SRP13691

FISHES OF ARAVAIPA CREEK

GRAHAM AND PINAL COUNTIES, ARIZONA

LITERATURE REVIEW

AND HISTORY OF RESEARCH AND MONITORING

Sally E. Stefferud

Peter N. Reinthal

University of Arizona
Tucson, Arizona

Report to U.S. Bureau of Land Management
Safford, Arizona

Cooperative Agreement AAA000011
Task Order AAF030025

DRAFT FINAL

October 15, 2004

EXECUTIVE SUMMARY

PURPOSE: To summarize the history of fish monitoring and research in Aravaipa Creek, Graham and Pinal Counties, Arizona, and review associated literature. To relate this knowledge to conservation and management efforts in Aravaipa Canyon and assess the value of monitoring in relation to those efforts.

RESULTS: Aravaipa Creek is an important resource for conservation of native fish, retains 7 native species and has relatively low incidence of nonnative fishes. It is the most extensively studied native fish community in the Gila River basin. Research and monitoring have been occurring since 1943. Since 1963, Arizona State University has focused substantial research and monitoring effort on Aravaipa Creek. This has assisted substantial conservation efforts by The Nature Conservancy, Bureau of Land Management, and other organizations. Long-term monitoring is being continued by the University of Arizona.

Monitoring constitutes 47% of all fish sampling in Aravaipa Creek. The long-term monitoring data set of 41 years is the longest such effort for native fish in Arizona and the Gila River basin. Monitoring intensity is variable, with an average of 3 monitoring events per year. Monitoring shows that the native fish community continues to be robust despite substantial changes in human uses, but also shows a gradual and increasing invasion and spread by nonnative fishes, indicating instability that may result in long-term negative change. Analyses of long-term data reveal sensitivity of native fish to human and natural changes that reduce the heterogeneity of the aquatic environment or alter the natural hydrograph. Short-lived native fish show positive responses to flooding, while nonnative fish show negative responses, indicating that natural flooding patterns are critical to maintenance of the native fish community. Long-term trends in fish community composition in the upper and canyon reaches of Aravaipa Creek show shifts in relative abundance of native species. The lower reach fluctuates in a cyclical manner, but shows long-term declines in spikedace. Differences in trends and other factors indicate changes in the lower reach are being driven by different factors than in the canyon and upper reaches. Lower reach changes appear to be associated with increasing presence of nonnative fish.

CONCLUSIONS: Research and monitoring on fish have been important tools in conservation and management of Aravaipa Canyon. The extensive knowledge of the fishes of Aravaipa Creek has supported conservation efforts such as land acquisition and has steered management actions, such as fish barrier construction. Knowledge gained in Aravaipa Creek has provided valuable assistance in conservation efforts for native fish throughout the Gila River basin and elsewhere. Long-term data on the fish community of Aravaipa Creek indicate that control and removal of nonnatives and prevention or reversal of activities that lower habitat heterogeneity should be the highest priority for management.

RECOMMENDATIONS: Continue long-term biannual monitoring using protocols consistent with, and supplemental to, those for the 40-year existing data set. Evaluate increasing the intensity of monitoring, including increased sampling events consistent with the 40-year data set, as well as short-term efforts using alternative methodologies to answer other questions. Provide for improved long-term storage and retrieval of all Aravaipa Creek fish sampling data with periodic summary reports.

ACKNOWLEDGMENTS

We would like to thank a number of people who contributed time and information to this report. Assistance in accessing files was provided by Mary Richardson at U.S. Fish and Wildlife Service, Heidi Blasius and Jeff Simms at the U.S. Bureau of Land Management, Rob Clarkson at the U.S. Bureau of Reclamation, Rob Bettaso, Kirk Young, Jeremy Voeltz, and Don Mitchell at the Arizona Game and Fish Department, and Tom Collazo at The Nature Conservancy. Information on historic place names was provided by Mark Haberstich at The Nature Conservancy Aravaipa Preserve and Diana Hadley of the Arizona State Museum. Assistance in obtaining information on historic sampling was provided by Dean Hendrickson and Clark Hubbs at the University of Texas at Austin, Tony Velasco of the U.S. Fish and Wildlife Service, Doug Nelson at the University of Michigan Museum of Zoology, and Jim Johnson, Chief of Endangered Species for U.S. Fish and Wildlife Service Region 2 from 1980 to 1989. Jon Fuller of JE Fuller Hydrology and Geomorphology, Inc. provided file information and gave permission to use maps from his 2000 report, and Larry Roberts, of TetraTech, provided a copy of his thesis.

This report would not have been possible without access to the extensive Aravaipa Creek resources of the late Dr. W.L. Minckley of Arizona State University. Access was facilitated by Paul Marsh, Mike Schwemm, Tom Dowling, and Peter Unmack.

Review and additions to lists, tables, and summaries were kindly provided by Heidi Blasius, Jeff Simms, Mark Haberstich, Tom Collazo, Paul Marsh, and Tony Velasco. The final report benefited from review by Jerome Stefferud.

TABLE OF CONTENTS

TABLES AND FIGURES

Page

INTRODUCTION

This report reviews the history and current status of monitoring and research, and the resulting literature, on fishes of Aravaipa Creek, Graham and Pinal Counties, Arizona. One of the premier remnants of the imperiled Gila River basin fish fauna, Aravaipa Creek has been the focus of significant study over the past 50 years. This report summarizes this work and discusses its contribution to native fish conservation and land management efforts. Recommendations are made regarding the need for future monitoring and study.

AREA DESCRIPTION

Aravaipa Creek is located in southeastern Arizona, near the towns of Dudleyville and Mammoth. It flows north, then west, to join the San Pedro River about 12 miles upstream of the confluence with the Gila River (Figure 1). The watershed is of moderate size (541 square miles) and although the stream is 55 miles long, perennial surface flow is presently confined to approximately 21 miles in the lower portion of the watershed (JE Fuller Hydrology and Geomorphology 2000). Elevation at the confluence with the San Pedro River is 2150 feet above mean sea level and the upper end of perennial flow is at about 3300 feet, with yearly and seasonal variation. Perennial flow begins as the creek turns west, leaving a wide upper valley and entering a narrow steep walled canyon. Depending upon the year and season, perennial flow may be found up to 27 miles, from above the canyon to the confluence with the San Pedro River. However, in most years, flow disappears into alluvial deposits after the valley bottom widens about 6 miles upstream of the San Pedro River. For detailed geographical, geological, and biological information on Aravaipa Creek, see Minckley (1981) and for hydrographical and geomorphological information, see JE Fuller Hydrology and Geomorphology (2000).

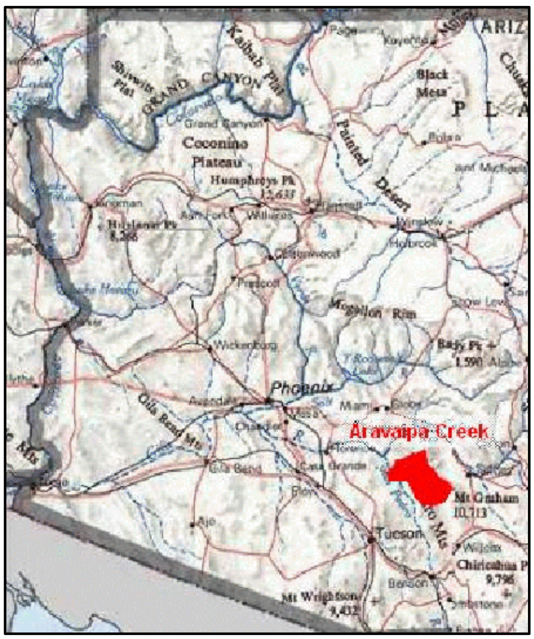


Figure 1. Location of Aravaipa Creek Watershed

Land ownership in the Aravaipa watershed is mixed (Figure 2). Upper watershed areas are on the Coronado National Forest. Private lands dominate the upper valley bottom and include many holdings along the perennial areas outside of the narrow core canyon. Tablelands on either side of the canyon are under the control of the Bureau of Land Management (BLM), as is the core portion of the canyon, which is a designated Wilderness. Substantial valley bottom areas in the upper and lower canyon are owned by The Nature Conservancy (TNC) as the Aravaipa Preserve. Allotted lands of San Carlos Apache Tribal members are located along about 1.5 miles of the lower stream.

FIGURE 2

map 11 X 17 inches of entirety of Aravaipa Creek with ownership

The gradient of Aravaipa Creek is generally less than 1.0% (JE Fuller Hydrology and Geomorphology 2000). Valley bottom width in the area of perennial flow ranges from 200 to 1200 feet, widening to 4000 feet near the lower end. In the canyon in 1976, mean stream width was 24 feet, mean depth 4 inches, and mean maximum depth 2 feet (Minckley 1981). Below the canyon, they were 32 feet, 3 inches, and 13 inches. Aquatic habitat was predominantly riffle, with some pools and rapids. In 1999, two transects within and one above the canyon measured stream widths of 12.5-21.5 feet and mean depths of 6-12 inches (JE Fuller Hydrology and Geomorphology 2000). Qualitative observations concluded that the aquatic habitat had essential the same composition as in 1976, with riffles highly predominant. Predominant substrate material in 1999 was gravel.

Aravaipa Creek has a typical desert monsoonal hydrograph, with peaks of flow (discharge) in winter and again in the late summer. Based on a 50-year period of record, the mean monthly discharge of Aravaipa Creek ranges from 12 cubic feet per second (cfs) in June to 64 cfs in February (U.S. Geological Survey 2004). Flow has dropped as low as 1.9 cfs (June 1939). Like most desert streams, and due to the size of its watershed, Aravaipa Creek experiences substantial floods. The largest flow on record was in 1983, reaching an instantaneous peak flow of 70,800 cfs. The most recent large flood, in 1993, was an estimated 10+ year flood event with an instantaneous discharge of 13,000 cfs.

Base flow in Aravaipa Creek comes primarily from subsurface upwelling shortly upstream from the upper end of the inner canyon. However, some tributaries contribute to the mainstream and have areas of perennial water. These include Deer Creek, Turkey Creek, and Oak Grove Canyon.

METHODS

A literature search was conducted to identify all published literature addressing fishes, general aquatic resources, or hydrology of Aravaipa Creek. Literature on riparian vegetation and aquatic amphibians and reptiles was not included. The numerous documents associated with BLM efforts to obtain and protect instream flows rights in Aravaipa Creek also were not included. While protection of flows is an important aquatic resource issue and will benefit native fish, the details of water rights acquisition are not pertinent to native fish management and were considered to be outside of the scope of this review.

Literature sources searched included the library collections at Arizona State University (ASU), University of Arizona (UofA), and Northern Arizona State University. Published literature was searched using the abstracting services of Agricola, Aquatic Sciences and Fisheries Abstracts, Biological and Agricultural Index, BIOSIS, Ecology Abstracts, Fish and Fisheries Worldwide, and Zoological Record. In addition, Internet searches were made using Google.com.
A substantial amount of the material on Aravaipa Creek is gray literature. Our personal collections of memos, letters, emails, notes, data sheets, and other unpublished materials on Aravaipa Creek, covering the past 15-20 years, was used. Substantial material was obtained from the U.S. Fish and Wildlife Service (FWS) Ecological Services Office in Phoenix, who

made their files available. The Arizona Game and Fish Department (AGFD) Nongame Branch and Tucson Region 5 Office provided their agency's sampling data through the Nongame Native Fish database and limited sampling information of others through the Scientific Collecting Permit database (both current only through 1999). Biologists with BLM in Safford and Tucson provided additional information from their files, and the U.S. Bureau of Reclamation (USBR) provided fish barrier monitoring data. The Arizona Nature Conservancy provided information they possessed, including the data from Williams and Siebert's work on fish movement. The also provided locations for early site names. The literature collection and files of the late Dr. W.L. Minckley at Arizona State University were made available to us and yielded substantial data and documents. Information on early work and collectors was provided by a variety of biologists and others involved in southwestern fishes.

The SONFISHES database was used to identify all sampling events at Aravaipa Creek that resulted in deposition of museum specimens (Arizona State University 2002, Unmack 2002a). For some sampling events there are both documents (published or gray) and museum specimens. For those, documents were used preferentially because of their more complete information. All entries for Aravaipa Creek from SONFISHES are located in Appendix 3. This database includes all known museum records for fishes from Aravaipa Creek, records from primary literature, and data from AGFD.

Fish data for Aravaipa Creek has conventionally been subdivided into three reaches based on topography (Minckley 1981, Meffe and Minckley 1987). Our analysis follows that convention. The reaches are identified in Table 1 and shown in Figures 3, 4, and 5, along with all site names used by various efforts to describe fish sampling locations within those reaches.

The SONFISHES database, summary tables of Minckley's long-term data set (Minckley 2000), and a collection of various literature and documents were used to construct a history of Aravaipa Creek fish sampling efforts, by lower, middle, and upper reach. The literature and documents used for specific sampling events are listed in Appendix 1.

Drafts of the sampling chronology, lists of studies, literature, funding, and conservation actions were reviewed by a number of people presently or historically involved with Aravaipa Creek fishes, to help identify missing documents or gaps in information.

TABLE 1
STANDARD REACH DEFINITIONS FOR ARAVAIPA CREEK FISH SAMPLING

REACH NAMES	LOCATION DEFINITION	STANDARD SAMPLING SITES WITHIN THE REACH	OTHER SAMPLING SITE NAMES WITHIN REACH
eastern east end upper above canyon reach 1 (Minckley unpub.) reach III (Williams 1991a)	"headwaters to above Turkey Creek confluence (not including Turkey Creek site)"Minckley (1990); "above and not including the mouth of Turkey Creek" (Minckley 2000).	TNC guest house (Pecan grove) The Chimney (or Chimney Rock) stations 14-16 (Barber and Minckley 1966) stations 24-27 (Minckley 1972-73, Schreiber 1975) stations 7-9 (Minckley and Karp 1986) stations 1-2 (Velasco 1997) sites 1-2 (Reinthal unpub.)	west of Klondyke near headwaters (near source) E. boundary of USFS/TNC properties (prob. meant BLM/TNC boundary) School House Tapia diversion Salazar Ranch Bear Canyon Crossing Goat Cave Crossing Bill's Crossing (last crossing above Wilderness) Bill Salazar's house Wilderness area (WA) parking lot) above Turkey Creek east end gauge (BLM) head of box canyon NW of Klondyke
middle canyon within canyon within gorge reach 2 (Minckley unpub.) reach II (Williams 1991a)	"from Turkey Creek confluence (including Turkey Creek site) to Wagner Ranch" (Minckley 1990, Minckley 2000) including "wilderness" subdivision by Velaso (1993a) and AGFD (Bettaso et al. 1995) – areas within designed Wilderness boundaries	Turkey Creek* (station 13) Hell Hole (Deer Creek or Old Deer Creek) Horse Camp Painted Cave Wagner Ranch* (Coleman Ranch) stations 8-13 (Barber and Minckley 1966) stations 9-21 (Minckley 1972-73, Schreiber 1975) stations 4-6 (Minckley and Karp 1986) stations 3-4 (Velasco 1997) sites 3-6 (Reinthal unpub.)	mouth of Turkey Creek west of Turkey Creek TNC/BLM wilderness boundary western visitors entrance to Wilderness upper (or east) boundary of Wilderness or primitive area Parsons Canyon Paisano Canyon Booger Canyon Virgus Canyon Javelina Canyon warm springs area of Aravaipa** Hell's Half Acre Canyon
western west end lower below canyon reach 3 (Minckley unpub.) reach I (Williams 1991a)	"Wood's Ranch to San Pedro River" (Minckley 1990) or "to near mouth" (Minckley 2000)	White's Ranch (Jeb, Jay, or Peggy White's house) Sycamore tree (now fish barriers, upper and lower) stations 1-7 (Barber and Minckley 1966) stations 1-8 (Minckley 1972-73, Schreiber 1975) stations 1-3 (Minckley and Karp 1986) stations 5-6 (Velasco 1997) sites 7-9 (Reinthal unpub.)	Wood's Ranch (Panorama Ranch) west end gauge (BLM) La Jolla Ranch (TNC headquarters, West Car Ranch) Brandenburg Wash or road Holy Joe Ranch diversion Dr. Geldmacher's ponds Aravaipa Farms or Ranch USGS gauge Newton Ranch end of paved road Highway 77 (Winkleman-Mammoth road) junction with San Pedro River NE of Mammoth ENE of Feldman

* The Turkey Creek and Wagner Ranch sites are included in the middle reach by Arizona State University and others. In 1992-95 sampling data AGFD also includes them as middle, but their 1999-2000 data are reported with the Turkey Creek site included in the upper reach and the Wagner Ranch site included in the lower reach.
** This was the description of a University of Arizona 1972 sampling site and apparently refers to near Painted Cave Canyon, where there are warm springs.

