23/98	Spring	c	2	55	6	8.5	2.5	31	7	0.5	0.5	5	3
5/23/98	Spring	t	2	49.5	6.5	34	2	13.5	5.5	0.5	0.5	2.5	0.5
10/10/98	Fall	c	2	65.5	2.5	6	4	23.5	1.5	2	0	3.5	0.5
10/10/98	Fall	t	2	48	3	33	5	16	8	1	0	2	1
6/5/99	Spring	c	2	39.5	2.5	22.5	5.5	32	2	1.5	0.5	6	1
6/5/99	Spring	t	2	57.5	4.5	22	7	13	7	2	0	5.5	4.5
10/2/99	Fall	c	2	58.5	6.5	10.5	3.5	20.5	4.5	2.5	1.5	7.5	0.5
10/2/99	Fall	t	2	42	0	39	9	16.5	10.5	1	0	2.5	0.5

Figure 14. Mean number of longfin dace caught in the four sampling periods for treatment and control stations in Bass Creek, Arizona.

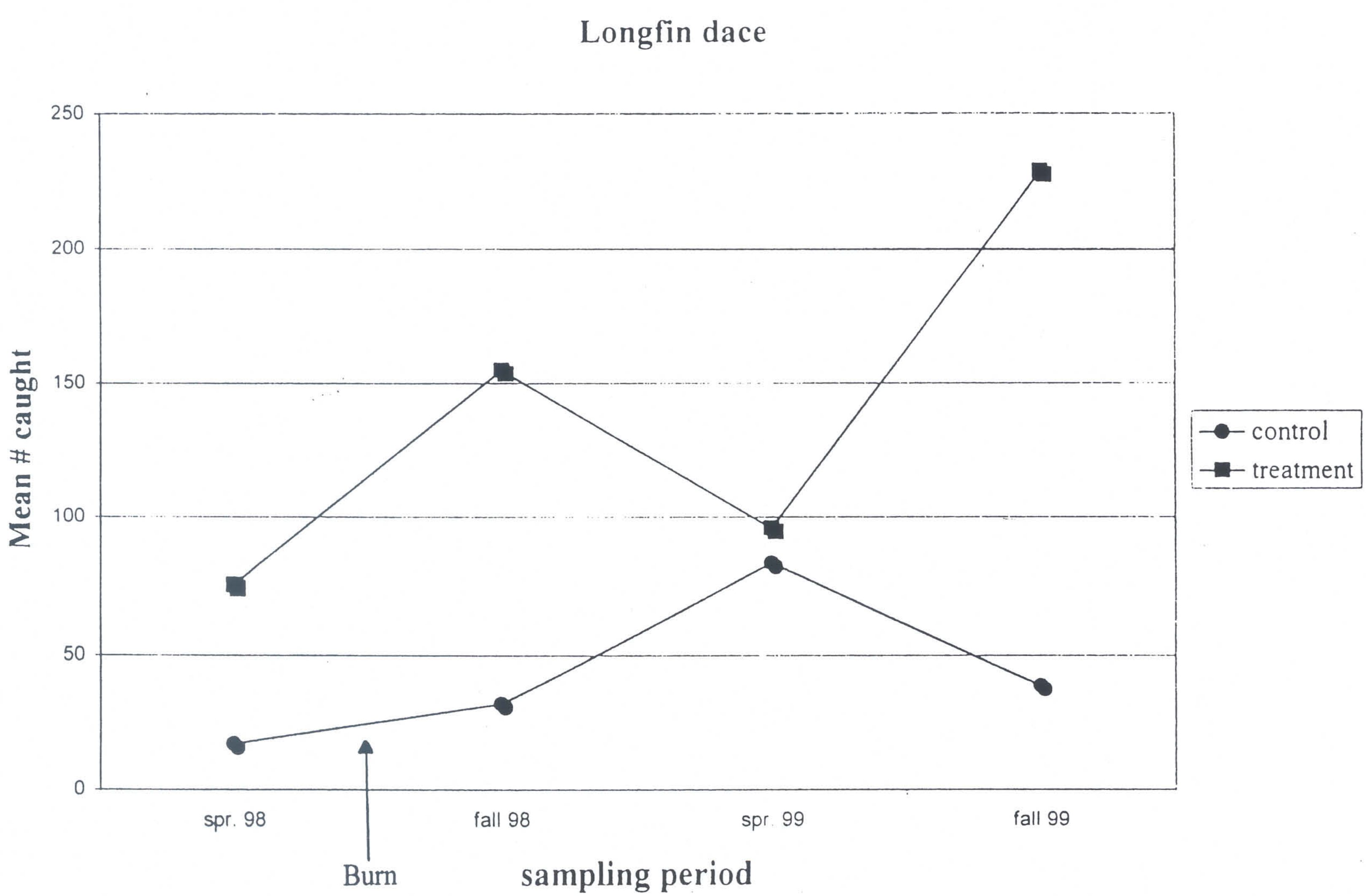


Figure 15. Mean abundance of longfin dace caught in control and treatment stations (n = 2) for spring and fall 1998 and 1999.

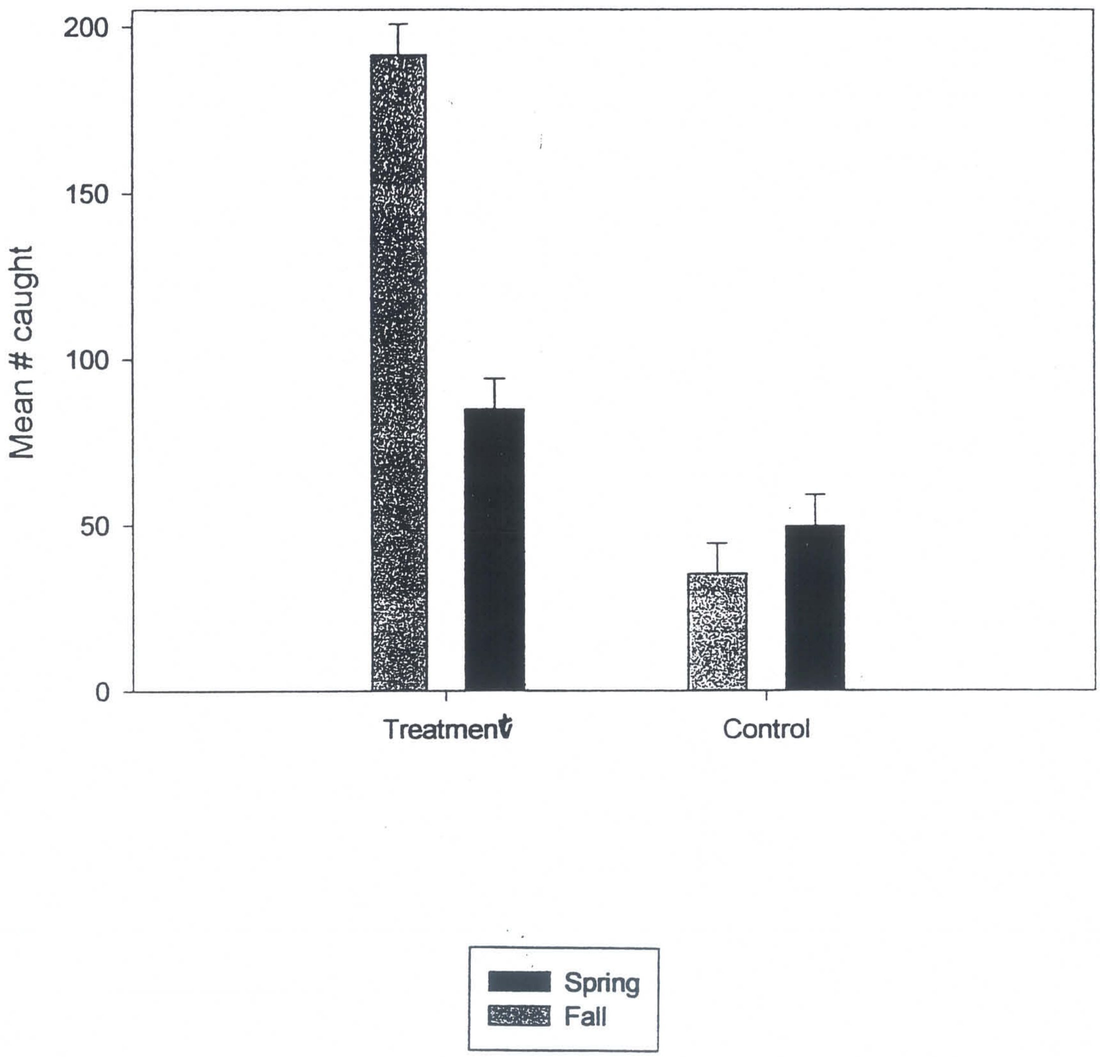


Figure 16. Mean number of speckled dace caught in the four sampling periods for treatment and control stations in Bass Creek, Arizona.