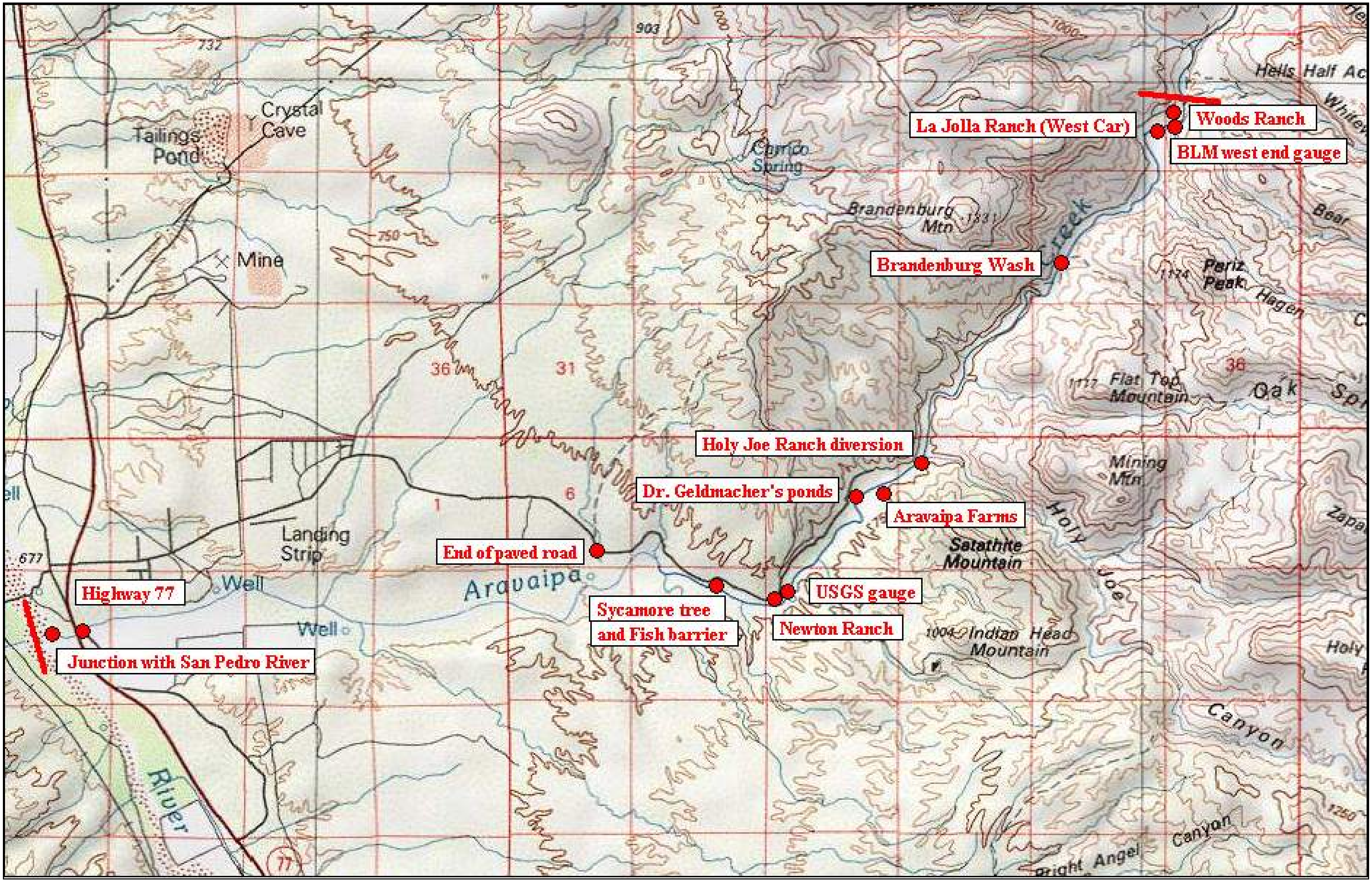


Figure 3. Lower (West) Reach of Aravaipa Creek
with Fish Sampling Site Names

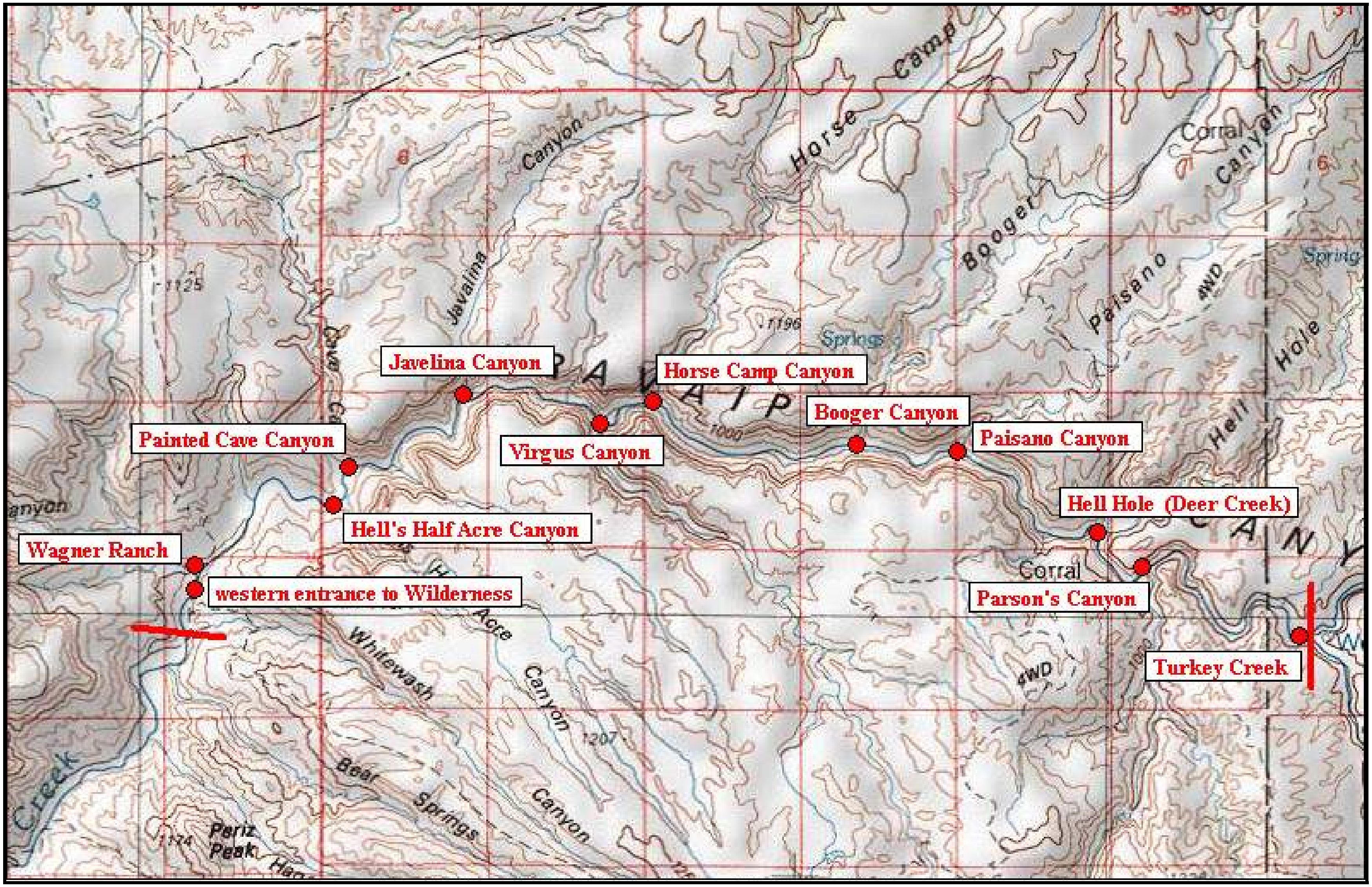


Figure 4. Middle (Canyon) Reach of Aravaipa Creek with Fish Sampling Site Names

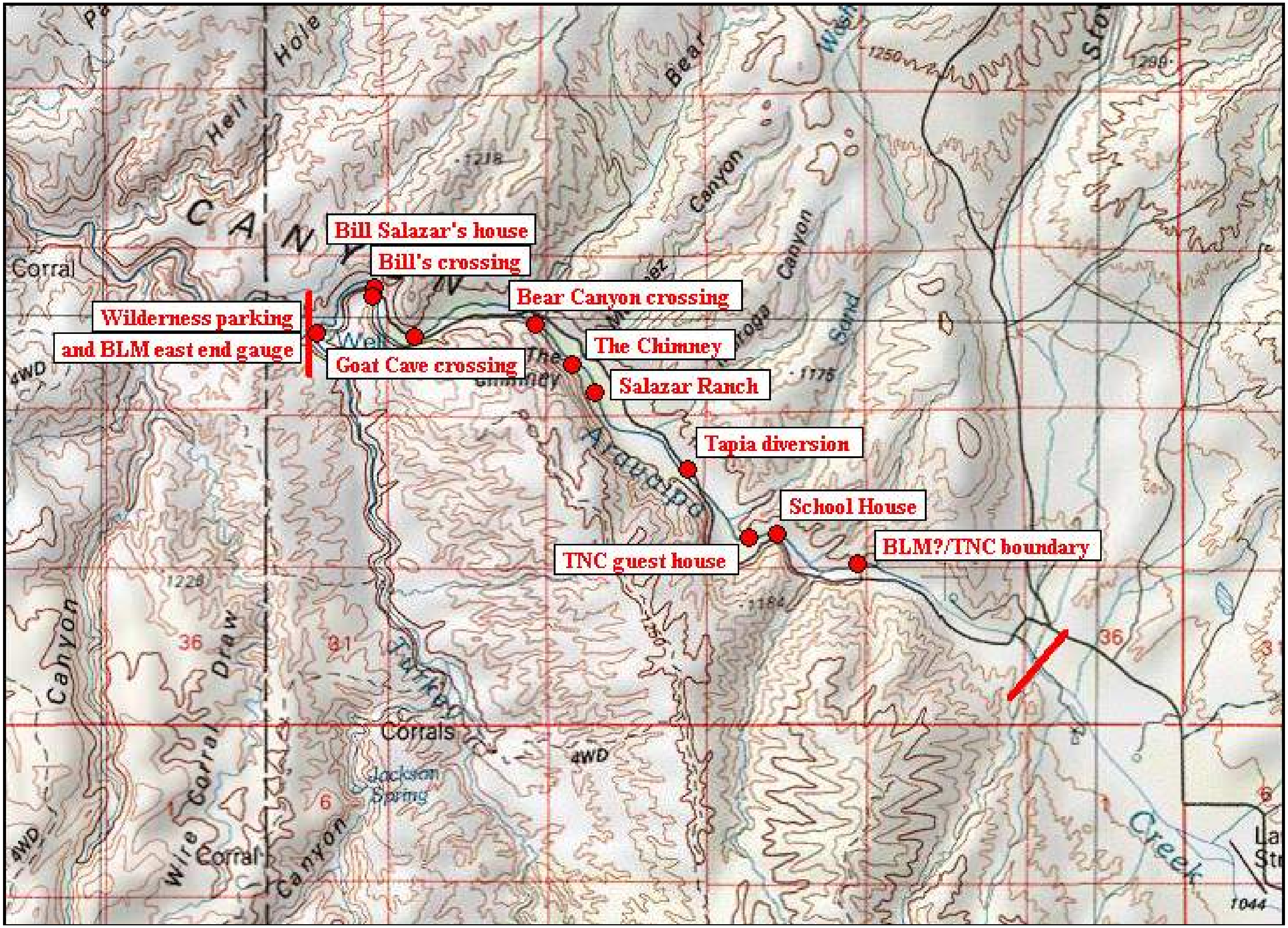


Figure 5. Upper (East) Reach of Aravaipa Creek
with Fish Sampling Site Names

HISTORICAL CHANGES AND HUMAN ACTIVITIES

Historical information on Aravaipa Creek has been reviewed by Cooke and Reeves (1976) from an erosional perspective, Minckley (1981) from an ecological perspective, Hadley et al. (1991) from an ethnoecological perspective, and JE Fuller Hydrology and Geomorphology (2000) from a hydrological and geomorphological perspective. Syntheses of early descriptions of Arizona places and natural resources that contain information on Aravaipa Creek include (Dobyns 1981, Davis 1986, Bahre 1991, Tellman et al. 1997).

The Aravaipa Creek area supported extensive Native American occupation by Hohokam, Mogollon, and Salado cultures. When Spaniards arrived in the 1500's, the area was occupied by agricultural Pima and Sobaipuri, but disruption of those cultures in the mid-1700's by European-caused changes, resulted in occupation of the area being taken over by Apache (Hadley et al. 1991). European settlement of the area did not become significant until the mid-1800's when Camp Grant was set up near the confluence of Aravaipa Creek and the San Pedro River, and later moved to the upper Aravaipa Valley. In this period, several accounts of travelers through the area contain descriptions of Aravaipa Creek, including (Hutton 1853, Parke 1857, Leach 1858, Bell 1869).

Ecologically, Aravaipa Creek remains generally similar to the stream in the 1800's. The greatest change has been loss of extensive cienega in the lower end of the upper valley, between Klondyke and the canyon (Minckley 1981, Hendrickson and Minckley 1984). Leopold (1951) is one of the earliest pieces of literature discussing change, where he briefly mentions the loss of the cienega in upper Aravaipa Creek as part of a larger discussion of vegetation changes throughout the southwest.

Early accounts indicate that the lower reach of Aravaipa Creek, near the San Pedro River, was often dry (Bourke 1980). However, the marshy area at the confluence of the two streams was such a source of malaria that a convalescence camp for soldiers from Camp Grant had to be established away from the river bottom (Hastings 1959).

The first documented era of ecological change in Aravaipa Creek accompanied European settlement, with ranches, farms, and mines established throughout the valley bottom and watershed. This resulted in the loss of the cienega, a downstream migration of the origin of perennial flow, extirpation of beaver, and changes in species composition, abundance and distribution of riparian vegetation (Minckley 1981, Hadley et al. 1991). Gradual drying of springs and tributary streams has also been reported.

A second era of ecological change along Aravaipa Creek occurred in the 1960's, when human population along Aravaipa Creek was declining. Hadley et al. (1991) report that local residents say prior to 1963 flooding, the creek had always been unincised and stable with a predominantly sandy bottom and large pools. The stream bed was commonly used as a roadway for horses and wagons with only one problematic drop-off in the canyon. Trucks were also driven through and in 1964 W.L. Minckley drove a 1955 Chevy through the canyon without difficulty. By the early

1970's downcutting and lateral cutting was occurring in areas, gravel was becoming a major proportion of the substrate, and deep holes were filling in. In the 1983 flood, substantial sediment was moved through and out of Aravaipa Creek, leaving a substrate of larger average size, ranging from gravel to boulder. These changes are related to earlier agricultural and road practices, long-term watershed alteration, and flood cycles (JE Fuller Hydrology and Geomorphology 2000).

At present, irrigated agriculture still occurs along the perennial portion of the stream, although much reduced from that of the mid-1900's. Livestock grazing occurs on much of the private and BLM lands, but is primarily cattle, with some horses and sheep. The large-scale goat ranching of the 1920-30's no longer occurs. Ranchette subdivision is increasing and a substantial proportion of the private parcels on the lower (west) end of Aravaipa Creek are second homes (Pinal County Assessor at http://apps.co.pinal.az.us/Assessor). At least one bed-and-breakfast operation is present. Recreational use of the Canyon is heavy, with vehicle-oriented picnicking, camping and general recreation along the east and west ends, and hiking and backpacking through the canyon. High clearance and 4-wheel drive roads limit access on the tablelands, but hunting, camping, and hiking occur at moderate levels. BLM maintains a ranger station on the west end.

FISHES OF ARAVAIPA CREEK

The perennial portion of the stream, plus a few tributaries, are presently the only known locations for native fishes in the Aravaipa watershed. The historical presence of perennial water in a larger portion of the upper reach has already been discussed and would have furnished a larger area and diversity of habitats for fish occupation than at present. Today, the presence of perennial water in a flowing, unregulated stream is a rare occurrence in the Gila River basin. The presence of an intact, or relatively intact, native fish assemblage is an even rarer occurrence, and Aravaipa Creek has both. Robust populations of seven native fish persist in Aravaipa Creek (see Table 2) making it one of the premier native fish habitats in the Gila River basin (Williams et al. 1985) and in Arizona.

In addition to seven native fishes presently found in Aravaipa Creek, five other native fishes have been recorded from the San Pedro River (Jackson et al. 1987) and may have once been present in Aravaipa Creek (Barber and Minckley 1966) (see Table 3). However, Colorado squawfish, and razorback and flannelmouth suckers disappeared from the river before 1900, much earlier than the first Aravaipa Creek fish sampling. Because of the lack of early fish records, it cannot be conclusively known whether those three species ever used Aravaipa Creek. As larger-bodied species they may have been limited to the lower portion of Aravaipa Creek, moving in and out during periods of connection with the San Pedro River, or using it for spawning or larval and juvenile habitat, such as flannelmouth sucker presently does in the Grand Canyon area (Otis 1994).

TABLE 2
EXTANT NATIVE FISHES
OF ARAVAIPA CREEK

FAMILY	COMMON NAME	SCIENTIFIC NAME	FEDERAL STATUS*
Cyprinidae	longfin dace	*Agosia chrysogaster*	2
Cyprinidae	speckled dace	*Rhinichthys osculus*	2
Cyprinidae	spikedace	*Meda fulgida*	T
Cyprinidae	loach minnow	*Tiaroga cobitis*	T
Cyprinidae	roundtail chub	*Gila robusta*	PE
Catastomidae	desert sucker	*Pantosteus clarki*	2
Catastomidae	Sonora sucker	*Catostomus insignis*	2

TABLE 3
EXTIRPATED PROBABLE NATIVE FISHES
OF ARAVAIPA CREEK

FAMILY	COMMON NAME	SCIENTIFIC NAME	FEDERAL STATUS*
Cyprinidae	Colorado squawfish	*Ptychocheilus lucius*	E
Catostomidae	razorback sucker	*Xyrauchen texanus*	E
Catostomidae	flannelmouth sucker	*Catostomus latipinnis*	2
Poeciliidae	Gila topminnow	*Poeciliopsis occidentalis*	E
Cyprinodontidae	desert pupfish	*Cyprinodon macularius*	E

*E = endangered; T= threatened; PE = petitioned for endangered; 2 = formerly on the FWS category 2 list, which contained those species for which indication existed that Federal listing might be warranted, but for which sufficient information was not yet available to make that determination. That list was abandoned by the USFWS in 1996.

Desert pupfish and Gila topminnow survived in the San Pedro basin until the 1950's and 1970's, respectively, but only in very localized areas. Historical cienega conditions above the canyon in Aravaipa Creek would have provided extensive habitat for both topminnow and pupfish, but that habitat disappeared before the first documentation of Aravaipa fishes. It is also likely that suitable habitat occurred in floodplain marshes and backwaters that were drained and filled for agricultural uses. Specimens from lower Aravaipa Creek sent to the University of Michigan in 1943 contained a Gila topminnow, however, it was assumed to be an accidental contaminant from an accompanying shipment of Gila topminnow specimens from Tanque Verde Creek, near Tucson (Simon et al. 1943). Unsuccessful efforts to reintroduce Gila topminnow are discussed later in the history of conservation actions.

As with all streams of the southwest, nonnative fish have been introduced or spread in Aravaipa Creek. Nine species of nonnative fish have been recorded from Aravaipa Canyon (see Table 4). Five of those species are known to have become established, with reproducing, self-sustaining populations. Three others are found only as isolated individuals and it is not known if they are reproducing in Aravaipa Creek or are being periodically introduced through unauthorized stocking, escape from stock tanks and residential ponds, or upstream migration from the San Pedro River. One has been found only in off-channel ponds.

TABLE 4 NONNATIVE FISHES OF ARAVAIPA CREEK				
FAMILY	COMMON NAME	SCIENTIFIC NAME	ESTAB-LISHED	YEAR FIRST RECORDED IN STREAM
Centrarchidae	Green sunfish	*Lepomis cyanellus*	Y	1963
Centrarchidae	Largemouth bass	*Micropterus salmoides*	?	1963
Ictaluridae	Yellow bullhead	*Ameiurus natalis*	Y	1963
Poeciliidae	Western mosquitofish	*Gambusia affinis*	Y	1981
Cyprinidae	Fathead minnow	*Pimephales promelas*	Y	1983
Cyprinidae	Common carp	*Cyprinus carpio*	?	1988
Cyprinidae	Red shiner	*Cyprinella lutrensis*	Y	1990
Ictaluridae	Black bullhead	*Ameiurus melas*	N	1990
Ictaluridae	Channel catfish	*Ictalurus punctatus*	N	1991 - in pond

Although Aravaipa Creek presently has fewer species and numbers of nonnatives than most streams in the Gila River basin, the number of species continues to rise. In 1981, Minckley (page 201) was able to say "No alien fish species has yet established a reproducing population for more than a year or two." Twenty-three years later at least five have done so. In 1981, only two species, green sunfish and largemouth bass, were found in the mainstream of Aravaipa Creek. Yellow bullhead and mosquitofish were present in stock tanks and ponds, but not the stream. Now all four are routinely found in the mainstream (although bass are not common), and four additional species have invaded (fathead minnow, red shiner, common carp, and black bullhead). Channel catfish have only been found in ponds alongside the stream and have not yet been documented in the creek.

Because of the large proportion of the stream under conservation-oriented management, the unregulated flow, the relatively intact native fish community, and the relative paucity of nonnative fish species, Aravaipa Creek is often called the "crown jewel" of native fish in Arizona. Aravaipa Creek is an irreplaceable and highly valuable native fish resource. However, it is only one of several, with others having more remaining native fish species or longer occupied stream length (see Table 5). Only two Arizona and Gila basin streams retain more native fish species than Aravaipa Creek. The upper Gila River in New Mexico (including West and East Forks) retains more native species and also has a longer stream length over which those species are found. Like Aravaipa Creek, all native species are still routinely encountered in sampling efforts. Eagle Creek, although it has more species and more length than Aravaipa Creek, is much more highly altered and two of its eight remaining native fishes are seldom encountered during sampling. Three other streams retain six original native fishes, and an additional ten streams retain five native species each.

What sets Aravaipa Creek apart is not just the number of native fish species, but also the relatively few well-established nonnative fishes, the relatively unaltered stream condition, high level of protection, and extensive data on the stream and its fishes. Thanks to the long period of collection, the high level of research, and continuity of the monitoring, more is known about the native fish community of Aravaipa Creek than any other stream in the Gila River basin.

TABLE 5
REMNANT NATIVE FISH COMMUNITIES IN THE GILA RIVER BASIN
RETAINING FIVE OR MORE NATIVE SPECIES
(not including species extirpated and then reintroduced)

STREAM	NO. OF NATIVE FISH SPECIES REMAINING	NO. OF NATIVE FISHES COMMONLY FOUND DURING ROUTINE SAMPLING [1]	APPROX. LENGTH OF WATER OCCUPIED BY NATIVE FISHES ASSEMBLAGE (miles)
Gila River, upper (NM) (inc. East and West Forks)	8	8	120
Eagle Creek	8	6	40
Aravaipa Creek	7	7	20
Fossil Creek	6	5	15
White River (inc. East & North Forks)	6	4*	40
Verde River, upper (above Verde Valley)	6	3	40
San Francisco & Tularosa Rivers	5	5	125
Blue River (inc. Campbell & Dry Blue)	5	5	60
Black River (upper) (inc. East Fork)	5	5	35
Bonita Creek	5	5	35
Hot Springs and Bass Canyons	5	5	15
Redfield Canyon	5	4	15
Sonoita Creek (below Patagonia Dam)	5	4	10
Verde River, Verde Valley to Horseshoe Reservoir	5	4	80
Cherry Creek	5	4	40
Canyon Creek	5	4*	45
Tonto and Rye Creeks	5	3	45

[1] Some species may be found only in local areas within the total reach, but are common in those locations.
* Recent sampling records are unavailable outside of the White Mountain Apache Tribe.

HISTORY OF FISH SAMPLING AND MONITORING

Fish in Aravaipa Creek have been sampled more frequently and over a longer term than any other native fish community in the Gila River basin. Nonnative sport fish, and to a lesser extent native trouts (as sport fish), have been frequently and continuously monitored since game and fish agencies were established in the early 1900's. However, native fish management in the basin was virtually nonexistent until the late 1970's or early 1980's (Rinne and Janisch 1995). Even academic studies, such as ones ongoing in Aravaipa Creek, were rare and usually of short duration.

Several other long-term data sets exist for Gila River basin native fishes, such as for the upper Gila River in New Mexico from 1988 to present (Propst 2002, J. Stefferud, pers. com. June 2004), Eagle Creek from 1987 to present (Marsh et al. 1990, P. Marsh, pers. com. June 2004), upper San Pedro River from 1990 to present (Stefferud and Stefferud 2003), Redrock Canyon and San Rafael Valley springs from 1988 to present (Stefferud and Stefferud 1993, Stefferud and Stefferud unpub. data), and upper Verde River from 1994 to present (Rinne et al. 1999). But, the longest of those is only 17 years, as compared to 41 years of monitoring at Aravaipa Creek.

Tables 6-9 depict the sampling history of Aravaipa Creek, separated by lower, middle, and upper reaches, and tributaries and isolated waters. Data sources are in Appendices 1 and 2. There are undoubtedly other sampling events unrecorded or for which records were not found (e.g. fish for taxonomic and genetic studies and not accessioned as museum specimens). However, most would be one-time events, mainly to obtain fish specimens for a specific study, and would not substantially alter the total picture of the sampling and monitoring history in Aravaipa Creek.

<table>
<tr><th colspan="2">THE FOLLOWING LEGEND APPLIES TO TABLES 6-9</th></tr>
<tr><td colspan="2">*indicates that ASU data exist for this year in Minckley's annual data set, but the month of sampling is unknown.
Blue italic font indicates data from the ASU SONFISHES or AGFD permit databases
Black regular font indicates data from a document</td></tr>
<tr><td>(yellow)</td><td>Yellow highlight indicates the ASU/UA biannual long-term sampling/monitoring.</td></tr>
<tr><td>(purple)</td><td>Purple highlight indicates monitoring under the October (Fall) Fish Count.</td></tr>
<tr><td>(green)</td><td>Green highlight indicates monitoring of BLM and TNC lands (performed by ASU, AGFD, TNC, and BLM).</td></tr>
<tr><td>(blue)</td><td>Blue highlight indicates monitoring specifically for the fish barriers.</td></tr>
<tr><td>ACVF = Arizona Conservation Voters Habitat Fund
ASU = Arizona State University
BLM = U.S. Bureau of Land Management
BR = U.S. Bureau of Reclamation
FWS = U.S. Fish and Wildlife Service
GF = Arizona Game and Fish Department
Multi = multiple entities
NMSU = New Mexico State University</td><td>OFC = October (or Fall) Fish Count
Smith. = U.S. National Museum, Smithsonian
TUL = Tulane University
UA = University of Arizona
UMMZ = University of Michigan Museum of Zoology
UNLV = University of Nevada, Las Vegas
USFS = U.S. Forest Service</td></tr>
<tr><td colspan="2">Codes used following the initials of the sampling entity (following a slash) indicate the following sampling purposes:
BM = barrier monitoring
M = monitoring
RS = search for red shiner

No initials after the slash indicates that sampling was for research, administrative studies, or other purposes.</td></tr>
</table>

TABLE 6
CHRONOLOGY OF SAMPLING EVENTS -- ARAVAIPA CREEK, LOWER
(Wood's Ranch to San Pedro River)

YEAR	MONTH											
	JAN.	FEB.	MAR.	APR.	MAY	JUNE	JULY	AUG.	SEPT.	OCT.	NOV.	DEC.
1943										UA		
1944												
1945												
1946												
1947												
1948												
1949		UA			Cornell					UA		
1950												
1951												
1952					UA							
1953												
1954												
1955										UA		
1956												
1957												UA
1958												UA
1959			UA	UA		UA						UA
1960												
1961										UA		
1962												
1963				ASU						ASU		
1964				ASU/M ASU		ASU		ASU		ASU	ASU ASU	ASU
1965		ASU		ASU/M	UA		ASU			ASU/M		
1966						ASU ASU	ASU ASU	ASU ASU	ASU	ASU ASU	ASU UA ASU	ASU ASU
1967	ASU	ASU ASU	ASU	ASU	ASU	ASU	ASU		ASU			
1968												
1969				ASU UNLV								
1970	*				UA							
1971						TUL						
1972				ASU/M ASU	ASU/M							
1973									ASU			
1974											ASU/M	
1975				ASU/M						ASU/M		
1976			ASU/M							ASU/M ASU		
1977		ASU		ASU/M ASU			ASU		ASU	ASU/M	ASU	ASU ASU
1978	ASU ASU	ASU	ASU ASU	ASU/M ASU	ASU ASU	ASU ASU	ASU ASU	ASU ASU	ASU ASU	ASU/M ASU	ASU	
1979		ASU	ASU/M ASU	ASU	ASU	ASU	ASU		ASU		ASU/M	
1980	ASU		ASU/M							ASU/M		

TABLE 6
CHRONOLOGY OF SAMPLING EVENTS -- ARAVAIPA CREEK, LOWER
(Wood's Ranch to San Pedro River)

YEAR	MONTH											
	JAN.	FEB.	MAR.	APR.	MAY	JUNE	JULY	AUG.	SEPT.	OCT.	NOV.	DEC.
1981				ASU/M						ASU/M		
1982												
1983				ASU/M *ASU*						ASU/M		
1984			ASU/M							ASU/M		
1985			ASU/M		FWS					ASU/M		
1986				ASU/M						ASU/M		
1987			ASU/M ASU	*ASU* ASU	ASU	ASU	ASU	ASU		ASU/M		
1988				ASU/M			*ASU*			ASU/M OFC		
1989		ASU	ASU	ASU/M ASU	ASU	ASU	ASU	ASU	ASU	ASU/M ASU	*GF* ASU OFC	
1990	ASU	ASU	ASU/M ASU			ASU			OFC	ASU/M Multi/RS		
1991		ASU/M	ASU/M	ASU/M	ASU/M	ASU/M	ASU/M	ASU/M	ASU/M	ASU/M *GF*	ASU/M	ASU/M
1992	ASU/M	ASU/M	ASU/M	ASU/M	ASU/M	ASU/M	GF/M	GF/M		ASU/M	GF/M	GF/M
1993	ASU/M	GF/M	GF/M	ASU/M	GF/M	GF/M	ASU/M *GF*	GF/M		ASU/M GF/RS	GF/M	
1994				ASU/M GF/M	GF	ASU/M				ASU/M		
1995				ASU/M				*ASU*		ASU/M	GF/RS	
1996				ASU/M						ASU/M		
1997				ASU/M						BLM & TNC/M	ASU/M *ASU*	
1998				ASU/M			GF/RS	*ASU*		ASU/M		
1999				ASU/M						ASU/M GF, TNC, & BLM/M	*ASU*	*ACVF*
2000			ASU	ASU/M ASU						ASU/M	GF/M	
2001				ASU/M			BR/BM				ASU/M	
2002				ASU/M			UA	GF		UA/M BR/BM		
2003				UA/M					UA/M	BR/BM		
2004				UA/M					BR/BM	UA/M		

TABLE 7
CHRONOLOGY OF SAMPLING EVENTS --ARAVAIPA CREEK, MIDDLE
(Turkey Creek confluence to Wagner Ranch)

YEAR	MONTH											
	JAN.	FEB.	MAR.	APR.	MAY	JUNE	JULY	AUG.	SEPT.	OCT.	NOV.	DEC.
1950					UMMZ							
1951												
1952												

TABLE 7
CHRONOLOGY OF SAMPLING EVENTS --ARAVAIPA CREEK, MIDDLE
(Turkey Creek confluence to Wagner Ranch)

YEAR	MONTH											
	JAN.	FEB.	MAR.	APR.	MAY	JUNE	JULY	AUG.	SEPT.	OCT.	NOV.	DEC.
1953			*UA*									
1954		*UA*										
1955		*UA*										
1956			*UA*									
1957			*UA*			*UA*						
1958												
1959												
1960			*UA*	*UA*								
1961												
1962												
1963												
1964				*ASU*							*ASU*	*ASU*
1965		*ASU*		ASU/M	*ASU*					ASU/M		
1966		*ASU*				*ASU* ASU	*ASU* ASU	*ASU* ASU	*ASU* ASU	*ASU* ASU	*ASU* ASU	*ASU* ASU
1967	*ASU* ASU	*ASU* ASU	*ASU* ASU	*ASU* ASU	*ASU* ASU	*ASU* ASU	*ASU* ASU	*ASU*				
1968												
1969	*											
1970				ASU/M						ASU/M		
1971												
1972		ASU/M		ASU/M *ASU*	ASU/M *ASU*					ASU/M		
1973				ASU/M	ASU/M				ASU/M *ASU*	ASU/M	*ASU*	
1974				ASU/M						ASU/M	ASU/M *ASU*	
1975				ASU/M						ASU/M *ASU*	*ASU*	
1976	*ASU*		ASU/M *GF*							ASU/M *ASU*	*ASU*	
1977							*ASU*		*ASU*			
1978	ASU	ASU	ASU	ASU/M ASU			ASU		ASU	ASU/M ASU	ASU	
1979		ASU	ASU/M	ASU		ASU				ASU/M		
1980				ASU/M						ASU/M		
1981				ASU/M						ASU/M		
1982				ASU/M						ASU/M		
1983				ASU/M					*ASU*	ASU/M GF		
1984			ASU/M							ASU/M		
1985					FWS					ASU/M		
1986	*											
1987			*ASU*	ASU/M	ASU					ASU/M		
1988			ASU/M						*GF*	ASU/M		

TABLE 7
CHRONOLOGY OF SAMPLING EVENTS --ARAVAIPA CREEK, MIDDLE
(Turkey Creek confluence to Wagner Ranch)

YEAR	MONTH											
	JAN.	FEB.	MAR.	APR.	MAY	JUNE	JULY	AUG.	SEPT.	OCT.	NOV.	DEC.
1989		ASU	ASU	ASU/M ASU	ASU	ASU	ASU	ASU	ASU	ASU/M ASU GF	ASU	ASU
1990	ASU	ASU	ASU	ASU/M		ASU			OFC	ASU/M Multi/RS	GF/RS	
1991		ASU/M	ASU/M	ASU/M	ASU/M	ASU/M	ASU/M	ASU/M	ASU/M	ASU/M	ASU/M	ASU/M
1992	ASU/M	ASU/M	ASU/M	ASU/M	ASU/M	ASU/M	GF/M	GF/M		ASU/M	GF/M	GF/M
1993	ASU/M		GF/M	ASU/M	GF/M	GF/M		GF/M		ASU/M GF/RS		GF/M
1994				ASU/M GF/M		ASU/M				ASU/M		
1995	ASU			ASU/M						ASU/M		
1996				ASU/M						ASU/M		
1997				ASU/M						ASU/M BLM & TNC/M		
1998	ASU			ASU/M		GF/RS	GF, TNC/RS			ASU/M		
1999				ASU/M						ASU/M GF, TNC & BLM/M		
2000				ASU/M						ASU/M	GF/M	
2001				ASU/M							ASU/M	
2002			UA	ASU/M				UA		UA/M		
2003				UA/M		UA			UA/M			
2004				UA/M						UA/M		

TABLE 8
CHRONOLOGY OF SAMPLING EVENTS
ARAVAIPA CREEK, UPPER
(Headwaters to above Turkey Creek confluence)

YEAR	MONTH											
	JAN.	FEB.	MAR.	APR.	MAY	JUNE	JULY	AUG.	SEPT.	OCT.	NOV.	DEC.
1960					UA							
1961												
1962												
1963												
1964											ASU	ASU
1965				ASU/M	ASU					ASU/M		
1966			ASU			ASU	ASU	ASU	ASU	ASU	ASU	ASU
1967	ASU	ASU	ASU	ASU	ASU	ASU	ASU	ASU	ASU		ASU	
1968												
1969					ASU							
1970	#											
1971												
1972				ASU/M	ASU/M							
1973				ASU/M	ASU/M				ASU/M ASU			
1974											ASU/M ASU	
1975	ASU			ASU ASU/M			ASU			ASU ASU/M		
1976	ASU		ASU/M GF						ASU	ASU/M ASU	ASU	
1977		ASU	FWS GF	ASU			ASU		ASU ASU	ASU ASU	ASU	ASU ASU
1978	ASU ASU	ASU ASU	ASU ASU	ASU/M ASU	ASU	ASU ASU	ASU	ASU ASU	ASU	ASU/M	ASU	
1979			ASU/M	ASU		ASU					ASU/M	
1980	*				NMSU							
1981			NMSU	ASU/M			NMSU	NMSU			ASU/M	
1982		ASU/M							ASU/M			USFS
1983	ASU			ASU/M USFS				USFS	ASU/M			
1984		USFS	ASU/M				USFS		USFS		ASU/M	
1985										ASU/M		
1986				ASU/M	USFS						ASU/M	
1987				ASU/M				ASU		ASU/M		
1988				ASU/M					OFC GF	ASU/M		
1989			ASU	ASU/M ASU				ASU		ASU/M GF OFC		

TABLE 8
CHRONOLOGY OF SAMPLING EVENTS
ARAVAIPA CREEK, UPPER
(Headwaters to above Turkey Creek confluence)

YEAR	MONTH											
	JAN.	FEB.	MAR.	APR.	MAY	JUNE	JULY	AUG.	SEPT.	OCT.	NOV.	DEC.
1990		ASU	ASU	ASU/M		ASU			OFC	ASU/M	GF/RS	
1991		ASU/M GF	ASU/M	ASU/M	ASU/M	ASU/M ASU	ASU/M	ASU/M	ASU/M	ASU/M	ASU/M	ASU/M
1992	ASU/M	ASU/M	ASU/M	ASU/M	ASU/M TNC/ Smith.	ASU/M	GF/M	GF/M		ASU/M	GF/M	GF/M
1993	ASU/M	GF/M	GF/M	ASU/M	GF/M	GF/M	ASU/M	GF/M		ASU/M GF/RS	GF/M	
1994				ASU/M GFM		ASU/M				ASU/M		
1995				ASU/M						ASU/M		
1996	ACVF			ASU/M						ASU/M	BLM	
1997				ASUM		GF				ASU/M BLM & TNC/M FWS		
1998	ASU			ASU/M		GF/RS	GF, TNC/RS			ASU/M		
1999				ASU/M						ASU/M GF, TNC & BLM/M		
2000			ASU	ASU/M ASU						ASU/M	GF/M	
2001				ASU/M							ASU/M	
2002			UA	ASU/M		UA		UA	GF UA	UA/M		
2003				UA/M		UA			UA/M			
2004				UA/M						UA/M		

Mainstem Aravaipa Creek Sampling

Local residents of the 1880's and early 1900's, and Native Americans before that, ate fish from Aravaipa Creek. Colorado squawfish and razorback sucker remains were excavated from trash middens at Quibuiri, a Sobaipuri settlement on the upper San Pedro River north of Fairbank (Miller 1961, Minckley 1987). European settlers caught and ate the plentiful and easily caught larger-bodied species of fish, which they called as “suckers” or “catfish” (desert and Sonora sucker) and “mudfish” or “Aravaipa trout” (roundtail chub) (Hadley et al. 1991). Smaller-bodied fish were called “minnow.” They were caught only as bait and a 1930's commercial effort seined and transported thousands of Aravaipa Creek minnows to San Carlos Lake to sell as bait (Hadley et al. 1991). No records to species resulted from pre-1940's uses of Aravaipa fishes.

The first recorded fish sampling in Aravaipa Creek was in October 1943, by James R. Simon of the Naval Training School of the University of Arizona and two students John R. Hendrickson, and Marvin H. Frost, Jr. (see Appendices 1 and 2). Their sample locations were on the lower end of Aravaipa Creek and were described as "11-14 miles ENE of the Winkleman-Feldman road." Feldman was located on the east side of the San Pedro River about 2 miles north of Aravaipa Creek, near what is now known as Cook's Lake (Barnes 1988). Hendrickson, Simon, and Frost recorded all seven of the native fishes that are still present. Interestingly, John Hendrickson is the uncle of Dean Hendrickson who participated in Aravaipa Creek work in the 1980's and 90's, as a student at ASU and later as an employee of AGFD.

In 1949, W.I. Follett, of the California Academy of Sciences, sampled lower Aravaipa Creek "12 6/10 miles from Winkleman." His specimens, deposited at Cornell, indicate a co-collector R.C. Snyder. Snyder's identity could not be determined, but he made a collection by himself in May and deposited it at UofA, indicating a possible affiliation. Follett and Snyder obtained all seven native fish species.

Also sampling Aravaipa Creek in 1949 was R.J. Hock, from the UofA. His museum specimens give his location only as Aravaipa Creek, Pinal County. He collected longfin dace and desert sucker.

From March through June 1950, Robert R. and Fran H. Miller, Howard E. Winn, and the Miller children made a fish collecting trip through the lower Colorado River basin in Arizona, California, Baja California, and Sonora (Miller et al. 1991). One of their stops was upper Aravaipa Creek near the confluence with Turkey Creek and "near the head of box canyon NW of Klondyke flood tributary," where they collected all seven fish species.