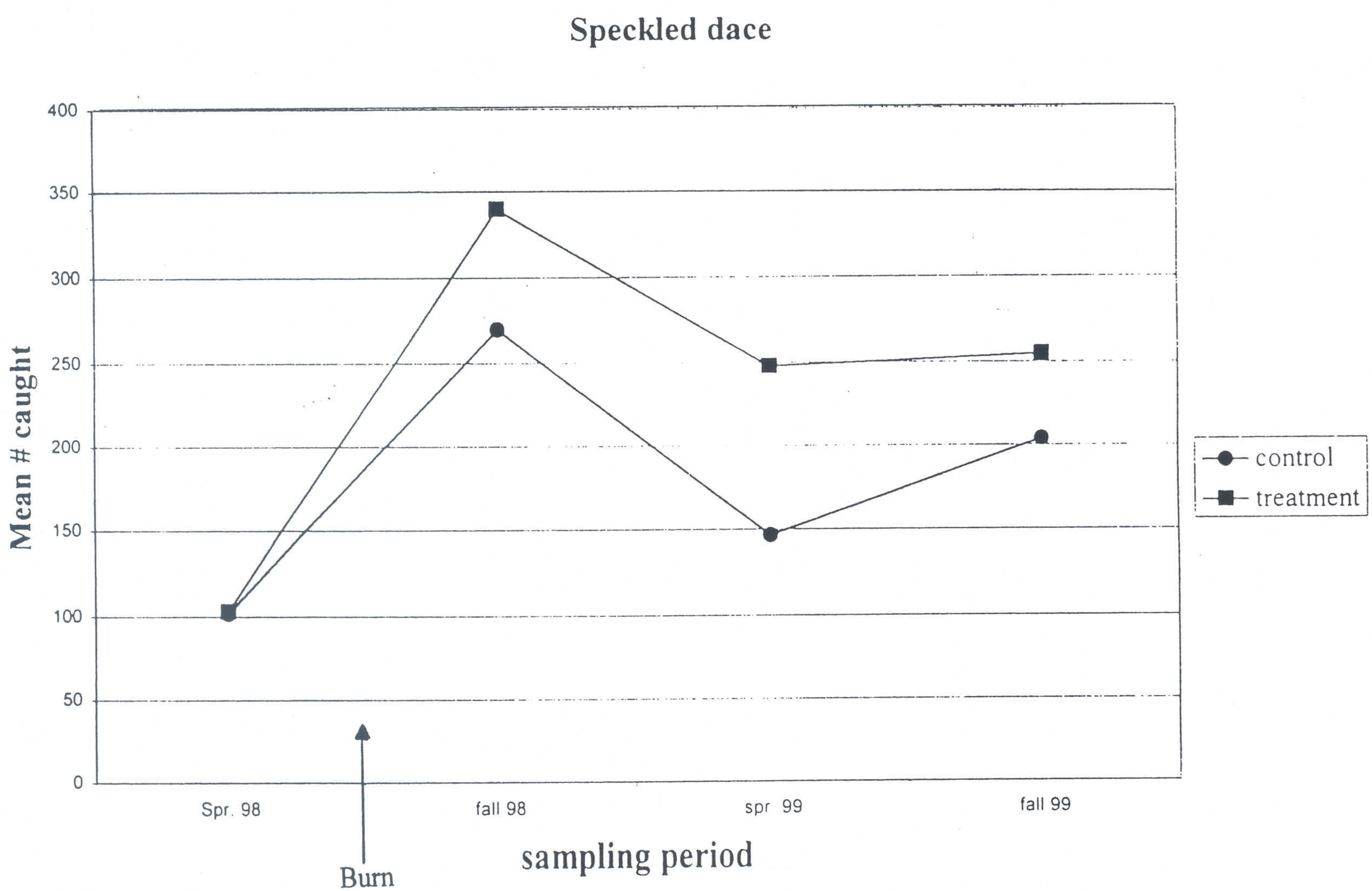


Figure 17. Mean number of Gila chub caught in the four sampling periods for treatment and control stations in Bass Creek, Arizona.

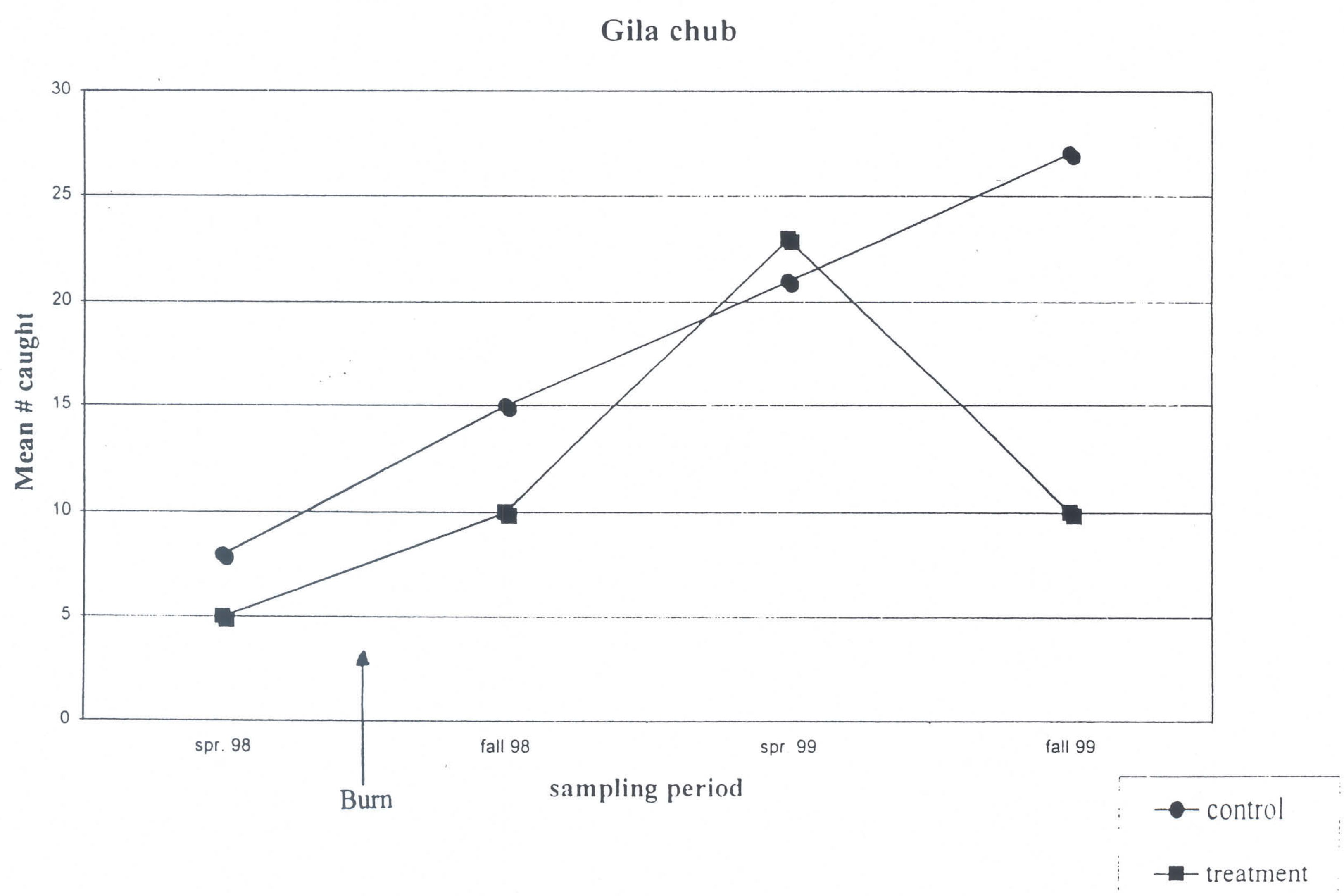


Figure 18. Mean number of desert sucker caught in the four sampling periods for treatment and control stations in Bass Creek, Arizona.