The UofA became interested in Aravaipa Creek in the early 1950's and several students and staff made collections. Robert A. Jantzen, later the Director of AGFD and then FWS, collected longfin dace and loach minnow from lower Aravaipa Creek in 1952, apparently as a student. Charles H. Lowe, a longtime professor at the UofA and his student Wallace G. Heath, collected in lower and middle Aravaipa Creek from 1953-60 (Barber and Minckley 1966). Records show that some of Lowe's trips were a class effort, indicating that use of students to sample Aravaipa Creek is a 50-year tradition.

In 1963, Wendell L. Minckley arrived at Arizona State University as an Assistant Professor of Zoology (Collins et al. 2002). He and his students began to sample Aravaipa Creek in 1963, as part of classwork and studies. Minckley began to accumulate a long-term monitoring data set for Aravaipa Creek through repeated standardized sampling. As seen in Tables 6-8, ASU sampling in upper, middle, and lower Aravaipa Creek has occurred frequently from 1963 to 2002. Following Minckey's death in 2001, long-term monitoring is being continued at the UofA, by one of the authors.

Post-1963 fish sampling in Aravaipa Creek can be divided into seven categories; 1) sampling for specific studies, 2) ASU/UofA long-term monitoring, 3) October (Fall) Fish Count, 4) post-1990

TNC/BLM monitoring, 5) monitoring of the fish barriers, 6) searches specifically for red shiner, and 7) miscellaneous.

1. Specific studies. Sampling for studies will be discussed in the later section on Research History. As you will note in Tables 6-8, there are several periods of intensive sampling. Those generally represent specific study designs.

2. ASU/UofA long-term monitoring. Sampling events for the long-term ASU monitoring data set are highlighted in orange on Tables 6-8. Based on parameters such as season, sampling methodology, location, and personnel, Minckley identified 66 sampling events (he referred to them as "Trips") that he included in his long-term monitoring data for Aravaipa Creek (Minckley 2001). These were distributed between spring and autumn sampling periods and included upper, middle, and lower reach stations. The earliest event in the set was in the lower reach in spring 1964. Upper and middle reach monitoring began in spring 1965, along with continuation on the lower reach. There was then a hiatus of six years in the upper and lower reach data set and of four years in the middle reach data set, although other sampling was ongoing during the period.

In 1972, Minckley produced his first monitoring report on Aravaipa Creek fishes, with a survey of water quality factors, for BLM and The Defenders of Wildlife (DOW) (Minckley 1972). Their commissioning this work was probably in response to the 1969 establishment of the BLM Aravaipa Primitive Area and DOW acquisition of preserve lands. Minckley and his student Donald Schreiber also monitored fish in 1973 and 1974, the results of which Minckley (1981) cites as reports to the two organizations (Minckley 1973, Schreiber 1975). The 1973 report recommends building twice a year monitoring of Aravaipa Creek fishes into conservation plans.

Beginning in 1975 through present, the ASU monitoring (including recent UofA continuance) in the upper reach of Aravaipa Creek occurred each spring and autumn, with the exception of three years (1977 1980, and 1985). In the middle reach, the monitoring occurred each spring and autumn from 1970 through the present, with the exception of four years (1971, 1977, 1985, and 1986). In the lower reach, monitoring occurred each spring and autumn from 1975 through the present, with the exception of one year (1982). Monitoring in 1985 in the upper and middle reaches was conducted and was submitted as a report to BLM and the George Whittell Trust for Aravaipa Canyon in 1986 (Minckley and Karp 1986), but Minckley did not include these data in his long-term monitoring data set, for reasons not specified.

Thus, the ASU monitoring of Aravaipa Creek fishes spans a 41 year period, with data from 35 of those years. There has been almost-continuous monitoring of the middle reach over the last 35 years and over the upper and lower reaches for the last 30 years. There is no data-set of this magnitude for any other Arizona or Gila River basin fishes.

3. October (Fall) Fish Count. In 1988, AGFD and FWS initiated a monitoring effort as part of the October (or Fall) Fish Count. The Fish Count was an attempt to mimic the highly successful Christmas bird count, which uses volunteers to gather extensive long-term data. However, technical difficulties of fish sampling and permitting requirements doomed the Fish Count,

which lasted only until 1994. On Aravaipa Creek, October Fish Count efforts were undertaken in the upper and lower reaches in 1988-90 by volunteers along with biologists and students from AGFD, FWS, BLM, TNC, and ASU. The middle reach was included only in 1990. These sampling events are highlighted in purple on Tables 6-8.

4. Post-1990 TNC/BLM monitoring. This category consists of monitoring conducted in response to post-1990 concerns about red shiner invasion. It was initiated and funded by TNC and BLM and carried out by them or by AGFD or ASU. These sampling events are highlighted in green on Tables 6-8. Increased monitoring was recommended by the Desert Fishes Recovery Team, a FWS advisory group, as part of their strategy to deal with the red shiner invasion (Desert Fishes Recovery Team 1990).

According to TNC, the TNC/BLM phase of monitoring began with monthly sampling in November 1990 (Brunson and Gori 2001). This apparently refers to the red shiner searches throughout the stream by AGFD, TNC, BLM, ASU, and FWS personnel on October 20 and November 6, 1990. No record of monitoring in December 1990 or January 1991 was found.

In February 1991, a multi-agency group met to discuss management of Aravaipa Creek. A monitoring proposal had been submitted by ASU and draft a Memorandum of Understanding was prepared for signature by FWS, BLM, BR, AGFD, and TNC. The MOU would have provided for cooperative funding of ASU monitoring, among other things. That MOU was never signed, but monitoring began in February 1991 by ASU under contract to TNC (Velasco 1993a). This spanned 17 months (Feb. 1991-June 1992), and included upper and lower reaches monthly and all reaches quarterly. It was combined with the ASU long-term monitoring efforts in April and October.

In October 1991, TNC and BLM entered a 5-year cooperative agreement to fund monitoring. Under the agreement, eight months of ASU monitoring was funded. Monthly monitoring was assumed by AGFD in July 1992 under the agreement. Their work continued through 1993, with no sampling in September 1992 and 1993 in upper and lower reaches, February and July 1993 in the middle reach, and December 1993 in all reaches. In addition, ASU long-term monitoring was incorporated so AGFD did not sample in October 1992 and 1993 and April 1992.

According to Brunson and Gori (2001), quarterly monitoring was conducted in 1994. The only records found, apart from the standard spring-fall ASU effort, were AGFD monitoring April (in addition to the standard ASU sampling) and ASU monitoring in June.

Following this period of intensive monitoring, the effort fell back to the long-term ASU biannual monitoring until autumn 1997. For three of the next four years additional autumn monitoring was conducted by BLM, TNC and AGFD. None of the three agencies have conducted monitoring in Aravaipa Creek since 2000, but they assist in the ASU/UofA monitoring and are presently providing funding.

In January 1999, a meeting was held among various parties interested in management of

Aravaipa Creek. A draft monitoring plan was tendered by BLM. The group recommended that monitoring be initiated to supplement, but not replace, the ongoing ASU effort. This additional monitoring would occur once a year in the autumn at fixed sites using sampling protocols set up by the Central Arizona Project nonnative management program (Clarkson 1996). The purpose would be to document status and distribution of the fish community with an emphasis on red shiner. Apparently this proposal was not adopted. However BLM and TNC are presently working jointly on a monitoring plan and protocol for Aravaipa Creek (H. Blasius, BLM, pers. com. March 3, 2004).

5. Monitoring of the fish barriers. In 2001, two barriers to upstream fish movement were completed in lower Aravaipa Creek to prevent additional nonnative fish invasions. These barriers were required by a 1994 biological opinion from the FWS to the USBR, under the Endangered Species Act (U.S.Fish and Wildlife Service 1994). In a revision of that biological opinion, the Bureau of Reclamation committed to 100 years of monitoring in the vicinity of the Aravaipa Creek barriers (U.S.Fish and Wildlife Service 2001b). Barrier monitoring efforts are highlighted on Table 6 in blue and occurred in 2001, 2002, and 2003, with no detection of novel species or significant changes in fish distribution.

6. Searches specifically for red shiner. After invasion of red shiner into Aravaipa Creek in 1990, intensive sampling efforts occurred to document its invasion and spread. These were not monitoring efforts, but instead targeted habitat with the highest likelihood for presence of red shiner. These occurred in October 1990, October 1993, November 1995, and July 1998 in the lower reach, October and November 1990, October 1993, and June and July 1998 in the middle reach, and November 1990, October 1993, and June and July 1998 in the upper reach. They were coordinated by ASU, AGFD, TNC, and BLM and also included FWS, USBR, and UofA.

7. Miscellaneous. Some sampling has occurred in Aravaipa Creek for reasons that do not appear to be connected to specific studies or to monitoring. These efforts include a few isolated events for unknown reasons as well as two sampling events for youth education. These last two were in January 1996 and December 1999 and were conducted by Robert Beatson with the Arizona League of Conservation Voters.

Tributary and Isolated Waters Sampling

In addition to mainstem Aravaipa Creek, there has been infrequent sampling of tributaries and isolated waters of the basin (see Table 9). In 1972, Minckley and his ASU class sampled lower Hell Hole Canyon and found only longfin dace. They also sampled Oak Grove and Turkey Creeks where they found longfin and speckled dace, and desert and Sonora sucker. Other

TABLE 9
CHRONOLOGY OF SAMPLING EVENTS
ARAVAIPA CREEK TRIBUTARIES AND MISCELLANEOUS WATERS

YEAR	MONTH											
	JAN.	FEB.	MAR.	APR.	MAY	JUNE	JULY	AUG.	SEPT.	OCT.	NOV.	DEC.
1965		streamside pond near White's			streamside pond near White's							
1966												
1967												
1968												
1969												
1970												
1971												
1972					ASU/ Hell Hole Oak Grove Turkey							
1973												
1974										ASU/ Virgus		
1975	ASU/RimRock pool (Virgus)											
1976										ASU/ Virgus		
1977												
1978												
1979												
1980												
1981												
1982												
1983												
1984												
1985												
1986												
1987						GF/stock tanks	GF/stock tanks					
1988												
1989												
1990												
1991										BLM/ Turkey	GF/ Geldmacher & Rubins ponds	
1992												
1993												
1994												
1995			BLM/ Turkey				BLM/ Deer & Oak Grove					
1996												
1997												
1998												
1999												
2000												

TABLE 9
CHRONOLOGY OF SAMPLING EVENTS
ARAVAIPA CREEK TRIBUTARIES AND MISCELLANEOUS WATERS

YEAR	MONTH											
	JAN.	FEB.	MAR.	APR.	MAY	JUNE	JULY	AUG.	SEPT.	OCT.	NOV.	DEC.
2001												
2002												
2003												
2004												

Minckley classes sampled Virgus Canyon in 1974 and 1975, finding Sonora sucker and green sunfish, leading to concerns that the sunfish might be moving down into Aravaipa Creek from stock tanks in the watershed. Turkey Creek was again sampled in 1991, when Jeff Simms (BLM) found longfin and specked dace, loach minnow, desert and Sonora sucker, and roundtail chub. He revisited Turkey Creek, along with its tributary Oak Grove, in 1995 and found all of those except loach minnow. In 1995, Simms sampled Deer Creek and found loach minnow at least 1.75 miles above the mouth, as well as speckled and longfin dace and desert sucker.

Floodplain ponds have been built and maintained at several ranches along Aravaipa Canyon, for various reasons, including raising nonnative fish for sport and food. In 1965, Barber and Minckley included one shortly below White's Ranch in their study. They found green sunfish, black bullhead, and Sonora sucker. In 1991, AGFD sampled ponds along lower Aravaipa Creek on the Geldmacher (or Holy Joe) Ranch and at the Rubin Ranch. They found green sunfish, mosquitofish, Sonora sucker, largemouth bass, yellow and black bullhead, and channel catfish.

Stock tanks are common throughout the watershed of Aravaipa Creek and are often stocked with nonnative fish. In 1975 Donald Schreiber, a Minckley student, sampled the Virgus Canyon Rim Rock pool and found green sunfish. Concern about stock tanks in the watershed feeding nonnative fish into Aravaipa Creek resulted in a 1987 survey of stock tanks by AGFD, which found fish (green sunfish) in only two tanks (Rim Rock and Four Mile) (Bagley 1987).

As Tables 6-8 illustrate, Aravaipa Creek is heavily sampled and there is substantial knowledge of the fishes of Aravaipa Creek. However, unlike the mainstem, the tributary streams are sampled infrequently and the extent to which they support native fish on a long-term basis, and the distribution of that use, is poorly known.

Sampling Funding

Fish sampling and monitoring in Aravaipa Creek has been funded by a variety of entities over 40 years (Table 10). These were identified in acknowledgments and contract numbers in various reports, but dollar figures not available for many projects, so are not included in Table 10. A large proportion were self-funded, with staff, vehicles, and equipment provided by the organization doing the sampling and those are not included in Table 10. This is particularly true of ASU long-term monitoring, which was largely unfunded by any outside entity, with the exception of some grants in early years and TNC funding of the 1991-92 monitoring. Long-term ASU monitoring with little funding was made possible by use of University resources and students sampling labor. This served a dual purpose of providing students with exposure and training on native fishes while accomplishing a labor-intensive effort over a long period of time at little expense. Use of students in Aravaipa Creek sampling began in the 1950's with Lowe's UofA classes (see SONFISHES) and was continued by Minckley at ASU. The first record found for ASU use of classes was in 1972 (Minckley 1972), although it was likely occurring unrecorded earlier, as use of students was not considered as unusual and in need of noting. Minckley's field notes, which may contain such information, were not examined. Use of students continued through 2003, when it was ended due to concerns by AGFD.

In addition to student labor, sampling efforts were often staffed by biologists from a variety of agencies who came to help. This was particularly true during the early 1990's when concern over the red shiner invasion was at its peak. Table 10 shows only the entities that provided monetary support, with the exception of AGFD, where matching funds for Federal grants are normally provided by in-kind contributions of staff time and equipment.

With the exception of the October or Fall Fish Count, administration of which was funded by the FWS through a Section 6 grant to AGFD, money for monitoring of Aravaipa Creek has been primarily provided by DOW, TNC, and BLM.

TABLE 10
FUNDING SOURCES FOR ARAVAIPA CREEK SAMPLING
(not including time, vehicles, and equipment used by agencies and organizations in their own sampling

FUNDING ENTITY	PROJECT	MONITORING?
Arizona State University	Barber and Minckley's work 1963-67	Y
	Rinne 1976	
	Mpoame and Rinne 1983	
	Hendrickson and Minckley 1984	
	Meffe and Minckley 1987	
	Douglas et al. 1994	
	Williams 1991a	
American Museum of Natural History	Barber and Minckley's work 1963-67	Y
Defenders of Wildlife (Whittell Trust)	Minckley 1972	Y
	Minckley 1973 (31-W-WL-7-20)	Y

TABLE 10
FUNDING SOURCES FOR ARAVAIPA CREEK SAMPLING
(not including time, vehicles, and equipment used by agencies and organizations in their own sampling

FUNDING ENTITY	PROJECT	MONITORING?
	Ellingson 1980	
	Schreiber and Minckley 1981	
	Adar 1985	
	Minckley and Karp 1986	Y
	Minckley and Meffe 1987	
	Bagley 1987	
U.S. Bureau of Land Management	Minckley 1972	Y
	Minckley 1973	Y
	Schreiber 1975	Y
	Siebert 1980 (YA-512-CT6-98)	
	Minckley 1981 (YA-512-CT6-98)	
	Schreiber and Minckley 1981	
	Clarkson and Minckley 1985 (YA-512-CT6-98)	
	Minckley and Karp 1986	
	Meffe and Minckley 1987	
	Bagley 1987	
	Williams 1991a	
	Velasco 1993 and 1997	Y
	Bettaso et al. 1995	Y
	Voeltz and Davidson 2002 (A950A40006)	Y
	Reinthal in progress	Y
The Nature Conservancy	Rinne 1976	
	Meffe and Minckley 1987	
	Hardy et al. 1990	
	Williams 1991a	
	Bettaso et al. 1995 (AZFO121394-1)	Y
	Velasco 1993 and 1997 (AZFO-053091-1)	Y
Sport Fishing Institute	Barber and Minckley's work 1963-67	Y
	Rinne 1976	
	Meffe and Minckley 1987	
African-American Institute	Mpoame and Rinne 1983	
U.S. Fish and Wildlife Service	Ginnelly 1977	
	Turner and Tafanelli 1983	

TABLE 10
FUNDING SOURCES FOR ARAVAIPA CREEK SAMPLING
(not including time, vehicles, and equipment used by agencies and organizations in their own sampling

FUNDING ENTITY	PROJECT	MONITORING?
	Hendrickson and Minckley 1984	
	Meffe and Minckley 1987	
	Marsh et al. 1989 and Abarca 1989	
	October Fish Count (Sheldon and Hendrickson 1988, Corman et al. 1989, Young 1994, Young and Lopez 1995)	Y
	Williams 1991a	
	Vives 1995	
Arizona Game and Fish Department	Ginnelly 1977 (Federal Aid match)	
	Bagley 1987	
	Meffe and Minckley 1987	
	Marsh et al. 1989 and Abarca 1989(Section 6 in-kind match)	
	October Fish Count (Sheldon and Hendrickson 1988, Corman et al. 1989, Young 1994, Young and Lopez 1995) (Section 6 in-kind match)	Y
	Vives 1995 (Section 6 in-kind match)	
	Bettaso et al. 1995	Y
	Voeltz and Davidson 2002	Y
U.S. Forest Service	Rinne 1985, 1989,1991, 1992 Rinne and Kroeger 1988	
	Meffe and Minckley 1987	
	Moody, Odem, and Neary 1998	
National Science Foundation	Douglas et al. 1994	
	Eby et al. 2003	
U.S. Bureau of Reclamation	Matter 1991	
	Bagley and Marsh 1995	
	Remington 2002	
Nat'l Council of Science & Technology of MX	Abarca 1989	
U.S. Bureau of Reclamation/Fish and Wildlife Service Central Arizona Project Nonnative fish management and native fish recovery program	JE Fuller Hydrology and Geomorphology	
	Childs 2004	

HISTORY OF FISH RESEARCH AND STUDIES

Numerous studies have been conducted on the fishes of Aravaipa Creek, from basic descriptive work applicable only to Aravaipa Creek to complex analyses of community variation over time that inform a wide range of biological thought. Table 11 lists all research or studies of fishes or hydrology and fluvial geomorphology of Aravaipa Creek for which citable results could be found. This does not include reports of monitoring activities, which were discussed in an earlier section of this report.

The majority of the studies of Aravaipa Creek fishes have been done at ASU. Minckley found Aravaipa Creek to be an outstanding natural laboratory and directed not only a significant effort of his own, but that of many of his students, toward understanding the Aravaipa Creek fish community and its habitat. Summary studies of Aravaipa Creek include Minckley's detailed 1981 report as well as part of a more region-wide analysis (Minckley 1985).

TABLE 11
RESEARCH AND STUDIES RELATING TO ARAVAIPA CREEK FISHES

GENERAL TOPIC	SPECIFIC TOPIC	PUBLICATION OF DATA AND RESULTS
Summaries/syntheses	Aravaipa Creek southwestern aquatic habitats	Minckley 1981 Minckley 1985
General fish studies	fishes of Aravaipa Creek biology of spikedace biology of longfin dace flooding effects on fish thermal tolerances	Barber and Minckley 1966 Barber et al. 1970 Minckley and Barber 1971 Meffe and Minckley 1987 Minckley and Meffe 1987 Carveth and Widmer in-progress at University of Arizona Coop. Research Unit
Fish reproduction	longfin dace loach minnow spikedace & loach minnow captive propagation loach minnow artificial propagation	Kepner 1982 Vives and Minckley 1990 Vives 1995 Childs 2004
Fish food habits	all Aravaipa fishes spikedace spikedace, loach minnow, and red shiner desert & Sonora sucker	Schreiber 1978 Schreiber and Minckley 1981 Barber and Minckley 1983 Abarca 1989 Marsh et al. 1989 Clarkson 1982 Clarkson and Minckley 1988
Fish movement	roundtail chub, desert & Sonora sucker larval fish drift	Siebert 1980 Williams 1991a Remington 2002
Fish parasites		Mpoame 1981 Mpoame 1982 Mpoame and Rinne 1983

TABLE 11
RESEARCH AND STUDIES RELATING TO ARAVAIPA CREEK FISHES

GENERAL TOPIC	SPECIFIC TOPIC	PUBLICATION OF DATA AND RESULTS
Fish habitat	general overview methods spikedace loach minnow all Aravaipa fishes role of woody debris relationship of stream discharge	Deacon and Minckley 1974 Rinne 1985 Rinne and Kroeger 1988 Rinne 1991 Rinne 1989 Rinne 1992 Minckley and Rinne 1985 Velasco 1997
Fish taxonomy	genus *Gila* roundtail chub, desert & Sonora sucker spikedace spikedace, loach minnow, & longfin dace longfin dace	Rinne 1969 Rinne 1976 DeMarais 1986 DeMarais 1992 Minckley and DeMarais 2000 Dowling and Marsh 1999 Uyeno and Miller 1973 Anderson and Hendrickson 1994 Tibbets 1993 Hendrickson 1987a Tibbets 1998
Fish status review	spikedace and loach minnow roundtail chub spikedace, loach minnow, & roundtail chub longfin & speckled dace, desert & Sonora sucker	Stefferud 1983b Stefferud 1983a Voeltz 2002 Desert Fishes Team 2003 Desert Fishes Team 2004
Fish population ecology	fragmentation community dynamics	Tibbets and Dowling 1996 Eby et al. 2003
Nonnative fishes and their control	redshiner/spikedace/loach minnow interactions potential for invasion via Central AZ Project barrier efficacy	Marsh et al. 1989 Douglas et al. 1994 Matter 1991 U.S.Fish and Wildlife Service 2001a Bagley and Marsh 1995
Invertebrates	general drift	Bruns 1977 Bruns and Minckley 1980 Holanov 1984
Water pollution	metals in fish	King and Martinez 1998 Mofin et al. 2003 Reinthal – in progress
Hydrology/ geomorphology	ground water hydrologic cycle flood events bankfull determinations overview and barrier design overview of hydrology and geomorphology	Gould and Wilson 1976 Adar 1984 Adar 1985 Adar et al. 1988 Ellingson 1980 Fuller and Roberts 1985 Roberts 1987 Moody et al. 1998 Moody 1999 Cullinan 1990 JE Fuller Hydrology and Geomorphology 2000
Instream flow needs	fish recreation	Turner and Tafanelli 1983 Hardy et al. 1990 Moore et al. 1990

Early Taxonomy and Zoogeography

The purpose of early sampling of Aravaipa Creek was simply to document what species were found where. Specimens of Aravaipa Creek fishes placed into museum collections from 1943 to 1950 contributed to various taxonomic and zoogeographic studies of the seven native fishes and the lower Colorado River basin. Those specimens continue to contribute to such studies today. Recent taxonomic and genetics work that may have used those specimens are discussed later.

Although the stream is not specifically mentioned in either paper, the 1950 sampling of Aravaipa Creek contributed to studies at the University of Michigan that culminated in such important work as a key to larval native fishes of the lower Colorado River Basin (Winn and Miller 1954) and Robert R. Miller's seminal 1961 paper on the human-caused changes to the fish fauna of that basin (Miller 1961).

Basic Descriptive Biology

Barber and Minckley (1966) mention work in the 1950's by Charles Lowe and Wallace Heath at the UofA on Aravaipa Creek, with special reference to thermal ecology of fishes. They state that the results of this research are "soon to be published elsewhere." Lowe and Heath produced a paper on thermal tolerances of desert pupfish and a Masters thesis on that subject for Gila topminnow (Heath 1962, Lowe and Heath 1969), but neither of those species were in Aravaipa Creek in the 1950's. There is no indication the Aravaipa work was ever published.

The first identifiable research on Aravaipa Creek was in the 1960's by William Barber and W.L. Minckley at ASU. The sampling for their work can be seen in Tables 6-8 in 1964-1967. That work resulted in the first description of Aravaipa Creek and its native fishes (Barber and Minckley 1966). It also resulted in the first descriptions of the biology of the spikedace and longfin dace and a description of the feeding ecology of spikedace (Barber et al. 1970, Minckley and Barber 1971, Barber and Minckley 1983).

Defining the food type and needs of native fish is important in understanding and conserving those species. Donald Schreiber completed a Masters thesis on the feeding habits of all of the fishes of Aravaipa Creek based on sampling there in 1975-76 (Schreiber 1978). Additional work was conducted by another Minckley student, Robert Clarkson (Clarkson 1982). He concentrated on the two suckers, Sonora and desert, and their hybrids in Aravaipa and Bonita Creeks. Both published their results in conjunction with Minckley (Schreiber and Minckley 1981, Clarkson and Minckley 1988).

Minckley student Dale Bruns described the species, distribution, and variability of aquatic invertebrates in Aravaipa Creek (Bruns 1977, Bruns and Minckley 1980). A student at the U of A also worked on invertebrates in Aravaipa Creek and produced a Masters thesis regarding drift movement (Holanov 1984).

Many other Minckley students also worked on Aravaipa Creek. Darrell Siebert, produced a Masters Thesis on movement of fishes in Aravaipa Creek (Siebert 1980). His sampling can be seen in Tables 6 and 8 in 1978-79. He concluded that the larger-bodied fishes of Aravaipa Creek (i.e. Sonora sucker, desert sucker, and roundtail chub) demonstrated predictable movements to occupy Aravaipa Canyon in summer and again to occupy reaches outside of the canyon, both up and downstream, in winter. Spring and autumn were the periods for these migrations. Caryl Williams followed up on this work in 1989-90 in an ASU Masters thesis (Williams 1991a). Her work was initiated in response to concerns over effects of proposed fish barriers on Aravaipa Creek fish movement. Using both her own and Siebert's data, Williams was unable to reveal a seasonal component to the pattern of movement, although larger fish seemed to travel toward the canyon (both from up and downstream) throughout the year. She attributed this to a tendency for the larger fish to seek greater heterogeneity (i.e., deeper, cooler water and greater permanence of habitat) to be found in that hard-bottomed, constrained area, as opposed to greater variability and less heterogeneity in the more alluvial reaches up and downstream.

Working on lower Colorado River basin fishes, Mbida Mpoame completed a PhD Dissertation on fish parasites (Mpoame 1981). He published a subset of these data from Aravaipa Creek, identifying ten parasitic species in seven fish species (Mpoame 1982), as well as more broadly based work (Mpoame and Rinne 1983).

William Kepner worked in Aravaipa Creek to define the reproductive biology of longfin dace, a common Aravaipa species (Kepner 1982). He found that longfin dace are capable of spawning on a year-long basis, but the peak reproductive activity occurs in spring and late summer. His sampling activity can be seen in Tables 6 and 8 in 1978.

An example of the benefits of frequent, regular sampling is illustrated by a serendipitous discovery during the October Fish Count at Aravaipa Creek in 1988. Two loach minnow nests were found in a stream reach temporarily dried by an irrigation diversion. This is the first, and to date only, documentation of autumn spawning by loach minnow (Vives and Minckley 1990).

Research is currently underway on thermal tolerances of spikedace and loach minnow, using fish from Aravaipa Creek and elsewhere. This work is being conducted at the UofA Cooperative Fish and Wildlife Research Unit by students Cori Carveth and Ann Widmer.

Habitat Relationships

As early as the 1970's, the information gathered in Aravaipa Creek was used to elucidate relationships between fishes and their habitats (Deacon and Minckley 1974). This became the focus of more of the Aravaipa Creek research in the 1980's, reflecting increasing knowledge and concern regarding the status of native fishes and effects of human activities. Work oriented toward describing the habitats used by these fishes resulted in several publications on habitat of spikedace and loach minnow in Aravaipa Creek (Rinne 1985, Rinne and Kroeger 1988, Rinne 1989, Rinne 1991, Rinne 1992). Sampling events for these data can be seen on Table 8 in 1982-85. In another habitat-related study, Aravaipa Creek and its relatively intact native riparian vegetation furnished information used to examine the historical role of large woody debris in low desert streams (Minckley and Rinne 1985).

Other studies examined the role of flooding and natural hydrograph retention in the persistence and stability of fishes in Aravaipa Creek and its role in native-nonnative interactions (Meffe and Minckley 1987, Minckley and Meffe 1987). These studies provided a basis for the understanding that although flooding is not a solution to nonnative fish invasion, there are differing responses to flooding by natives and nonnatives. Flooding may result in depression of some nonnative populations. This work helped illuminate the importance of natural, free-flowing hydrographs to the conservation of native fishes.

The relationship between hydrology and fish populations was the Masters study by Tony Velasco at ASU (Velasco 1997). He used the ASU long-term monitoring data set, along with the monthly monitoring during the 1991-92 period to analyze the relationship between variance in stream discharge and fish populations. Velasco found that habitat heterogeneity in Aravaipa Creek is maintained by the annual cycles of discharge variance (i.e. magnitude, duration and frequency of flood events) and that short-lived species in Aravaipa Creek (i.e., spikedace, loach minnow, speckled dace, and longfin dace) have strong positive responses to flooding.

Nonnative Invasions

The adverse effects of nonnative fishes on native fishes began to get serious recognition in the late 1980's. One of the first studies attempted to determine relationships between red shiner and spikedace and loach minnow (Marsh et al. 1989). Aravaipa Creek had not yet been invaded by red shiner and was one of the control streams. Although this study did not provide any definitive results regarding the mechanism of red shiner displacement of spikedace, it yielded substantial theoretical insights that have been valuable to management (Douglas et al. 1994). To better define red shiner and spikedace interactions, Francisco Abarca, an ASU student, completed a Masters Thesis on potential competitive overlap in food between the two species (Abarca 1989). Again, Aravaipa Creek served as a control, and food overlap was found to be low.

The potential for red shiner or other novel nonnative fish invasion of Aravaipa Creek came up in the late 1980's in the context of the Central Arizona Project, a interbasin water transfer bringing Colorado River water into the central Gila River basin. The CAP canal interfaces with the Gila River and several interconnected canals downstream of Aravaipa Creek raising concerns about possible species transference. The USBR commissioned a study of five possible fish species whose potential spread into Aravaipa Creek might be encouraged by CAP (Matter 1991). Although that study did not find much basis for concern, additional analysis by the FWS concluded substantial basis for concern (U.S.Fish and Wildlife Service 1994, U.S.Fish and Wildlife Service 2001a, U.S.Fish and Wildlife Service 2001b).

Formulation of possible management to exclude or reduce nonnative species in Aravaipa Creek led to other studies. Three were related to the construction of fish barriers on the lower reach (see later section on conservation actions). William's fish movement study has already been mentioned. A review of the swimming ability of potential Aravaipa Creek non-native fish invaders was conducted to assess their ability to overcome a barrier (Bagley and Marsh 1995). A third study, conducted by Rachael Remington, was commissioned to define concerns about loss of drifting larval fish over the barrier. Her sampling efforts are seen on Table 6 in March and April 2000. She found little basis for concern, with larval drift at the barrier sites low compared to upstream collections and indications that larvae drift only short distances (Remington 2002).

Human Perturbations

As the problems of past and potential future human changes to the Aravaipa Canyon environment gained greater recognition and definition, studies were initiated to deal with specific issues.

Concerns about surface and ground-water pollution from mine wastes along the banks of Aravaipa Creek near Klondyke resulted in some studies. The tailings remain from lead, zinc, copper and gold mines that operated in the area from the late 1800's to the 1950's (Minckley 1981, Hadley et al. 1991). Efforts to assess and remediate this problem began in 1992, but no action has yet been taken. Various reports and assessments have been prepared by the Arizona Department of Environmental Quality, but did not include fish sampling data, so are not discussed here.

In October 1997, the FWS sampled fish in upper Aravaipa Creek and found high levels of arsenic and cadmium (King and Martinez 1998). They also found contamination in all 14 fish samples of desert and Sonora sucker and yellow bullhead from TNC property on upper Aravaipa Creek. Lead concentrations in all but one of these samples exceeded the National Contaminant Biomonitoring Program 85th percentile. However, these samples were muscle tissue that has a low bioaccumulation rate and potentially toxic lead levels in whole body fish are unknown. While they conclude that lead is unlikely to be affecting fish health and reproduction, further analysis of liver and kidney tissues are suggested.

Morphin et al. (2003) use ratios of lead isotopes (Pb206, Pb207, and Pb208) to identify sources of lead contamination from the Aravaipa watershed. Each mine tailings has a unique isotopic signature and that signature from the Klondyke mine tailings most closely matches those found in Aravaipa Creek stream sediments. However, recent analyses (Reinthal et al. unpub. data) of lead in fish livers from the TNC property on upper Aravaipa Creek indicate levels in certain species (highest in Sonora sucker) that would result in reproductive failure (levels greater than 50 mg/g lead in liver). Furthermore, signatures of isotopic ratios in fish livers link contamination to the Grand Reef/Laurel Canyon mines. rather than the previously implicated Klondyke mines. This indicates that lead may be entering the Aravaipa Creek food web by methods of deposition other than runoff from the Klondyke mines.

Concerns regarding effects of surface and groundwater manipulations by humans on Aravaipa Creek and its fishes have resulted in studies to determine the amount and source of water. Some are part of larger attempts to describe Arizona’s water resources, such as a map of ground water conditions (Gould and Wilson 1976), or the long-term discharge measurement gauges of the U.S. Geological Survey (USGS). In the late 1970's The Defenders of Wildlife, having recently acquired substantial holdings along Aravaipa Creek, initiated inquiries into the nature of the water supplies and the effects of diversion and groundwater pumping on future stream flows. Charles Ellingson (1980) completed a Masters Thesis at the UofA concluding that surface flow in Aravaipa Creek resulted from groundwater forced to the surface by bedrock constriction and that recharge of the aquifer was equal to discharge, so that no diminution of stream flow should be expected under conditions current at the time. In 1984-88, Eilon Adar at the UofA worked on groundwater issues in Aravaipa Creek and discusses the potential for changes in streamflow based on groundwater pumping (Adar 1984, 1985, Adar et al. 1988).

Other aspects of hydrology also have been studied. Moderate to extreme floods tend to receive inordinate attention due to the damage they may cause to human interests in the canyon, but they are also important factors in determining the availability and distribution of habitat used by fishes within a stream. As noted earlier, studies have shown they may play an important role in the native/nonnative fish composition. The 1983 flood in Aravaipa Creek is the largest on record, but there is disagreement over the peak flow of that event. The flood demolished the USGS gauging station so the peak flow has been estimated based on other methods. While USGS estimates 70,800 cfs, an analysis using alternative modeling estimates between 17,600 and 23,000 cfs (Fuller and Roberts 1987). The same work at the UofA also reconstructed paleohydrological flood events of Aravaipa Creek (Roberts 1987).

Moderate level flows are the prime determiners of the shape of the stream channel. Aravaipa Creek was included in a study to determine return intervals for bankfull flows in streams of southern and central Arizona (Moody et al. 1998, Moody 1999).

More legalistic aspects of streamflow resulted in two studies that attempted to predict fish responses to altered flows and thereby support establishment of minimum instream flow recommendations. The first of these was conducted for FWS by Paul Turner and Robert Tafanelli of New Mexico State University in the upper reach of Aravaipa Creek (Turner and Tafanelli 1983). This sampling can be seen in Table 8 in May 1980 and March, July, and August 1981. The second, conducted for TNC by Thomas Hardy used fish data from the earlier study (Hardy et al. 1990). In contrast to studies to identify minimum stream flows required for native fish, a study on the effects of altered flows on recreational use in Aravaipa Canyon identified differing needs (Moore et al. 1990). Although not directly related to fish, 33.6% of the study's survey respondents identified observation and identification of fish as a strongly desired attribute of the Aravaipa Creek experience.

A variety of BLM and TNC documents exist regarding amounts and timing of stream flow were used in efforts to obtain instream flow water rights in Aravaipa Creek. These will not be addressed here.

Beginning in the 1960's, concerns arose about changes in the stream channel in upper Aravaipa Creek. Minckley believed that channelization in the upper reach had created an ongoing incision process (Barber and Minckley 1966, Desert Fishes Recovery Team 1990). In addition, plans for fish barriers on the lower end raised hydrological and geomorphological questions. As a result, the FWS prepared a report summarizing information on Aravaipa Creek hydrology (Cullinan 1990). In a further attempt to define hydrologic and geomorphologic conditions at Aravaipa Creek, the FWS and BR funded, through the Central Arizona Project native fish recovery program, an evaluation of trends in surface water, groundwater, and channel geomorphology (JE Fuller Hydrology and Geomorphology 2000). The report concludes that wet conditions over the previous 21 years resulted in increased surface flow in the 1990's, that groundwater conditions were in a nearly steady-state condition, immediate threats to water supplies were low, and there was no indication of a trend of change in channel geomorphology.

Taxonomy and Genetics

Taxonomic and genetics studies using fishes from Aravaipa Creek have occurred over many years. The first are undoubtedly various works at the University of Michigan, and fishes from Aravaipa Creek figured prominently in taxonomic works at ASU over the years. The first work identifable as Aravaipa-related was by John Rinne in 1969 on the genus *Gila* as a Masters thesis at ASU (Rinne 1969, Rinne 1976). As with most of taxonomic and genetic work, it is not possible to identify specific sampling events in Aravaipa Creek. Taxonomists and geneticists have deposited museum specimens from Aravaipa Creek, but their work also relies heavily on existing museum material, and live specimens are often taken only in one or two brief sampling events that are too minor to be documented in their description of methods.

In 1986, another Minckley student took up the complex taxonomic questions of the genus *Gila* and allied species. Bruce DeMarais completed both a Masters and PhD at ASU on this issue (DeMarais 1986, DeMarais 1992). Although materials used spanned a large geographic range, DeMarais sampled *Gila robusta* in Aravaipa Creek. This work has resulted in contributions to the wider understanding of the role of introgressive hybridization in evolution of certain fishes (Dowling and DeMarais 1993). It also contributed to the redefinition of species within the *Gila robusta* complex (Minckley and DeMarais 2000).

The morphology and classification of longfin dace was the subject of a PhD Dissertation by Minckley student Dean Hendrickson (Hendrickson 1987a). His study was range-wide and found that two distinct morphological forms existed, one in the Gila, Bill Williams, Sonoyta, and de la Concepcion River basins, including Aravaipa Creek, and another in the Willcox Playa, Rio Yaqui, Fuerte, Maya, and Sinaloa basins. Later, he and a colleague examined morphologic variation in spikedace within the Gila River basin, where it is endemic (Anderson and Hendrickson 1994). They found that there was significant differences between the four remnant populations of spikedace, with Aravaipa Creek and the Verde River at the extremes and Eagle Creek and the upper Gila River (NM) intermediate.