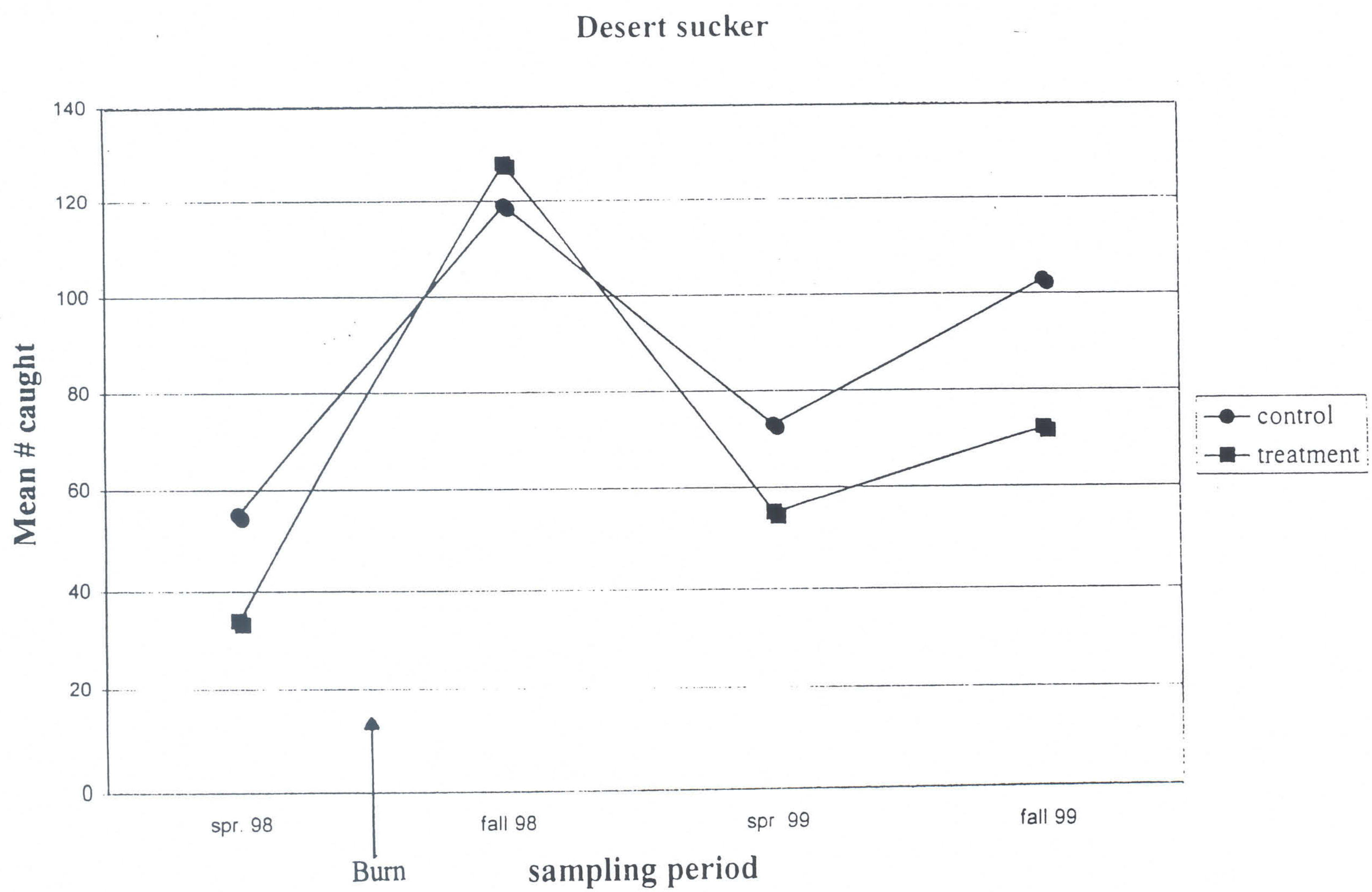
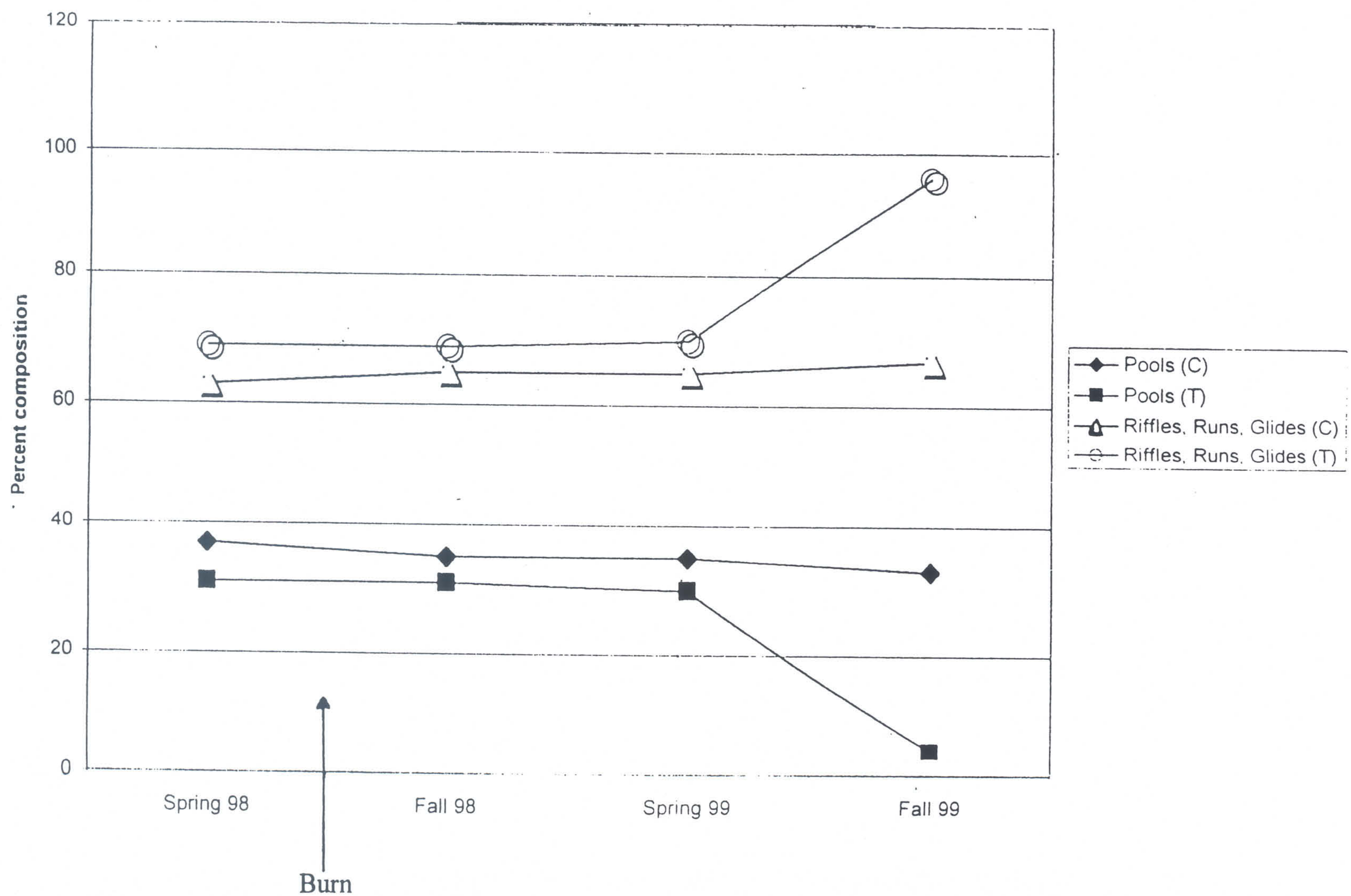


Table 12. Water chemistry results obtained from ADEQ averages for years 1992, 1993, 1994, and 1997 for selected streams in southeastern Arizona.
ND = not detected.

	Stream name					
	Bass	Hot Springs	Redfield	Double R	San Pedro River	Unnamed
DO	7.9	8.7	9.1	7.9	8.4	8.1
Temp.	15	16	13	16	17	16
pH	7	8	8	7	8	8
Ca	15.7	27.2	26.7	33.1	68.1	58.1
Mg	4.7	7	5.8	12.1	16.1	24.2
Na	14.7	33.6	16.8	24.2	52.4	26.6
K	3.86	3.8	2.6	3.2	5.35	3.4
HCO_3	100	177	111	200	260	330
SO_4	13.7	16.5	38.5	15.3	18.3	10.2
Cl	17	7	7	8	19	12
Alkalinity	103	173	91	160	217	270
NO_2	ND	ND	ND	ND	ND	ND
NO_3	ND	ND	ND	ND	ND	ND
Ammonia	ND	ND	ND	ND	ND	ND
Turbidity	0.01	0.31	0.45	0.29	2.2	0.54

DO, Ca, Mg, Na, K, HCO_3, SO_4, Cl, alkalinity, NO_2, NO_3, and Ammonia units = ppm.
Temperature measured in °C.
Turbidity measured in NTU's.