In 1993, Alana Tibbets completed a Masters Thesis at ASU on genetics of spikedace, loach minnow, and longfin dace (Tibbets 1993). Aravaipa Creek was the most divergent of the upper Gila River samples for all three species (Tibbets and Dowling 1996). She followed this up with a PhD Dissertation on longfin dace genetics and evolution (Tibbets 1998). Her conclusions support those of Hendrickson and Anderson, indicating a substantial degree of separation between populations within the Gila River basin (including Aravaipa Creek) in spikedace and loach minnow, and to a lesser, and different, degree longfin dace. She concludes that spikedace and loach minnow populations represent evolutionarily independent lineages, which argues for increased attention to, and protection of, Aravaipa Creek.

It is anticipated that the fishes from Aravaipa Creek will be an important genetic reservoir as populations around Arizona and the Gila River basin are disappearing with alarming regularity. The taxonomic work on Aravaipa Creek fishes will help define that importance and how it can be used in conservation of those species.

Status Reviews of Fish Species

Information from Aravaipa Creek has been included in several status reviews for native Gila River basin fishes. In preparation for proposed Federal listing, status reviews were conducted for spikedace and loach minnow (Stefferud 1983a, Stefferud 1983b). Roundtail and headwater chub distribution, abundance, and threats to them were assessed by Voeltz 2002) under funding by the joint USBR/FWS Central Arizona Project Nonnative Management and Native Fish Recovery Programs. Reports on status of Aravaipa fishes were also made at several meetings of the Desert Fishes Council, a professional society dedicated to conservation of fishes or arid lands. In 1973, (LaBounty 1973) reported on the status of spikedace and loach minnow and noted that loach minnow was “not abundant” in Aravaipa Creek in fall 1972. He also reported that spikedace had not been collected in Aravaipa Creek since 1963, but this was in error, as Minckley collected it there in 1965-69, 1970, and 1972-73. The same year, McNatt (1973) reported that loach minnow numbers were down and that all seven species have shown “extreme fluctuations over a 13-year period of study.” McNatt was an ASU student and was presumably basing his conclusion on the long-term ASU monitoring data.

By 1978, Minckley reported to Desert Fishes Council (Minckley 1977) for Aravaipa Creek that “native fish in that stream are in excellent condition, despite low discharges, with *Meda fulgida* (surprisingly) being the most abundant species in many habitats.” But by 1998, it was reported that red shiner were again present and that yellow bullhead and green sunfish were established and increasing (Stefferud et al. 1998).

Conservation Action Investigations

Conservation actions to protect and recover native fishes raise questions that may not be answerable by basic research. Applied research studies with a species-wide focus, but addressing Aravaipa Creek as one component, have been conducted for several native fishes. The need for holding native fish in captivity for refuge and repatriation stock, has long been recognized (Desert Fishes Recovery Team 1990). In 1993, the FWS funded a study of spikedace and loach minnow artificial propagation (Vives 1995). Fish for that work were taken from Aravaipa Creek (Arizona Game and Fish Department 1995). Unfortunately, the effort was unsuccessful in getting either species to breed in captivity. Loach minnow from Aravaipa Creek are currently under a captive propagation study by AGFD, funded through the joint USBR/FWS Central Arizona Project Nonnative Management and Native Fish Recovery Program (Childs 2004). This project has succeeded in breeding both loach minnow and speckled dace, although there are unsolved problems in long-term holding and maintenance of populations. A similar project for spikedace is ongoing at the University of New Mexico, but is working with fish from the upper Gila River (Parmenter and Platania 2004).

Community Composition and Ecological Theory

One of the benefits of long-term data on a single system, such as Aravaipa Creek, is that as the basic biological data accumulates it lends itself to syntheses that address larger ecological issues with application beyond the local system. Tibbets and Dowling (1996) used genetic data on spikedace, loach minnow, longfin dace, including data from Aravaipa Creek, to examine the question of effects of habitat fragmentation. The long-term data set from Aravaipa Creek has been subjected to extensive analysis directed at understanding the inherent variability of the system in order to increase the ability to detect and predict response to human and natural disturbances (Velasco 1997, Eby et al. 2003). These will be discussed in the following section summarizing monitoring and sampling conclusions and benefits.

SUMMARY OF THE MONITORING EFFORT AND ITS RESULTS

Although sampling in Aravaipa Creek occurred sporadically through the 1940's and 50's, the “modern” period of Aravaipa Creek sampling, and the long-term monitoring data set, began in the early 1960's. Following the lead of Minckley, we use 1964 to present time for our summary of monitoring. The uncompleted year 2004 was omitted from the summary analysis. Data used are found in Appendix 2.

In a “normal” year, there are 5 months during which at least one sampling of Aravaipa Creek fishes occurs (mode number of months per year with sampling events). That reflects all sampling events, for whatever purpose and by a variety of collectors. However, intensity of sampling efforts varies greatly year to year, from no sampling to sampling year-round. The range in number of sampling events per year is 0-17, with an average of 6.6 and a mode of 6. This variation reflects initiation and completion of specific studies and the intense monitoring in the early 1990's in response to red shiner invasion. Figure 6 illustrates how sampling varies over time.

Three periods of heavy sampling have occurred. The first was in the 1960's, from the Barber and Minckley studies. The second occurred in the late 1970's and early 80's, and was the work of several Minckley students, including Kepner and Siebert. The third spanned from 1989 to 1993, and had two components; Williams’ sampling in 1989-90, and the monthly monitoring of 1991-93. Except for 2002, when Carveth and Widmer’s UofA work increased sampling intensity, the 1994 to present period has seen below average sampling intensity in Aravaipa Creek. That reflects the lack of specific studies as well as the reduction in monitoring.

FIGURE 6. ARAVAIPA CREEK FISH SAMPLING INTENSITY
(as variation around the mean)

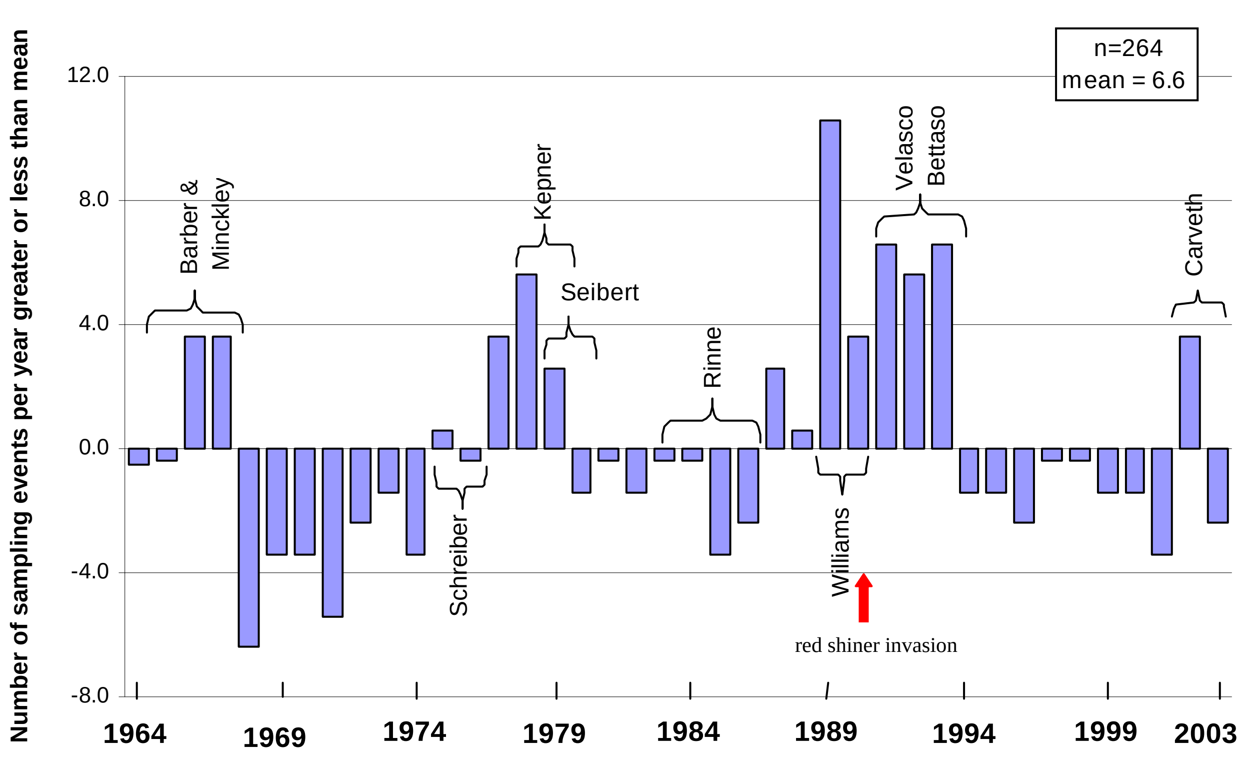
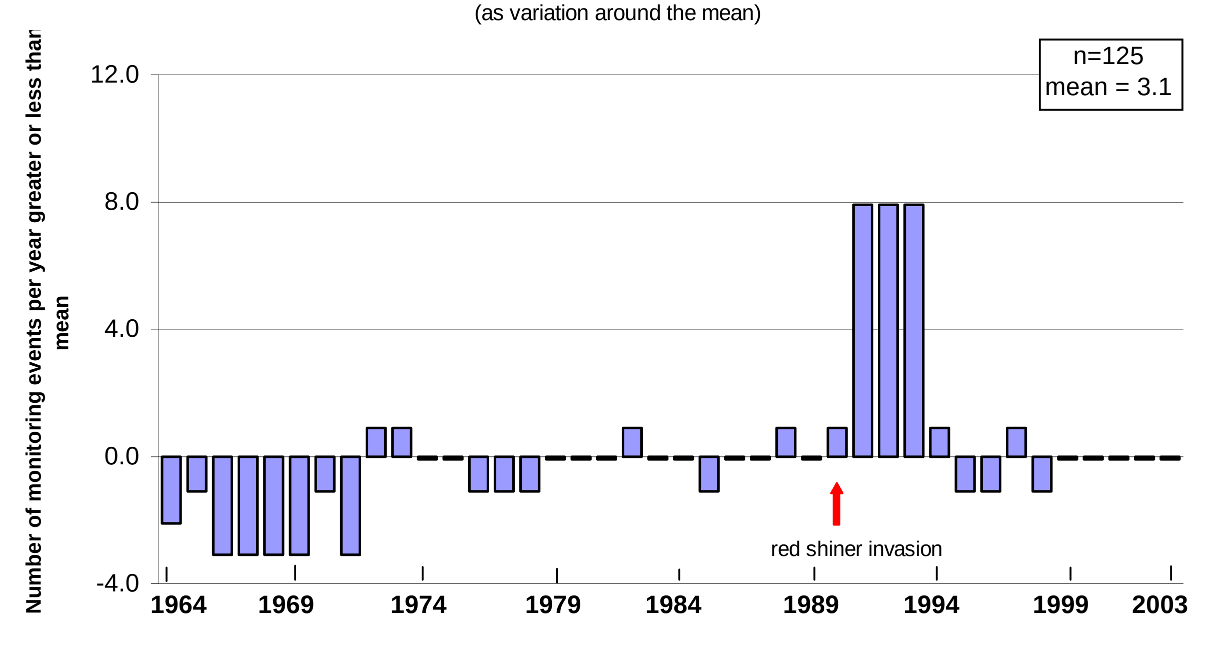


FIGURE 7. ARAVAIPA CREEK FISH MONITORING INTENSITY
(as variation around the mean)



Monitoring is a subset of the total sampling and makes up 47% of the fish sampling events in Aravaipa Creek. While less variable than total sampling, monitoring also has substantial variability (see Figure 7), with an average of 3.1 monitoring events per year, a mode of 3, and a range of 0-11 . Because a monthly basis is used to enumerate sampling events, this analysis slightly overestimates the number of monitoring events. In some years the reaches were sampled during different months (i.e. upper reach in October and lower reach in November) resulting in them being counted as two events. Nevertheless, the pattern is clear. In the late 1960's, monitoring was sporadic, with no sampling specifically for monitoring during 1966-69. From 1970 to 1990, with the exception of 1971, all years had a minimum of 2 sampling events (the spring and autumn ASU long-term data collection) and a maximum of 4. From 1990 through 1993, monitoring to define the red shiner invasion resulted in 11 sampling events per year. In 1994, the biannual sampling pattern of the ASU effort resumed, continued from 2002 to present by Peter Reinthal at UofA, with a minimum of 2 and a maximum of 4 monitoring events each year.

What has 40 years of fish monitoring in Aravaipa Creek told us? At the most basic level it has given us two very important pieces of information. First, that the native fish in Aravaipa Creek generally have continued to persist in relatively substantial numbers, and second, that nonnative fish have slowly, but steadily, continued to gain ground.

The first piece of information could be seen by some as an indication that the monitoring is a waste of effort because it, in essence shows that *nothing* has happened (i.e. the native fish are still doing well). It is human nature to want monitoring to show that *something* is happening. However, given that trends in native fish in the Gila River basin are downward in almost every other location (Desert Fishes Team 2003, Desert Fishes Team 2004), a monitoring outcome that demonstrates a different situation in Aravaipa Creek is not only worthwhile, but provides invaluable scientific information for management of Aravaipa Creek and conservation of native fishes throughout their range. It indicates that the human caused changes and the variation in climate and hydrology experienced in Aravaipa Creek over the past century, have not yet been of sufficient influence to cause the substantial declines of native fishes seen elsewhere. This does not mean that finer-scale changes in the fish community have not occurred nor that the status quo will be maintained in the future.

The second piece of information provides warning of an increasingly ominous situation. Additional nonnative species have become established and nonnatives are more common in samples, with numbers and range creeping upward. This, Minckley believed, is an indication of undetected ecological change that has tipped the balance, allowing the non-natives that have been available nearby for decades to finally colonize Aravaipa Creek. This may represent the same type of time-lagged invasion as recently described between the Gila River basin as a whole and the adjacent Rio Yaqui basin (Unmack and Fagan 2004). The knowledge that nonnative species are expanding in Aravaipa Creek has led to several management actions to control such expansions (see history of conservation actions).

Basic conclusions such as those above, can be drawn from Aravaipa Creek monitoring data on a gross scale, however, more in-depth analyses are needed to identify finer-scale changes. The ongoing monitoring program provides opportunity to continue to refine the fine-scale analysis., and allows for standardization of techniques to obtain comparable data and avoid a haphazard approach.

In 1981, Minckley had 15 years of monitoring data and experience with fishes of Aravaipa Creek. Based on that and historic sampling information, he concluded that "patterns of abundance of fishes within the stream have been remarkably consistent since the 1940's," with longfin dace most abundant in the lower reach, speckled dace most abundant in the upper reach and rare in the lower, loach minnow common in the upper reach, and the remaining four species (Sonora sucker, desert sucker, roundtail chub, and spikedace) most abundant within the gorge, but also common downstream. He also found that although biomass of fishes in Aravaipa Creek is "spectacularly high at some times of year" there was substantial variability between stream segments and over time. He also found that no nonnative fishes had yet established reproducing populations within the creek itself.

By 2001, Minckley had 37 years of data and experience on fishes of Aravaipa Creek, from which he made a number of conclusions in an unpublished manuscript he was working on just before his death (Minckley 2001). He found that patterns of increased red shiner presence are associated with low relative abundance of spikedace and desert sucker in the lower reach of Aravaipa Creek. Analysis of responses to flooding showed upward population responses in short-lived fish species, with the 1983 flood increasing average relative abundance of spikedace by a factor of 10. Conversely, periods of low flows decreased relative abundance of spikedace. Relative abundance of speckled dace also increased in response to flooding, while there was a decrease in loach minnow. Abundance of spikedace and longfin dace were inversely correlated. The three longer-lived species showed only negligible shifts in relative abundance.

Velasco (1997) used Minckley's long-term monitoring data (1964-1990) to examine patterns of variation within native fish populations of Aravaipa Creek, particularly in relation to variation in streamflow (discharge). He supplemented this with additional monitoring during 1991-93, to serve two purposes; providing data for his study and monthly monitoring of Aravaipa Creek fishes during initial years of red shiner invasion. He concluded that much of the variation seen in the long-term data set was explained by variation in spatial distribution of habitat, which was, in turn, explained by variation in stream discharge. He reported no long-term trends, either up or down, in native fish populations in Aravaipa Creek. Short-term trends were noted in some species, with strong positive responses to flooding in short-lived species.

Velasco's findings led him to believe that the remarkably large fish biomass supported by Aravaipa Creek (Minckley 1981), is probably a result of the high level of habitat heterogeneity, which in turn is created by the highly variable, and unregulated, stream discharge hydrograph. He concludes that naturally-occurring disturbance patterns are a driving element of the Aravaipa Creek ecosystem. Because human activities (water diversion, channelization, etc.) tend to alter natural disturbance patterns and increase hydrographic and habitat homogeneity, Velasco concluded that the influence of ongoing human activities on Aravaipa Creek should be of concern.

A wider focus and more comprehensive analysis of the long-term data set was applied by Eby et al. (2003). Their analysis was based on the monitoring over 30 years in the canyon reach (1970-2000) and 25 years in the lower and upper reaches (1975-2000). Of the changes detected in the Aravaipa Creek fish community, one of the most striking is the decline in species richness in the lower reach in recent years. This is due to increasing rarity of spikedace in this reach and a corresponding increase in nonnative fish. However, the lower reach does not show a long-term directional trend, but rather cyclical fluctuation, with the native fish community in the 1990's becoming similar to that of the 1970's, with a high abundance of longfin dace and lowered occurrence of spikedace. In contrast, they found long-term trends in the canyon and upper reaches. The upper reach had the greatest change, while the canyon reach had slightly less. These changes included a shift from dominance by longfin dace with few spikedace, to a more evenly distributed species group.

These changes led Eby et al. to conclude that variability of fish populations in Aravaipa Creek is influenced by different factors during different periods. Alterations in base flow during the early 1980's were a strong influence on the Aravaipa Creek fish community, but more recent changes are more likely associated with the presence of nonnative fishes. Like Velasco, they also speculate that changes in stream channel, hydrology, and climate patterns may have decreased the variability of flow and thereby decreased habitat heterogeneity. This, together with an increase in the downstream connection with the San Pedro River, may have increased likelihood of nonnative fish establishment. In years of high flow variability, nonnatives decreased as a proportion of the fish community, while increasing in years of low flow variability.

Of particular importance to management is the conclusion by Eby et al. that the deviation of the changes in lower reach community composition from those of the upper and canyon reaches, indicates that the driving factor in the lower reach is presently different from that of the canyon and upper reaches. Earlier changes had been similar among reaches. This means that management strategies for the lower reach need to be different from those in the upper two reaches. The point of divergence of the lower from the canyon and upper reaches is 1990, the year with the highest proportion of nonnative species and the first appearance of red shiner. Based on this finding, control and removal of nonnatives and alteration of the habitat factors that promote their increase should be the highest priority for management in the lower reach.

Eby et al. and Velasco both pointed out the importance of habitat heterogeneity and naturally-occurring disturbance patterns in maintenance of the Aravaipa Creek native fish community and depression of non-native fish abundance. During the present period of major drought, the lack of large flood events decreases habitat heterogeneity thus fostering declines in native fish abundance while at the same time lessening controls on nonnative fish abundance. This may be a critical period for Aravaipa Creek native fish. While there is nothing management can do to alleviate the drought and lack of flooding, conclusions from monitoring data point to the need to halt or reverse human activities that result in loss of habitat heterogeneity (such as channelization, streambank alteration, input of fine sediment, etc.) while taking strong measures to control or remove nonnatives now present and prevent invasions by any novel nonnative species.

HISTORY OF CONSERVATION AND MANAGEMENT ACTIONS RELATING TO NATIVE FISH

Aravaipa Creek has been the beneficiary of many and varied conservation actions, a substantial portion of which are related to the stream and its fishes. Conservation of stream ecosystems is particularly difficult because a stream is a product of its watershed and on-site conservation measures can be easily overwhelmed or negated by activities or conditions in the watershed, particularly upstream. As a result, standard conservation methods, such as acquiring and protecting parcels of real estate, are not necessarily successful at protecting and enhancing stream ecosystems and their fishes. Fortunately watershed perturbation and human uses upstream of the TNC preserve and BLM Wilderness are, at least at present, relatively low. Many past uses (e.g. mining) that had substantial effects downstream, are now absent. This has allowed on-site conservation to benefit the aquatic ecosystem. This may not remain the situation, as upstream and downstream uses are changing (e.g. increasing subdivision of agricultural lands) and could affect basic preserve characteristics such as streamflow (e.g. upstream groundwater pumping).

Conservation actions in Aravaipa Canyon benefiting native fish fall into several broad categories.

Research and Monitoring

Conservation and management of native fishes in Aravaipa Creek began with the research sampling that identified the stream as supporting an important native fish community. When local residents, environmental organizations, and the BLM began to seriously move toward protection of Aravaipa Canyon in the 1970's, already substantial knowledge of the fish community was an important part of their belief that the Canyon was deserving of protection efforts.

Long-term monitoring of native fishes, as well as short-term efforts aimed at specific issues such as red shiner invasion or fish barriers, have given us an understanding of the native fish community of Aravaipa Creek that is exceptional in the southwest. No equivalent data exist for any other fish communities in the Gila River basin. This information has informed and guided all conservation actions in the canyon.

Land Acquisition and Management for Conservation Purposes

Hadley et al. (1991) describe early conservation efforts that were based primarily on scenic resources and recreational use. As early as the 1940's there were calls for a preserve of some sort at Aravaipa Canyon. These concerns helped turn back proposals by the U.S. Army Corps of

Engineers to construct several dams on the stream. Efforts to designate the area a National Park did not succeed.

A proposal for a dude ranch, complete with dams to create trout fishing waters, was thwarted in 1951 by purchase of the Wagner Ranch at the downstream canyon mouth by a conservation oriented buyer. His efforts to control hunting, fishing, and access were aimed at conservation of Aravaipa Canyon.

In 1970, TNC made their first purchase of land within Aravaipa Canyon, in the west end. In 1972, DOW purchased land on the east end and over the next two decades substantial lands on the east and west ends were acquired, now totaling 7,000 acres (http://nature.org/wherewework/northamerica/states/arizona/preserves). DOW managed their lands and those of TNC as the George Whittell Wildlife Preserve at Aravaipa Canyon until 1988, when TNC took over management, which they continue to the present. In addition, TNC has acted as intermediary in the sale of additional lands to conservation-minded buyers, with TNC holding conservation easements. While land acquisition and management has been the primary contribution of DOW and TNC to conservation in Aravaipa Canyon, they have also conducted educational and collaborative efforts with local landowners and assisted and supported research, protection and recovery for native fish.

In 1969, BLM designated the Aravaipa Primitive Area, which encompassed the core canyon of Aravaipa Creek. The Primitive Area was expanded and formally designated as Wilderness in 1984. It includes 19,410 acres and approximately 11 miles of Aravaipa Creek. In 1986, BLM acquired extensive areas of the watershed on the north and south tablelands.

Land acquisition within Aravaipa Canyon has been driven primarily by aesthetics, recreation, and terrestrial wildlife. In many preserves, lack of information and inherent lack of visibility often result in disinterest and indifferent management for fish, unless they are of value for sport fishing. Thanks to the extensive information being gathered on Aravaipa Creek fishes, the charismatic presence of Dr. W.L. Minckley, and perceptive staff at DOW and TNC, management of preserve lands on Aravaipa Creek have always had a strong orientation toward protection and recovery of native fishes (Williams 1991b).

Management of Land Uses to Ameliorate Adverse Impacts

A century of European settlement of the valleys and canyon of Aravaipa Creek resulted in many land uses with ongoing adverse impacts to the stream and its fishes. As part of conservation activities associated with the DOW and TNC preserve and BLM Wilderness, actions were taken to scale back or alter such activities and to prevent additional adverse activities.

Efforts to prevent damming of Aravaipa Creek and development of a nonnative trout fishery were mentioned above. Hunting, trapping, and predator removal were prohibited on DOW/TNC preserve lands. While this had little effect on the native fish, it denoted a tone of natural ecosystem restoration and management that was conducive to native fish conservation.

Livestock grazing was removed from the BLM Wilderness and from most of the DOW/TNC preserve lands, although the extent and intent of this has varied over time. Irrigated agriculture has been substantially scaled back, along with diversion of stream waters.

Roads, which in early years often followed or used the creek bed, had a significant impact on the stream and its fishes. In the past 40 years, numerous efforts were made to improve the roads, reduce their contribution to sediment and erosion, close portions, and reroute other portions out of the riparian zone. These access improvements have often also benefited fishes. Some efforts to remove localized areas of road impact have occurred specifically as conservation measures for native fish, such as installation of a bridge on the west end near the base of Brandenburg Mountain to replace a road section based on fill blasted from an adjacent cliff. Fill erosion during high flood events created up and downstream channel changes and required repeated reconstruction using heavy machinery in the channel. Adverse road impacts still exist on the stream and fish, particularly on the east end where multiple unprotected stream crossings exist (USFWS 1993, 1996).

Some conservation actions may also increase possible recreational impacts to native fish, although educational benefits may be gained. The DOW/TNC preserves and BLM Wilderness enhanced the growing reputation of Aravaipa Canyon as a scenic wonder and desirable camping and hiking spot. Bank compaction, riparian vegetation destruction, informal road and trail development, and pollution have been noted in areas as a result of recreational use in certain areas (USBR 1998). To minimize impacts in the canyon, BLM issues permits to 50 people per day to hike through the Aravaipa Wilderness, with a 3 day limit on stay (https://www.az.blm.gov/sfo/aravaipa). Management of recreational impacts on BLM and TNC lands are ongoing, and include parking areas, signs, restrooms, etc. Uncontrolled recreation on unfenced areas of the San Carlos Apache lands is an increasing concern.

<u>Formal Federal and State Listing and Protection of Fishes</u>

When protective efforts began in Aravaipa Canyon, none of its native fish were protected by Federal law, and only minimally by State law. By 1982, roundtail chub, spikedace, and loach minnow were listed by the State of Arizona as “species whose continued presence in Arizona could be in jeopardy in the foreseeable future” (Arizona Game and Fish Commission 1982). No habitat protection was provided, but regulations prohibited take of the species. In 1994, the Arizona Game and Fish Commission made roundtail chub a sport species and established angling regulations for its take. This was intended to increase public support for conservation of that species, allow use of sportfishing funds for its management, and preclude Federal listing of the species (Arizona Game and Fish Department 2002).

In 1985, the Desert Fishes Council and American Fisheries Society petitioned for Federal listing of spikedace, and in 1986, spikedace and loach minnow were listed as threatened under the Endangered Species Act. Recovery plans for spikedace and loach minnow were completed in 1991 (Marsh 1991a, Marsh 1991b). Aravaipa Creek was proposed as critical habitat for the two species in 1985, but that proposal was not finalized until 1994 (Federal Register 50(117):25380-

25398 and 59(45):10898-10915). Following overturn of the 1994 designation by the courts, Aravaipa Creek was again designated as critical habitat for both species in 2000 (Federal Register 65(80):24328-24372). That designation has again been overturned by the courts. Although efforts at obtaining Federal protection of habitat for spikedace and loach minnow in Aravaipa Creek have been unsuccessful, it is clear the stream is considered highly important for conservation of the two species.

Roundtail chub was petitioned for Federal listing as endangered in 2003, however the FWS has indicated it will not evaluate that petition or provide protection to roundtail chub in the near future (U.S.Fish and Wildlife Service 2003).

State and Federal listing of three of the seven native fishes of Aravaipa Creek has not directly contributed to conservation of Aravaipa Canyon. It has, however, enhanced awareness by the Federal and private entities managing the canyon and contributed to their willingness to take conservation actions. In addition, through section 7 of the Endangered Species Act, modification and mitigation of human actions with adverse effects on the fishes has occurred. To date, there have been five formal and five informal consultations on Federal actions in Aravaipa Canyon that would affect spikedace and loach minnow (see Table 12). Two others, of larger scope, have addressed fish barriers in Aravaipa Canyon.

Riparian Vegetation Restoration

Restoration of riparian vegetation in Aravaipa Canyon has been primarily passive. Fencing projects (listed in Table 12), were funded by FWS for private lands to remove livestock grazing and allow riparian vegetation to recover. Removal of livestock grazing from BLM and TNC lands has also allowed riparian vegetation restoration. TNC and others have allowed former fields and pastures to regenerate in natural vegetation. In addition, TNC has done proactive restoration by removal of nonnative vegetation (citrus and tamarisk) on their lands.

Riparian vegetation management also includes the policies of BLM and TNC not to remove downed woody debris and debris windrows from the riparian area. Such removal continues on private lands and along county road easements. Woody debris plays a significant role in forming fish habitat and in determining the rate and pattern of movement of water through the channel and its removal is generally undesirable for ecological health (Minckley and Rinne 1985).

Streamflow Restoration and Protection

As mentioned earlier, proposals for dams within Aravaipa Canyon have been averted by land acquisition and wilderness designation. Both BLM and TNC have applied for, and received, instream flow water rights in Aravaipa Creek. This was an important step in providing the necessary underpinnings for conservation of Aravaipa Creek.

Irrigation diversion, via ditch or pump, has been common in Aravaipa Creek. Several of these diversions were on lands acquired by DOW and TNC. Many of those diversion have now ended and the waters now remain in the stream channel. This has provided for a more constant, and larger, base flow in Aravaipa Creek (JE Fuller Hydrology and Geomorphology 2000). Increasing groundwater pumping in the upper and lower canyons and in the upper valley above the canyon is of concern for preservation of future streamflow.

TABLE 12
ARAVAIPA CREEK SECTION 7 (ESA) CONSULTATION HISTORY

DATE	ACTIVITY	BIOLOGICAL OPINION FINDING	FEDERAL ACTION AGENCY	CONSULTATION NUMBER (FWS)
July 10, 1987	Eradication of exotic fish in Aravaipa watershed	beneficial effect	BLM	2-21-87-I-88
October 20, 1993	Flood control and repair (rip-rap) at White's house	non-jeopardy	NRCS	2-21-93-F-140
October 20, 1993	Flood control and repair (rip-rap) at TNC house (upper reach)	non-jeopardy	NRCS	2-21-93-F-166
April 20, 1994	Transportation and delivery of Central Arizona Project water to the Gila River basin in Arizona and New Mexico	jeopardy	USBR	2-21-90-F-119
January 17, 1995	Fencing for riparian enhancement at Barassi property by Partner's for Wildlife Program	not likely to adversely affect	FWS	2-21-95-I-110
February 15, 1995	Aravaipa Creek road repair	non-jeopardy	FEMA and BLM	2-21-94-F-090
October 3, 1995	Fencing for riparian enhancement at Gorman-Hedrick property by Partner's for Wildlife Program	not likely to adversely affect	FWS	2-21-95-I-535
November 7, 1996	Road repair and bridge placement on lower Aravaipa Creek	non-jeopardy	FEMA and BLM	2-21-94-F-090
July 31, 1998	Temporary barrier on upper Aravaipa Creek, Partner's for Wildlife funding to The Nature Conservancy	non-jeopardy	FWS	2-22-98-F-347
March 9, 1999	Prescribed fire in Aravaipa watershed	not likely to adversely affect	BLM	2–21-99-I-143
April 17, 2001	Transportation and delivery of Central Arizona Project water to the Gila River basin and its potential to introduce and spread nonnative aquatic species	non-jeopardy	USBR	2-21-90-F-119a
December 31, 2001	Informal consultation on the East Aravaipa trailhead, Graham County, Arizona	not likely to adversely affect	BLM	2-21-02-I-041

BLM = U.S. Bureau of Land Management
FEMA = Federal Emergency Management Agency
FWS = U.S. Fish and Wildlife Service
NRCS = U.S. Natural Resources Conservation Service
USBR = U.S. Bureau of Reclamation

Reintroduction of Native Fish

Management of native fish in Aravaipa Creek has mostly been indirect through management of human and human-related activities that affect the stream and its fishes. The only direct management of native fish is the attempted reintroduction of Gila topminnow into the Aravaipa Creek system (Minckley 1969). The first of these occurred in 1965 in a marshy area adjacent to the creek near the former White Ranch in the center of the northeast quarter of section 34, township 6 south, range 17 east (Minckley 1972). They survived there for at least 3 years, with some individuals caught from the adjacent stream channel. In 1966, another stocking was made into the stream downstream from Stowe Gulch in the northwest quarter of the northwest quarter of section 35, township six south, range nineteen east (Minckley 1972). They survived in this location for at least 4 years, although apparently only in small numbers. Stock for both of these locations was from Monkey Spring in the Santa Cruz River basin (Minckley and Brooks 1985).

A third attempt to reestablish Gila topminnow took place in 1977. The location of this stocking is unclear, with Minckley and Brooks (1985) simply recording it as Graham County and citing AGFD records. They also record it as being stocked with fish from Monkey Spring. However, AGFD reports the stocking as having occurred in the "upper Klondyke area of Aravaipa Creek" with fish from Boyce-Thompson Arboretum (Voeltz and Davidson 2002). Gila topminnow in Boyce-Thompson were a mixed stock, with a strong base of Monkey Spring.

Recently, efforts are underway to establish Gila topminnow into springs and perennial stream sections in southern portions of the Aravaipa Creek watershed. This effort began in 2001 and paperwork for the stocking is still in progress. Three sites are being considered in middle to upper Oak Grove Canyon, including the stream in the vicinity of, and including, Jackson Spring (BLM land), upper Oak Grove Canyon including an unnamed spring (BLM), and Parsons Grove Spring (TNC and BLM). Another three sites are being considered in the Virgus Canyon drainage including the Virgus Canyon/Sycamore Creek confluence (BLM), Bleak Springs (TNC), and Cement Tank Spring (TNC).

Nonnative Fish Removal and Control

As discussed earlier, concerns arose in the 1970's that stock tanks in the watershed were feeding nonnative fish into mainstream Aravaipa Creek. At that time nonnative fish were not reproducing in the mainstream and it was thought that immediate action to remove them from all stock tanks might prevent their establishment in the stream. The first documented management discussion of this apparently occurred in an April 1986 meeting of the Desert Fishes Recovery Team. A letter was sent to the FWS Regional Director with a recommendation that all stock tanks in the watershed be surveyed (Desert Fishes Recovery Team 1986). The recommendation and a proposal to chemically remove nonnative fish found in stock tanks were discussed at the October 13, 1986 and April 1-2, 1987 meetings of the Team.

A 1987 stock tank survey found two tanks with green sunfish (Bagley 1987). After preparation of an environmental assessment and consultation with the FWS, the one tank on BLM land (Rim Rock) was pumped to lower the water level and treated with chlorine on August 4-5, 1987 (Hendrickson 1987b). The other tank was located on private land and AGFD was working to obtain permission to renovate that tank also. That renovation never occurred (D. Hendrickson, Univ. of Texas, pers. com. July 14, 2004), but the tank was dry in summer 2003 (M. Haberstich, TNC, pers. com. July 12, 2004). Two other stock tanks are presently known to harbor nonnative fishes (ibid.).

Concerns about nonnative fish in Aravaipa Creek led to two administrative actions by the State of Arizona to control the threat. In 1986, they denied a permit to the owner of the Holy Joe Ranch in lower Aravaipa Creek, to stock fathead minnow (*Pimephales promelas*), largemouth bass, channel catfish, and tilapia (*Tilapia* sp.) into streamside ponds (Campbell 1988). Then in 1998, the Arizona Game and Fish Commission closed Aravaipa Creek to fishing (Commission Order 40, effective January 1, 1998). The closure reduces the likelihood of unauthorized stocking of nonnative sport fish into the basin and incidental introduction of nonnative bait fish.

One result of the controversy over the 1986 proposed stocking of nonnative fish in ponds at Holy Joe Ranch was a proposal to construct a fish barrier on Aravaipa Creek on lands donated by the ranch owner, located upstream of his ponds. This fit into concerns about nonnative species present in the San Pedro River, particularly red shiner, and their potential to move upstream into Aravaipa Creek. The lead in the barrier effort came from TNC, but involved AGFD and FWS. In 1988, the Desert Fishes Council sent a resolution to TNC, BLM AGFD, and USBR, expressing concern about red shiner invasion of Aravaipa Creek and recommending a fish barrier be constructed. In 1989, the FWS funded a $10,000 feasibility study by AGFD for a barriers on Aravaipa Creek, but funds were reprogrammed within AGFD and the study was never produced. Because of the potential for a barrier on Aravaipa Creek to serve as mitigation for wetland losses in connection with the Central Arizona Project or for mitigation for the Pima Lateral Canal water deliveries, in 1989 BR became involved in the barrier effort.

The discovery of red shiner invasion in fall 1990 lent impetus to the barrier efforts and plans began to be made to construct a temporary barrier in an upstream location to prevent red shiner from invading the entire system. The Desert Fishes Recovery Team considered possible chemical renovation of Aravaipa Creek, but did not recommend immediate renovation (Desert Fishes Recovery Team 1990). They did recommend construction of three barriers, one at the lower end, a temporary one near Turkey Creek, and a third somewhere in the middle. This was in concert with the 1991 spikedace and loach minnow recovery plans, which called for barriers on Aravaipa Creek. In January 1991 the Desert Fishes Council sent a resolution urging immediate action to “determine the most acceptable means of restoring and maintaining the integrity of the natural ecosystem of Aravaipa Creek” including genetic studies, captive propagation of native fishes, prevention of further nonnative invasion, and reestablishment of a native fish community in the adjacent San Pedro River.

In April 1994, the FWS issued a biological opinion to USBR regarding the potential for introduction and spread of nonnative fishes through the Central Arizona Project. One of the mitigation measures required was construction of a pair of fish barriers on lower Aravaipa Creek. However, opposition had arisen among local landowners due to a variety of factors including the flood damage of 1993 and general anti-Federal sentiments. Substantial controversy continued through the final construction, including public meetings, letters to congressional representatives, and newspaper accounts. The paired fish barriers were completed in April 2001 and monitoring indicates they are functioning successfully.

In 1998, FWS provided TNC with funding to construct the temporary earthen upper barrier that had been under consideration since 1990. In 1992 the Desert Fishes Recovery Team recommended putting the barrier on hold for several reasons including the apparent disappearance of red shiner (Desert Fishes Recovery Team 1991). Following reappearance of red shiner in 1997, the Team recommended the temporary barrier be built (Desert Fishes Recovery Team 1997). TNC constructed that barrier in September 1998. It was reconstructed after several flood events and after the lower barriers were complete it was allowed to gradually wash away.

CONCLUSIONS

Aravaipa Creek is very important in the conservation of native southwestern fishes. Much of our knowledge of Gila River basin fishes, their life history, ecology, habitat, and conservation needs, comes from work at Aravaipa Creek. Many things learned there have also been valuable in understanding desert stream ecosystems in general and have helped guide conservation efforts for native fishes throughout the desert southwest.