Figure 19. Microhabitat changes over time in treatment and control stations.



APPENDIX A

WATER QUALITY DATA FOR MAY 1998 -OCTOBER 1999.

Water Data
Station #1

Date	Temp	Turbidity	Alkalinity	NH_4N	CO_2	Cloride	D.O.	Hardness	NO_2N	pH
5/27/98	18	0	118ppm	.2ppm	11ppm	20ppm	8.8ppm	74ppm	0	6.5
6/6/98	18	0	118ppm	.2ppm	11ppm	20ppm	8.8ppm	76ppm	0	6.5
6/12/98	19	0	118ppm	.2ppm	11ppm	20ppm	8.6ppm	76ppm	0	6.5
6/19/98	19	0	114ppm	.2ppm	10ppm	18ppm	7.2ppm	80ppm	0	7
6/28/98	20	0	111ppm	.2ppm	9.2ppm	16ppm	6.0ppm	88ppm	0	7.5
7/2/98	20	0	110ppm	.2ppm	9.2ppm	16ppm	6.5ppm	88ppm	0	7.5
7/9/98	21	0	95ppm	.2ppm	9ppm	18ppm	6.5ppm	96ppm	0	7.5
7/18/98	21	0	96ppm	.2ppm	9ppm	16ppm	6.0ppm	100ppm	0	7.5
7/26/98	21	0	100ppm	.2ppm	9ppm	16ppm	6.0ppm	100ppm	0	7.5
8/4/98	21	0	102ppm	.2ppm	9ppm	16ppm	6.0ppm	102ppm	0	7.5
8/10/98	21	0	102ppm	.2ppm	9.2ppm	16ppm	6.6ppm	102ppm	0	7
8/16/98	21	0	104ppm	.2ppm	10ppm	18ppm	7.6ppm	96ppm	0	7
8/22/98	21	0	108ppm	.2ppm	10.2ppm	18ppm	7.6ppm	96ppm	0	7
8/30/98	21	0	110ppm	.2ppm	10.2ppm	18ppm	7.6ppm	100ppm	0	7
9/6/98	21	0	110ppm	.2ppm	11ppm	18ppm	7.8ppm	96ppm	0	7.5
9/13/98	20	0	112ppm	.2ppm	11ppm	19ppm	8.4ppm	88ppm	0	7.5
9/20/98	20	0	116ppm	.2ppm	11ppm	19ppm	8.4ppm	88ppm	0	7
9/27/98	20	0	116ppm	.2ppm	11ppm	19ppm	8.4ppm	90ppm	0	7
10/4/98	20	0	116ppm	.2ppm	11ppm	20ppm	8.6ppm	86ppm	0	7

Water Data

Station #2

Date	Temp	Turbidity	Alkalinity	NH_4N	CO_2	Cloride	D.O.	Hardness	NO_2N	pH
5/27/98	18	0	108ppm	.2ppm	10ppm	16ppm	8.2ppm	92ppm	0	7
6/6/98	18	0	108ppm	.2ppm	10ppm	18ppm	8.0ppm	90ppm	0	7
6/12/98	18	0	108ppm	.2ppm	10ppm	18ppm	7.6ppm	88ppm	0	7
6/19/98	19	0	106ppm	.2ppm	10ppm	18ppm	7.4ppm	94ppm	0	7
6/28/98	20	0	104ppm	.2ppm	11ppm	18ppm	7.8ppm	96ppm	0	7.5
7/2/98	20	0	104ppm	.2ppm	10ppm	16ppm	7.4ppm	96ppm	0	7.5
7/9/98	21	0	106ppm	.2ppm	9.2ppm	16ppm	6.8ppm	98ppm	0	7.5
7/18/98	21	0	108ppm	.2ppm	8.5ppm	16ppm	5.4ppm	100ppm	0	7.5
7/26/98	21	0	106ppm	.2ppm	8.4ppm	16ppm	5.4ppm	98ppm	0	7.5
8/4/98	21	0	104ppm	.2ppm	8.4ppm	15ppm	5.0ppm	98ppm	0	7.5
8/10/98	21	0	102ppm	.2ppm	8.2ppm	15ppm	5.0ppm	96ppm	0	7.5
8/16/98	21	0	98ppm	.2ppm	8.0ppm	15ppm	4.8ppm	100ppm	0	7.5
8/22/98	21	0	104ppm	.2ppm	8.4ppm	16ppm	5.4ppm	100ppm	0	7.5
8/30/98	21	0	108ppm	.2ppm	10ppm	16ppm	7.2ppm	98ppm	0	7.5
9/6/98	20	0	106ppm	.2ppm	10ppm	15ppm	7.4ppm	96ppm	0	7
9/13/98	20	0	104ppm	.2ppm	10ppm	16ppm	8.4ppm	100ppm	0	7
9/20/98	20	0	104ppm	.2ppm	10ppm	16ppm	8.2ppm	98ppm	0	7
9/27/98	20	0	106ppm	.2ppm	10ppm	18ppm	8.2ppm	96ppm	0	7
10/4/98	19	0	106ppm	.2ppm	10ppm	18ppm	8.4ppm	94ppm	0	7

Water Data

Station #3

Date	Temp	Turbidity	Alkalinity	NH_4N	CO_2	Cloride	D.O.	Hardness	NO_2N	pH
5/27/98	17	0	118ppm	.2ppm	11ppm	12ppm	6.0ppm	84ppm	0	7
6/6/98	17	0	118ppm	.2ppm	11ppm	12ppm	6.0ppm	86ppm	0	7
6/12/98	17	0	118ppm	.2ppm	11ppm	16ppm	6.0ppm	86ppm	0	7
6/19/98	17	0	114ppm	.2ppm	11ppm	16ppm	5.4ppm	88ppm	0	7
6/28/98	17	0	100ppm	.2ppm	14ppm	16ppm	4.8ppm	96ppm	0	7
7/2/98	17	0	104ppm	.2ppm	15ppm	14ppm	4.4ppm	98ppm	0	7
7/9/98	17	0	108ppm	.2ppm	16ppm	16ppm	4.2ppm	100ppm	0	7
7/18/98	17	0	112ppm	.2ppm	16ppm	16ppm	3.8ppm	104ppm	0	7
7/26/98	18	0	110ppm	.2ppm	18ppm	14ppm	3.6ppm	104ppm	0	7
8/4/98	18	0	108ppm	.2ppm	18ppm	14ppm	3.4ppm	100ppm	0	7
8/10/98	18	0	108ppm	.2ppm	18ppm	14ppm	3.4ppm	100ppm	0	7
8/16/98	18	0	104ppm	.2ppm	16ppm	16ppm	4.2ppm	92ppm	0	7
8/22/98	18	0	106ppm	.2ppm	11ppm	16ppm	5.4ppm	96ppm	0	7
8/30/98	18	0	108ppm	.2ppm	11ppm	14ppm	5.8ppm	104ppm	0	7
9/6/98	18	0	112ppm	.2ppm	11ppm	14ppm	6.0ppm	104ppm	0	7
9/13/98	18	0	110ppm	.2ppm	11ppm	12ppm	6.4ppm	102ppm	0	7
9/20/98	17	0	110ppm	.2ppm	11ppm	12ppm	6.4ppm	102ppm	0	7
9/27/98	17	0	112ppm	.2ppm	10ppm	14ppm	6.8ppm	104ppm	0	7
10/4/98	17	0	112ppm	.2ppm	10ppm	14ppm	6.8ppm	98ppm	0	7

Water Data
Station #4

Date	Temp	Turbidity	Alkalinity	NH_4N	CO_2	Cloride	D.O.	Hardness	NO_2N	pH
5/27/98	20	0	118ppm	.2ppm	7ppm	12ppm	7.4ppm	98ppm	0	7
6/6/98	20	0	118ppm	.2ppm	7ppm	12ppm	7.4ppm	98ppm	0	7
6/12/98	20	0	118ppm	.2ppm	7ppm	12ppm	7.2ppm	96ppm	0	7
6/19/98	20	0	117ppm	.2ppm	8ppm	16ppm	6.8ppm	90ppm	0	7
6/28/98	20	0	116ppm	.2ppm	9ppm	16ppm	5.6ppm	84ppm	0	7
7/2/98	20	0	112ppm	.2ppm	10ppm	14ppm	5.2ppm	88ppm	0	7
7/9/98	21	0	110ppm	.2ppm	12ppm	14ppm	4.5ppm	90ppm	0	7
7/18/98	21	0	108ppm	.2ppm	16ppm	12ppm	4.0ppm	96ppm	0	7
7/26/98	21	0	106ppm	.2ppm	16ppm	12ppm	3.8ppm	92ppm	0	7
8/4/98	21	0	106ppm	.2ppm	15ppm	12ppm	3.8ppm	94ppm	0	7
8/10/98	21	0	104ppm	.2ppm	13ppm	14ppm	4.8ppm	98ppm	0	7
8/16/98	21	0	100ppm	.2ppm	11ppm	12ppm	5.4ppm	100ppm	0	7
8/22/98	21	0	104ppm	.2ppm	9ppm	12ppm	6.2ppm	98ppm	0	7
8/30/98	20	0	106ppm	.2ppm	7ppm	12ppm	7.0ppm	102ppm	0	7
9/6/98	20	0	112ppm	.2ppm	7ppm	14ppm	8.4ppm	100ppm	0	7
9/13/98	20	0	112ppm	.2ppm	7ppm	14ppm	9.8ppm	98ppm	0	7
9/20/98	20	0	114ppm	.2ppm	7ppm	14ppm	9.2ppm	96ppm	0	7
9/27/98	20	0	114ppm	.2ppm	7ppm	16ppm	8.4ppm	92ppm	0	7
10/4/98	20	0	116ppm	.2ppm	7ppm	16ppm	8.0ppm	94ppm	0	7

APPENDIX B

MICROHABITAT DATA FOR CONTROL AND TREATMENT STATIONS FORM
MAY 1998 - OCTOBER 1999.

Microhabitat Data

Date	Season	C or T	pre/post	% Runs	% glide	% Riffle	% Pool	Mean Depth Runs	Riffle	Glide	Pool
5/23/98	1	c	pre	48	0	16	36	12.3	11	0	36.75
10/10/98	2	c	post	47	0	15	38	11.3	8.9	0	35.95
6/5/99	1	c	post	28	0	32	40	3	4.2	0	31.8
10/2/99	2	c	post	48	0	16	36	11.1	9.7	0	36.9
5/23/98	1	c	pre	28	34	8	30	9.2	6.95	9.96	39.5
10/10/98	2	c	post	36	18	14	32	7.3	8.45	4.6	49.5
6/5/99	1	c	post	0	48	22	30	0	10.25	10.96	42.3
10/2/99	2	c	post	37	23	10	30	2.85	10.5	3.73	52.5
5/23/98	1	t	pre	70	0	0	30	10.56	0	0	45.7
10/10/98	2	t	post	70	0	0	30	7.96	0	0	62
6/5/99	1	t	post	20	16	34	30	2.33	4.7	8	33.4
10/2/99	2	t	post	28	36	34	2	2.86	0	9.55	23.2
5/23/98	1	t	pre	44	16	8	32	12.83	4	11.05	32.4
10/10/98	2	t	post	50	18	0	32	4.95	11.7	6.25	46.9
6/5/99	1	t	post	50	20	0	30	0	0	6.1	40
10/2/99	2	t	post	74	20	0	6	2.8	7.2	15.65	25.5

Date	Season	C or T	pre/post	Runs	Maximum Depth Riffle	Glide	Pool
5/23/98	1	c	pre	22.3	30	0	95
10/10/98	2	c	post	18.7	12	0	68
6/5/99	1	c	post	7	10	0	71
10/2/99	2	c	post	22.33	18	0	72
5/23/98	1	c	pre	19	13	17.66	95
10/10/98	2	c	post	11.75	6	6.66	83
6/5/99	1	c	post	0	20.3	24.3	85
10/2/99	2	c	post	12	5.3	10	92
5/23/98	1	t	pre	18.33	0	0	100
10/10/98	2	t	post	15	0	0	118
6/5/99	1	t	post	3.33	12	15.5	100
10/2/99	2	t	post	4.66	0	16.5	42
5/23/98	1	t	pre	24.3	20	20	45
10/10/98	2	t	post	8	0	9.5	87
6/5/99	1	t	post	0	10	15	73
10/2/99	2	t	post	4	0	29	46

APPENDIX C

FISH DATA FOR FIVE SPECIES OF FISH: LONGFIN DACE, SPECKLED DACE, SONORA SUCKER, DESERT SUCKER, AND GILA CHUB FOR CONTROL AND TREATMENT STATIONS FROM MAY 1998 - OCTOBER 1999.

FISH DATA

Date	Site #	C or T	Pre/Post	#RHOS	#AGCH	#PACL	#CAIN	#GIIN	pRHOS	pAGCH	pPACL
5/23/98	1	C	pre	78	10	60	0	12	49	6	38
	2	C	pre	127	23	50	3	4	61	11	24
	3	T	pre	84	46	11	1	4	56	32	8
	4	T	pre	126	103	56	0	5	43	36	19
10/4/98	1	C	post	357	58	127	12	17	63	10	22
	2	C	post	220	6	79	5	12	68	2	25
	3	T	post	292	219	48	8	5	51	38	8
	4	T	post	375	238	199	4	15	45	28	24
6/5/99	1	C	post	147	60	120	2	23	42	17	34
	2	C	post	146	106	118	7	19	37	28	30
	3	T	post	279	129	28	8	6	62	29	6
	4	T	post	216	62	82	9	40	53	15	20
10/2/99	1	C	post	186	52	89	5	28	52	14	25
	2	C	post	221	25	56	14	25	65	7	16
	3	T	post	149	171	20	2	11	42	48	6
	4	T	post	193	138	124	1	9	42	30	27

Date	Site #	C or T	pCAIN	pGIIN
5/23/98	1	C	0	8
	2	C	1	2
	3	T	1	3
	4	T	0	2
10/4/98	1	C	2	3
	2	C	2	4
	3	T	1	1
	4	T	1	3
6/5/99	1	C	1	7
	2	C	2	5
	3	T	2	1
	4	T	2	10
10/2/99	1	C	1	8
	2	C	4	7
	3	T	1	3
	4	T	1	2

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Appendix G

Directory of Photographs On Compact Discs

Directory

Disc Title: Mule/Fish 1
Contents:

- Muleshoe
  - Fish
    - Hot Springs
    - Bass
      - Station 1
      - Station 2
      - Station 3
      - Station 4
      - Station 5
      - Station 6
      - Station 7 (incomplete; complete version on Disc Mule 2)

Disc Title: Mule 2
Contents:

- Muleshoe
  - Fish
    - Bass
      - Station 7
      - Station 8
      - Relocation
    - RR
    - Wildcat
  - Geomorph
  - Riparian
  - Upland Veg
    - AWPF
    - Marty's Mom
    - White Rocks (incomplete; complete version on Disc Mule 3)

Disc Title: Mule 3
Contents:

- Muleshoe
  - Upland Veg
    - Amole
    - Bear
    - Before Browning
    - Benchmark
    - Bighorn
    - Breakdown
    - Cherry Spring
    - Fenceline
    - Grants
    - Green Acres
    - Hookers View
    - Ignition Rest
    - Jesus Tank (incomplete; complete version on Disc Mule 4)

Disc Title: Mule 4
Contents:

- Muleshoe
  - Upland Veg

🗁Jesus Tank
🗁Larry's
🗁Lil Rattler
🗁Mule Deer
🗁North Pole
🗁Old Pride Trap
🗁Pride Ridge
🗁Pride View
🗁Red Baron
🗁Repeater View
🗁Running Dear
🗁South Elan
🗁Stone Cabin
🗁Swamp Springs
🗁White Rock (incomplete; complete version on Disc Mule 5)

Disc Title: Mule 5
Contents:
- 🗁 Muleshoe
  - 🗁Upland Veg
    - 🗁White Rock
    - 🗁Wildcat

Photo Code Descriptions

Photo Codes are 7 or 8 digit descriptors that vary by location. The table below translates the codes for the different locations.

Muleshoe Upland Vegetation	
Photos oriented N, E, S, or W	
Digit position:	**Meaning**
1 & 2	Abbreviation for plot name. See attached sheet titles "Abbreviations)
3	Position on plot (N, E, S, or W)
4, 5, & 6	Compass bearing
7 & 8	Year
Photos oriented NE, NW, SE or SW	
Digit position:	**Meaning**
1 & 2	Abbreviation for plot name. See attached sheet titles "Abbreviations)
3 & 4	Position on plot (NE, NW, SE or SW)
5, 6 & 7	Compass bearing
8	Year (for 8, assume 98; etc. All files in the 1990's or 2000's)
Photos in Ignition Rest Plot:	
Digit position:	**Meaning**
1 & 2	Abbreviation for plot name. See attached sheet titles "Abbreviations)
3	Position on plot (N, E, S, or W)
4, 5, & 6	Compass bearing
7	Year (for 8, assume 98; etc. All files in the 1990's or 2000's
Example: Irn1968 is the Ignition Rest Plot, N position, compass bearing 196°, year 1998	

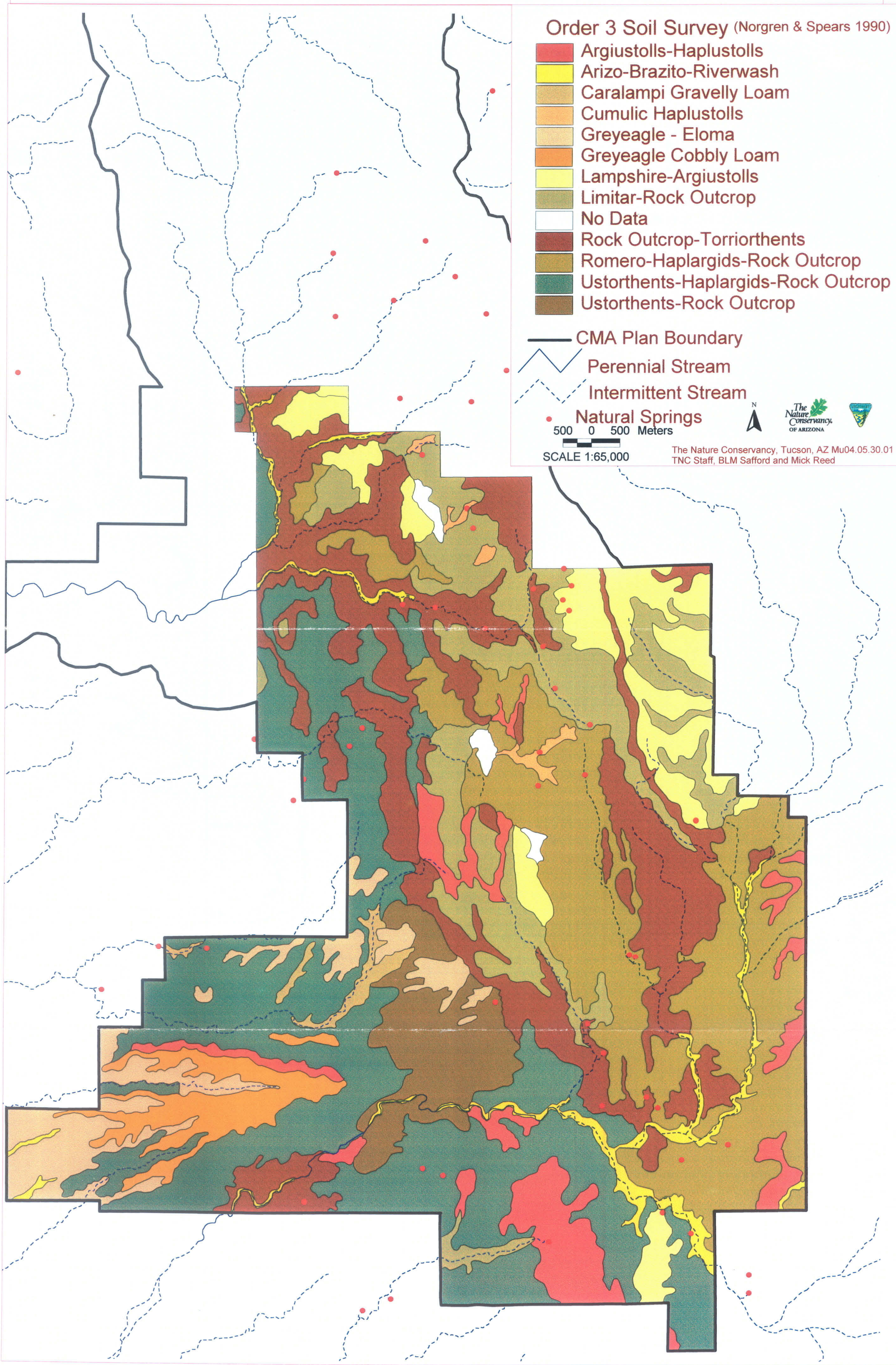
Muleshoe Fish	
Digit position:	**Meaning**
1	Location: B (for Bass), H (Hot Springs), R (RR), W(Wildcat)
2	Station number
3	Plot location: (0=begin, 1 = end, m = mid point)
4	U for looking upstream D for looking downstream
5.,6, 7	Compass Bearing
8	Year
Example: b2mu1239 bass, station 2, mid point, looking upstream, bearing 123, 1999	

Abbreviations			
Monitoring Plots		**Control Plots**	
Abbreviation	**Plot Name**	**Abbreviation**	**Plot Name**
AM	Amole	HV	Hooker's View
BC	Bill C.	LM	Larry's Mistake
BD	Breakdown	IR	Ignition Rest
BH	Big Horn	RB	Red Baron
BM	Bemchmark	RV	Repeater View
BW	Black Waterfall	SE	South Elan
CS	Cherry Spring	SS	Swamp Spring
FL	Fenceline		
GA	Green Acres	**Fish Monitoring**	
GR	Grants	B	Bass Creek
JT	Jesus Tank	H	Hot Springs
LR	L'il Rattler	R	Double R
MC	Monica	W	Wildcat
MD	Muledeer		
MM	Marty's Mom		
NP	North Pole		
OP	Old Pride Trap		
PR	Pride Ridge		
PV	Pride View		
RD	Running Deer		
SC	Stone Cabin		
WR	White Rocks		
WC	Wildcat		

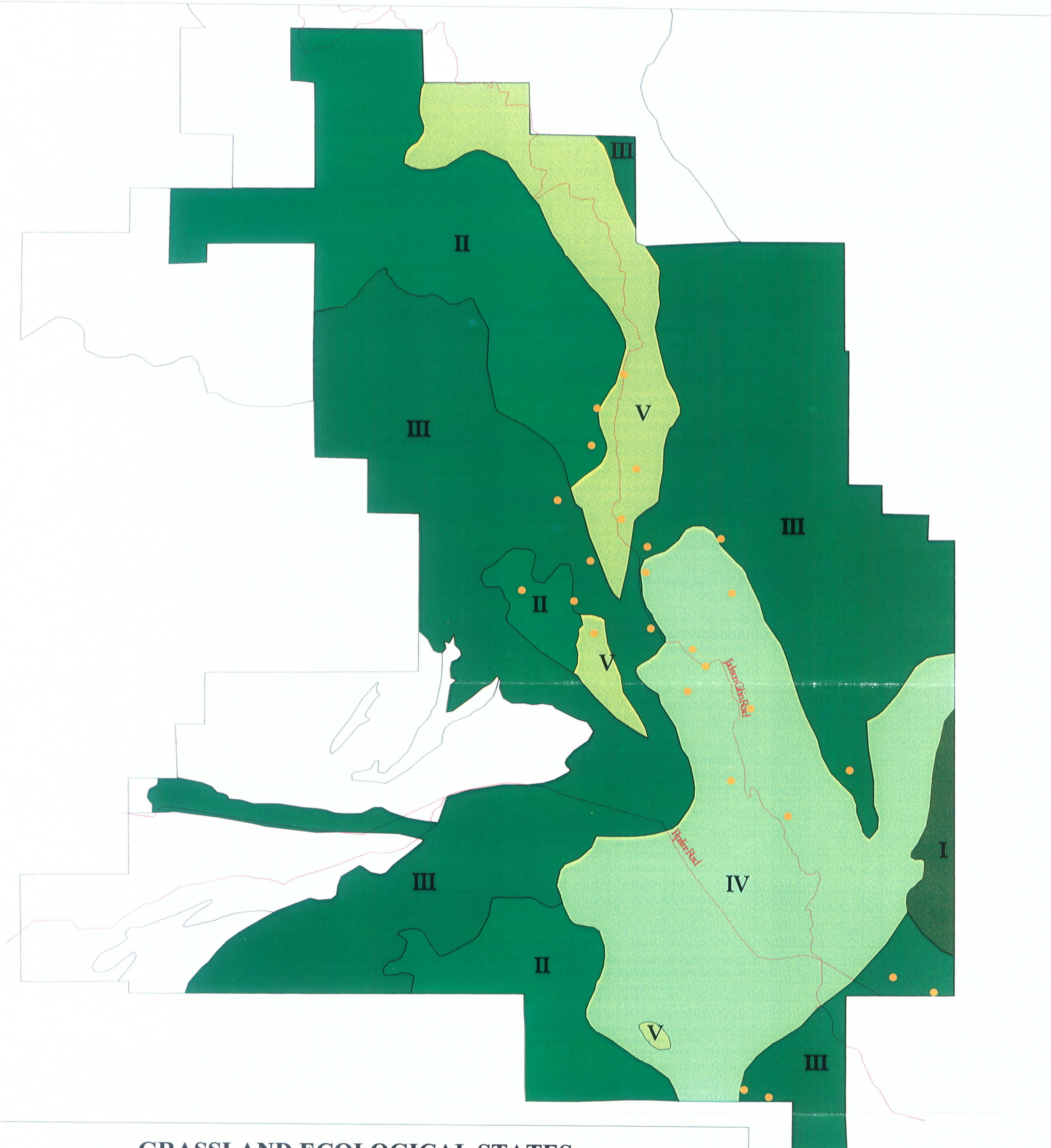
Appendix H

Maps

Map 4: Muleshoe Ranch CMA: Soil Complexes and Springs



Map 5: Muleshoe Ranch Allotment-Grassland Ecological States



GRASSLAND ECOLOGICAL STATES

Ecological States-based on the composition of the vegetation (amount of shrub invasion, amount of perennial versus annual grass and amount of mid-tall statured perennial grasses. States assigned based on BLM 1994 transect data (BLM 1998).

State	Description	Shrub Canopy	Perennial Grass	Mid Grass	Annuals
I	Perennial Grassland, Mid Grass Dominant	<20%	>70%	>50%	<30%
II	Shrubby Grassland, Mid Grass Dominant	>20%	>70%	>50%	<30%
III	Shrubby Grassland, Short Grass Dominant	>20%	>70%	>50%	<30%
IV	Shrubs and Annuals, Annual Grass Dominant	>20%	<70%	<50%	>30%
V	Perennial Grassland, Short Grass Dominant	0%	>70%	<50%	>30%

● Upland Vegetation Monitoring Plot

1000 0 1000 2000 Meters

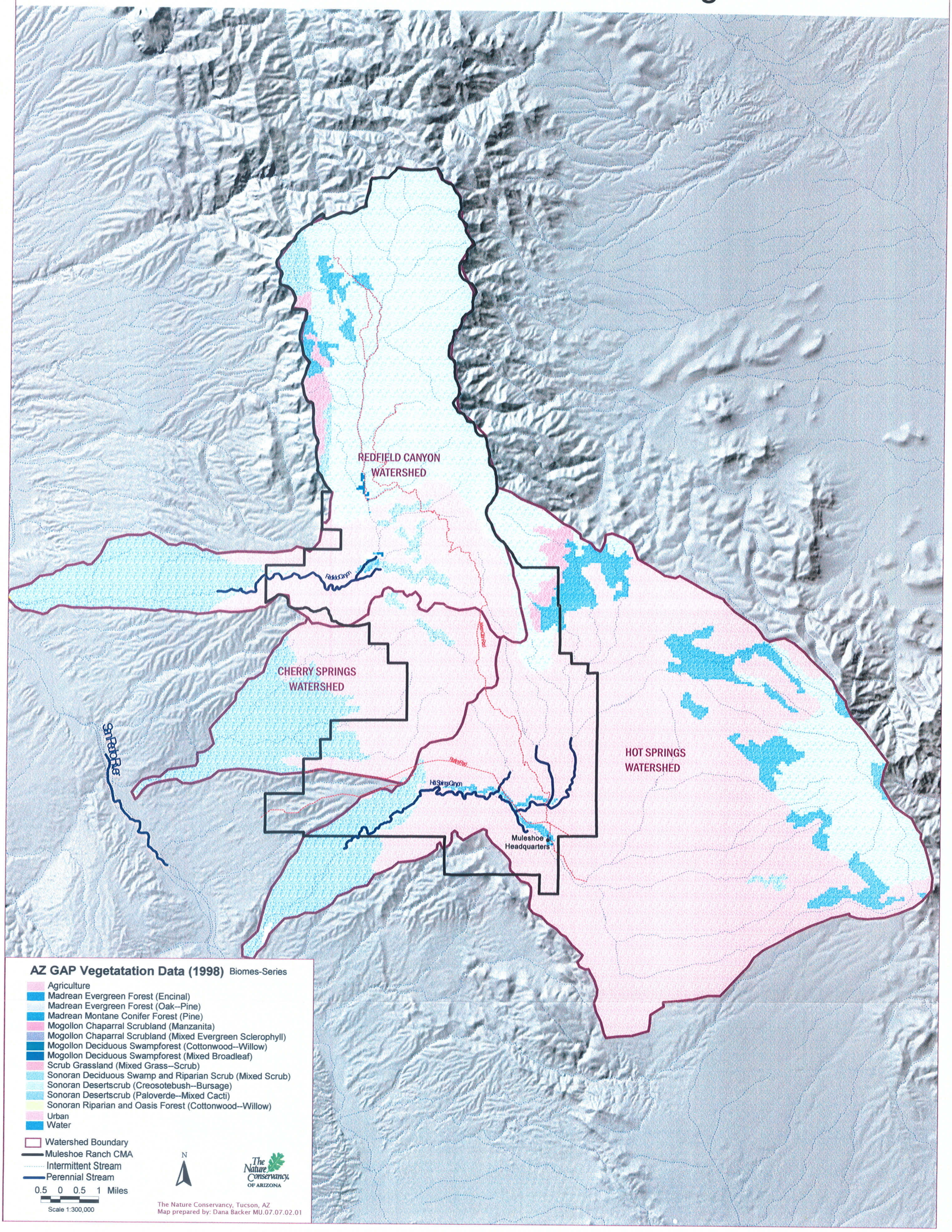
SCALE 1:60,000

N

The Nature Conservancy of Arizona

The Nature Conservancy, Tucson, AZ MU05.06.06.01
Data prepared by BLM Tucson District
Map prepared by Dana Backer

Map 7: Watershed Boundaries within the Lower San Pedro Basin and GAP Vegetation



Appendix I

Community Outreach Photographs










Appendix J

Revised Graphs of Appendix H

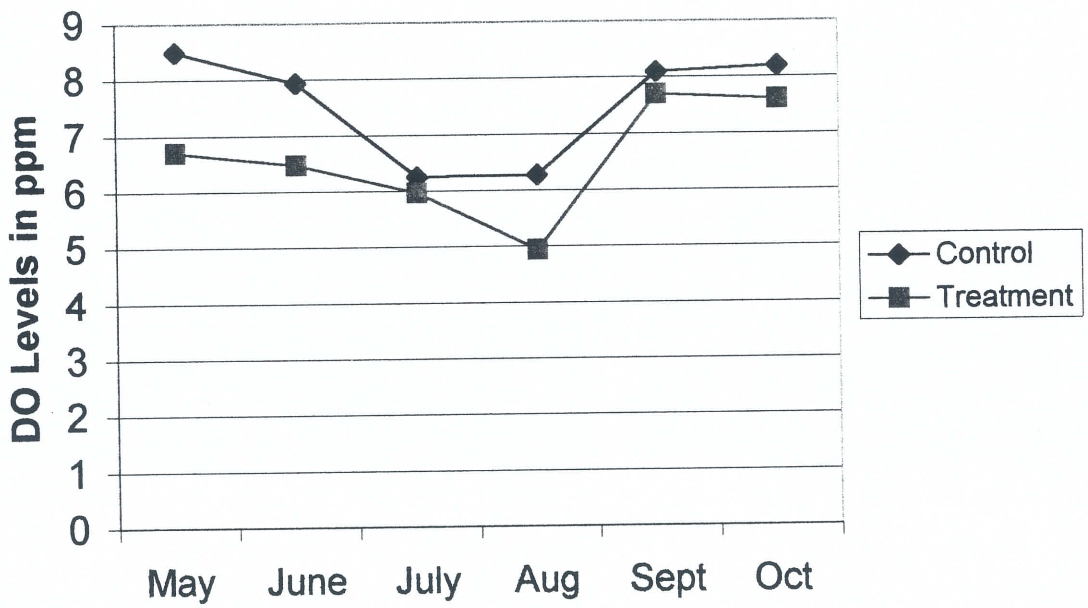


Figure 6. Dissolved oxygen (DO) levels over time in control and treatment stations (n = 2 for both). The Double R burn was conducted on June 23, 1998.

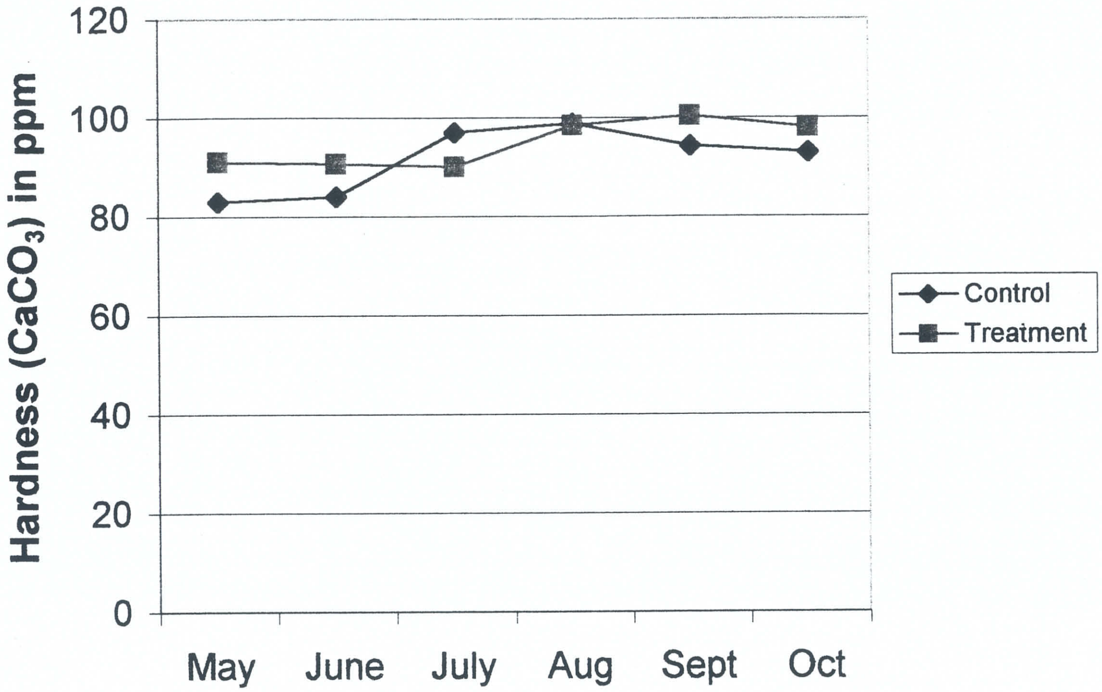


Figure 7. Water hardness levels ($CaCO_3$ in ppm) over time in control and treatment stations (n = 2 for both). The Double R burn was conducted on June 23, 1998.

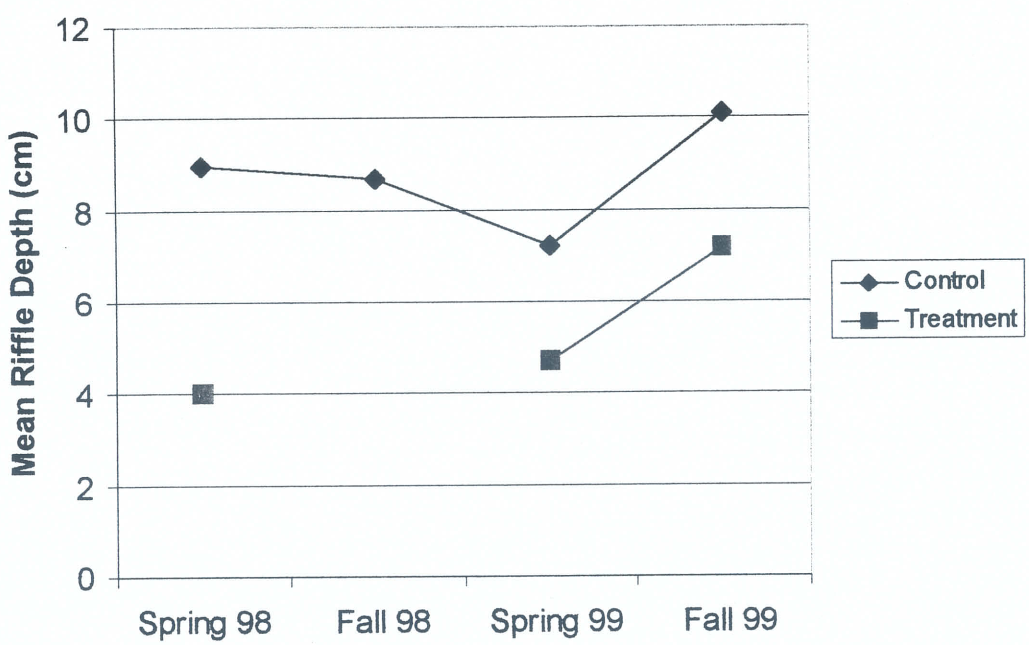


Figure 9. Mean depth of riffles in control and treatment stations (n = 2 for both). The Double R burn was conducted on June 23, 1998.

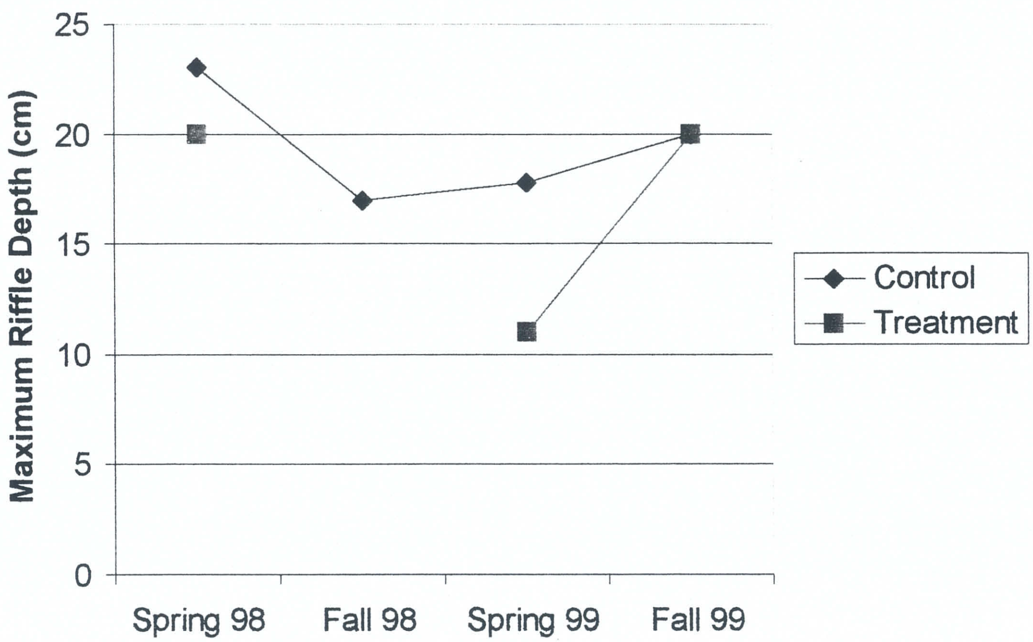


Figure 10. Maximum depth of riffles in control and treatment stations (n = 2 for both). The Double R burn was conducted on June 23, 1998.

Appendix K

Example Sign:

"NO VEHICLES OFF ROAD"

**Example of signs
Posted in Hot Springs
And Bass Canyons.**

TUFFFLEX

TuffFlex

The name says it all. Carsonite's newest member of the utility marker family, the TuffFlex marker is tough enough to drive easily in hardpan soil yet flexible enough to withstand vehicle impacts.

Warning and identification graphics can be integrated into the surface of the post and can be placed on one or both sides of the post. Adding customized graphics and company logos are no problem.

A nearly flat profile and lightweight fiberglass reinforced composite materials make installation a snap. An optional anchor barb prohibits unauthorized removal.

MATERIAL	Fiberglass reinforced composite
DIMENSION	Width 3.8" (97mm)
LENGTHS	5'2" (1.575m), 5'6" (1.676m), 6' (1.829m), 6'6" (1.981m)
COLORS	White, Yellow, Orange, Red, Green, Blue
PRODUCT #	CTFM0 _ _ _ _