The concentrated work on Aravaipa Creek has allowed us to build a picture of a desert stream ecosystem that is unparalleled. Nine master’s theses have been done on fishes of Aravaipa Creek and another is in progress, not including those taxonomic and genetic studies using Aravipa fishes. Two were done on aquatic invertebrates. Twenty publications in scientific journals have been generated, at least ten agency reports, and Aravaipa work has contributed to at least three book chapters.

Monitoring comprises a large part of the work that has occurred on Aravaipa Creek fishes. When monitoring began 40 years ago there was probably little expectation that it would become the most important tool in defining status and variation of the fish community. Long-term data sets often begin for a specific short-term reason, such as the research of Barber and Minckley, and are simply continued without a well defined plan for future use of the data. Such was the case in Aravaipa Creek. Like many investments in the future, it is only after a number of years that the complete value of the data set begins to become apparent. Although a good plan is desirable at the outset, it is impossible to foresee in the beginning of such a long-term program all the possible uses for the data at the end of a several decades. There is no way Minckley could have foreseen what Eby and Fagan could do with the Aravaipa Creek data 40 years later.

Monitoring has been identified as a need for native southwestern fishes for decades. In 1971, the Desert Fishes Council recommended regular monitoring of threatened or potentially threatened desert fish populations (Desert Fishes Council 1971). Recovery plans for spikedace and loach minnow populations call for monitoring all populations, (Marsh 1991a, Marsh 1991b), as does the draft conservation agreement for roundtail chub (Utah Division of Wildlife Resources 2004), and recent status reports on Gila River basin fishes by the Desert Fishes Team (Desert Fishes Recovery Team 1986, Desert Fishes Team 2003, Desert Fishes Team 2004).

Although monitoring had already been underway for decades in Aravaipa Creek, it was the 1990 discovery of red shiner in Aravaipa Creek that spurred recommendations for increased monitoring. The Desert Fishes Recovery Team recommended immediate increases in system-wide monitoring to once a month from March to October and less often during winter (Desert Fishes Recovery Team 1990). In February 1992, the Team recommended that monthly monitoring be continued for one or more years and that a long-term monitoring plan be put in place (Desert Fishes Recovery Team 1992a, Desert Fishes Recovery Team 1992b). The monthly monitoring that occurred in response to these recommendations lapsed in late 1993, and the Team again reiterated its recommendation for regular monitoring and a monitoring strategy in December 1997 (Desert Fishes Recovery Team 1997). That recommendation was repeated in June 1998 for intense monitoring (Desert Fishes Recovery Team 1998). And, in January 1999, monitoring was identified as the most important action needed at that time in Aravaipa Creek (Desert Fishes Recovery Team 1999).

In addition to the Recovery Team, meetings of biologists from concerned organizations met in February 1991 and January 1999 to discuss monitoring Aravaipa Creek (Collazo 1991, Stefferud 1999). Both groups recommended continuation of monitoring.

Monitoring yields substantial benefits to conservation and management of Aravaipa Creek. By providing knowledge that a relatively intact native fish community exists in Aravaipa Creek, it helped identify the need for protection of the area. It provided much of the information on distribution and abundance of fish to identify lands and waters important for acquisition and protection. Monitoring information helps define human activities that adversely impacting the stream and fish, such as irrigation diversion and channelization, so that management action can be implemented. Monitoring information was used to help obtain Federal listing of some fish and plan a recovery program.

From a management standpoint, one of the most important contributions of monitoring has been the identification of nonnative fish invasions and establishment. It was the ASU long-term sampling that first documented the appearances of the 9 nonnative fishes recorded from Aravaipa Creek. It was monitoring that provided information on the ebb and flow of green sunfish indicating they were being fed into the creek from stock tanks in the watershed (U.S.Bureau of Land Management 1987). That identification led to removal of sunfish from one of the stock tanks. Monitoring has defined patterns by which nonnatives first appear as isolated individuals, then young appear, followed by increasing relative abundance of the species. Without the long-term monitoring, knowledge of when, how, and where nonnative fish came to Aravaipa Creek and patterns of colonization, would be unknown. Colonization patterns revealed by the monitoring provide information important in management, such as the apparent vulnerability of nonnative fishes to population reduction by flooding. That knowledge identifies protection of a natural hydrograph as a high priority management goal as well as predicting the effectiveness of fish barriers. By monitoring Aravaipa Creek fishes on a regular and standardized basis, we gain the opportunity to respond to changes before they become a crisis situation.

Knowledge about nonnative invasions gained by monitoring identified the need for fish barriers in Aravaipa Creek. Timely action on that knowledge would have allowed for barrier installation in time to prevent the 1990 invasion of red shiner. But barrier efforts were not initiated until 1988 and no funding was available. Information from the 1990 monitoring that red shiner had gained access to Aravaipa Creek was still not sufficient to result in barrier installation. Monitoring information gave reassurance that there was still time, as the red shiner invasion appeared to have been unsuccessful. In 1994, barrier efforts gained momentum as a result of adoption as a mitigation measure for the Central Arizona Project (U.S.Fish and Wildlife Service 1994) and the barriers were to have been completed by October 1997. In autumn 1997, monitoring again detected red shiner in Aravaipa Creek. But barrier installation was delayed and did not occur until April 2001, too late to prevent the second wave of red shiner invasion, but still valuable for prevention other species from moving upstream into Aravaipa Creek. The monitoring gave us the information needed to take management action to prevent red shiner invasion, but the inability of the management entities to take the needed action in a timely manner resulted in failure to use that information effectively.

Long-term monitoring is important to adaptive management efforts. Such efforts require an understanding of what does and does not constitute directional change within the context of an intrinsically variable system and what factors influence that change. "Communities can be highly variable over a few years, but remain fairly constant over the long term. Evaluating measures and examining the variability associated with long-term change is useful because it increases our understanding of and our ability to predict response to disturbances." (Eby et al. 2003:1566). The long-term monitoring data on Aravaipa Creek enables us to detect trends in the fish community and identify natural disturbance regimes associated with streamflow and increasing nonnative fish as factors influencing those trends. This identifies, as high priority, those management actions that retain or increase aquatic habitat heterogeneity and that remove or control nonnative fish.

RECOMMENDATIONS

Based on this analysis, we recommend monitoring be continued in Aravaipa Creek on a long-term basis. The highest priority should be to continue biannual, spring-autumn monitoring at locations with methods consistent with the ASU/UofA existing data set. Contrary to concerns of AGFD expressed during recent permit discussions, there is nothing in the monitoring history, data, or literature that would indicate adverse impacts to the fish (individually or community-wide) from monitoring. Increased monitoring intensity, as recommended by the Desert Fishes Recovery Team and others, should be considered under the long-term effort and should use those locations and protocols so the data are comparable. This may be quarterly sampling or may be in the form of a year of monthly sampling on a periodic basis (e.g. once every 10 years).

Locations and protocols for the ASU/UofA long-term monitoring need to be clearly spelled out in one document. Additions, such as electrofishing, should be clearly identified as not part of the original protocol, and data from those additions segregated.

The recommendation of the January 12, 1999 meeting on Aravaipa Creek monitoring, to supplement, but not to replace or alter, the long-term ASU/Uof A monitoring, should be implemented. This monitoring should be tailored to meet other, short-term monitoring needs, such as the distribution and abundance of red shiner. Sampling locations and methods can then be targeted toward those specific needs.

In response to recent concerns regarding possible adverse effects of sampling on Aravaipa Creek fishes, voucher specimens for future monitoring work should be minimized. A complete series of voucher specimens should be taken once every five to ten years, with vouchers between that limited to any novel species or specimen encountered and any incidental mortalities. This does not include specimens taken for studies or research.

Data gathering for this report showed clearly that there is a need for a better way to store and report the data from Aravaipa Creek monitoring. No agency or organization had all of the data in one place. Previously, Minckley was the major repository of the data, however his untimely death left records difficult to locate. In his 1990 monitoring proposal, Minckley suggested that AGFD might be the appropriate repository for all the Aravaipa Creek monitoring data. However, AGFD does not enter data of other entities into the Nongame Native Fish database and were unable to retrieve hard copies of non-AGFD monitoring data. In addition, they discard paper copies of data after computer entry, so that any information other than fish numbers is not available (R. Bettaso and K. Young, AGFD, pers. com. May 29, 2004). Although it would seem appropriate for all of the involved agencies to keep full copies of all Aravaipa Creek monitoring data, more permanent provisions should be made for storing the data and auxiliary information in one location, including retention of raw data and field notes.

Reporting of Aravaipa Creek monitoring data is currently via email to interested parties a short time after the sampling. This is a continuation of the practice started in 1991 to distribute the original data immediately after it was acquired, although earlier distribution was via hard mail. The email system appears to work well. However, with the exception of Velasco’s 1993 report and the two AGFD reports (Bettaso et al. 1995 and Voeltz and Davidson 2002) there has been no attempt to provide formal periodic reports of the Aravaipa Creek monitoring data. A 5-year report with basic data and a brief summary would be valuable. As the most heavily invested entities in the monitoring effort, responsibility for production and dissemination of a 5-year report might be best handled by BLM or TNC. Periodic in-depth analyses should also be included in the monitoring program.

Perhaps most importantly, organizations with management responsibility and authority for Aravaipa Creek should put in place a mechanism for acting on information gained from monitoring in a timely manner. Without such a mechanism, monitoring efforts, although still valuable for information and research, lose much of their value as a management tool.

In addition to monitoring, the agencies and organizations should continue to encourage research on Aravaipa Creek fishes. The long history of theses, dissertations, and publications on Aravaipa Creek and its fishes should not end with the death of W.L. Minckley. Research at Aravaipa Creek should continue to support and promote conservation of southwestern native fishes. While we know much about the fishes of Aravaipa Creek, we cannot rest on past work, nor can we predict future trends. Given its uniqueness and importance, it is our obligation and responsibility to continue monitoring and research to insure long-term survival of the Aravaipa Creek aquatic fauna.

REFERENCES

Abarca, F.J. 1989. Potential overlap of food habits between spikedace (*Meda fulgida*) and red shiner (*Cyprinella lutrensis*). MS thesis. Arizona State University, Tempe, AZ.

Abarca, F.J. 1990. Letter from Arizona Game and Fish Department to W.L. Minckley (AZ State University) transmitting sampling data for Aravaipa Creek and the San Pedro River for September 29, 1990. Arizona Game and Fish Department, Phoenix, AZ.

Abarca, F.J. 1991. Letter of October 18, 1991 to R.A. Fortuno re sampling data for October 11-12, 1991 in Dr. Gelmacher's ponds, Aravaipa Canyon, Arizona. Arizona Game and Fish Department, Phoenix, AZ.

Adar, E.M. 1984. Quantification of aquifer recharge distribution using environmental isotopes and regional hydrochemistry. PhD Dissertation. University of Arizona, Tucson, AZ.

Adar, E.M. 1985. The hydrology project at Aravaipa Valley: summary and recommendations. Defenders of Wildlife, Tucson, AZ.

Adar, E.M., S.P. Neuman, and D.A. Woolhiser. 1988. Estimation of spatial recharge distribution using environmental isotopes and hydrochemical data. I. Mathematical model and application to synthetic data. II. Application to Aravaipa Valley in southern Arizona, USA. Journal of Hydrology 97:251-302.

Anderson, A.A. and D.A. Hendrickson. 1994. Geographic variation in morphology of spikedace, Meda fulgida, in Arizona and New Mexico. The Southwestern Naturalist 39(2):148-155.

Arizona Game and Fish Commission. 1982. Threatened native wildlife in Arizona. Arizona Game and Fish Department Publication, Phoenix, AZ.

Arizona Game and Fish Department. 1995. Final performance report to U.S. Fish and Wildlife Service for Section 6 project E5-6, Job number 31 (FCN5596), segment 2 of 2: survey, monitor and reintroduce threatened and endangered species; spikedace and loach minnow propagation. Arizona Game and Fish Department, Phoenix, AZ.

Arizona Game and Fish Department. 2002. Letter of August 21, 2002 to U.S. Fish and Wildlife Service re candidate status for roundtail and headwater chub. Arizona Game and Fish Department, Phoenix, AZ.

Arizona Game and Fish Department. 2004. Scientific collecting permit database entries for Aravaipa Creek 1985-1999. Arizona Game and Fish Department, Phoenix, AZ.

Arizona State University. 2002. SONFISHES: Lower Colorado River fish database. www.peter.unmack.net/gis/fish/colorado (abbrev.) [accessed: 2004].

Bagley, B.E. 1987. A survey for exotic fish in the Aravaipa watershed. Arizona Game and Fish Department, Phoenix, AZ.

Bagley, B.E. and P.C. Marsh. 1995. Swimming ability of non-native fishes and their potential interaction with exotic fish exclusion structures (EFES) at Aravaipa Creek, Arizona. U.S. Bureau of Reclamation, Phoenix, AZ.

Bahre, C.J. 1991. A legacy of change. Historic human impact on vegetation in the Arizona borderlands. University of Arizona Press, Tucson, AZ.

Barber, W.E. and W.L. Minckley. 1966. Fishes of Aravaipa Creek, Graham and Pinal Counties, Arizona. The Southwestern Naturalist 11(3):313-324.

Barber, W.E. and W.L. Minckley. 1983. Feeding ecology of a southwestern Cyprinid fish, the spikedace, *Meda fulgida* Girard. The Southwestern Naturalist 28(1):33-40.

Barber, W.E., D.C. Williams, and W.L. Minckley. 1970. Biology of the Gila spikedace, *Meda fulgida*, in Arizona. Copeia 1970(1):9-18.

Barnes, W.C. 1988. Arizona place names. University of Arizona Press, Tucson, AZ.

Bell, W.A. 1869. New tracks in North America. Volumes 1 and 2. Chapman and Hall, London, England.

Bestgen, K.R. 1985. Results of identification of collections of larval fish made in the upper Salt and Gila Rivers, Arizona. U.S. Fish and Wildlife Service, Albuquerque, NM.

Bettaso, R.H. 1992a. Memo to Dave Gori (The Nature Conservancy) and Jeff Simms (Bureau of Land Management) re Aravaipa Creek Monitoring Data. December 15, 1992. Arizona Game and Fish Department, Phoenix, AZ.

Bettaso, R.H. 1992b. Memo to Dave Gori (The Nature Conservancy) re Aravaipa Creek Monitoring Data. December 8, 1992. Arizona Game and Fish Department, Phoenix, AZ.

Bettaso, R.H. 1992c. Memo to Dave Gori (The Nature Conservancy) re Aravaipa Creek Monitoring. August 21, 1992. Arizona Game and Fish Department, Phoenix, AZ.

Bettaso, R.H. 1992d. Memo to Dave Gori (The Nature Conservancy) re July 11-12, 1992 Aravaipa sampling. August 4, 1992. Arizona Game and Fish Department, Phoenix, AZ.

Bettaso, R.H. 1993a. Memo to Dave Gori (The Nature Conservancy) and Jeff Simms (Bureau of Land Management) re Aravaipa Creek monitoring data. July 15, 1993. Arizona Game and Fish Department, Phoenix, AZ.

Bettaso, R.H. 1993b. Memo to Dave Gori (The Nature Conservancy) and Jeff Simms (Bureau of Land Management) re Aravaipa Creek monitoring data. June 30, 1993. Arizona State University, Phoenix, AZ.

Bettaso, R.H. 1993c. Memo to Dave Gori (The Nature Conservancy) and Jeff Simms (Bureau of Land Management) re Aravaipa Creek monitoring data. March 1, 1993. Arizona Game and Fish Department, Phoenix, AZ.

Bettaso, R.H. 1993d. Memo to Dave Gori (The Nature Conservancy) and Jeff Simms (Bureau of Land Management) re Aravaipa Creek monitoring data. March 31, 1993. Arizona Game and Fish Department, Phoenix, AZ.

Bettaso, R.H. 1993e. Memo to Dave Gori (The Nature Conservancy) and Jeff Simms (Bureau of Land Management) re Aravaipa Creek monitoring data. November 17, 1993. Arizona Game and Fish Department, Phoenix, AZ.

Bettaso, R.H. 1995. Memo to distribution list re Aravaipa Creek red shiner survey: summary report. December 6, 1995. Arizona Game and Fish Department, Phoenix, AZ.

Bettaso, R.H. 2000. Email to interested parties re November 2000 Aravaipa fish summary. December 18, 2000. Arizona Game and Fish Department, Phoenix, AZ.

Bettaso, R.H., D.B. Dorum, and K.L. Young. 1995. Results of the 1992-1994 Aravaipa Creek fish monitoring project. Arizona Game and Fish Department, Technical Report 73, Phoenix, AZ.

Blasius, H.B. 1998a. Memo to W.L. Minckley (Arizona State University) re Aravaipa Creek sampling/monitoring (with field data sheets). June 19, 1998. Arizona Game and Fish Department, Tucson, AZ.

Blasius, H.B. 1998b. Memorandum to Dave Gori (The Nature Conservancy) re Aravaipa Creek survey. July 20, 1998. Arizona Game and Fish Department, Tucson, AZ.

Bourke, J.G. 1980. On the border with Crook. Time-Life Books, Inc.,

Brown, M. 1990. Internal Memo; Arizona Game and Fish Department: Aravaipa Creek sampling for red shiner. Arizona Game and Fish Department, Phoenix, AZ.

Brown, M. 1991. Memo re fish surveys, February 21, 1991. Arizona Game and Fish Department, Phoenix, AZ.

Bruns, D.A. 1977. Distribution and abundance of benthic invertebrates in a Sonoran desert stream. Arizona State University, MS thesis, Tempe, AZ.

Bruns, D.A. and W.L. Minckley. 1980. Distribution and abundance of benthic invertebrates in a Sonoran Desert stream. Journal of Arid Environments 3:117-131.

Brunson, E. and D.F. Gori. 2001. Letter of February 22, 2001 to Sally Stefferud (Fish and Wildlife Service), Rob Clarkson (Bureau of Reclamation) and Paul Marsh (Arizona State University) transmitting proposal for analysis of Aravaipa Creek fish data. The Arizona Nature Conservancy, Tucson, AZ.

Campbell, D. 1988. Memo of January 11, 1988 to involved parties, re Aravaipa Creek Coop (Holy Joe Ranch land gift). The Arizona Nature Conservancy, Tucson, AZ.

Carveth, C. 2004. Email of August 14, 2004 to S. Stefferud re Aravaipa Creek sampling information. University of Arizona, Tucson, AZ.

Childs, M.R. 2004. Development of propagation techniques for loach minnow. Final report to U.S. Bureau of Reclamation, September 30, 2004. Arizona Game and Fish Department, Phoenix, AZ.

Clarkson, R.W. 1982. Morphology and feeding behavior of hybrids between *Catostomus insignis* and *Pantosteus clarki* (Catostomidae). MS Thesis. Arizona State University, Tempe, AZ.

Clarkson, R.W. 1996. Long-term monitoring plan for fish populations in selected waters of the Gila River basin, Arizona. U.S. Bureau of Reclamation, Phoenix, AZ.

Clarkson, R.W. 2001. Aravaipa Creek fish collection forms, July 5, 2001. U.S. Bureau of Reclamation, Phoenix, AZ.

Clarkson, R.W. 2002. Aravaipa Creek fish collection forms, October 4, 2002. U.S. Bureau of Reclamation, Phoenix, AZ.

Clarkson, R.W. 2003. Aravaipa Creek fish collection forms, October 15, 2003. U.S. Bureau of Reclamation, Phoenix, AZ.

Clarkson, R.W. and W.L. Minckley. 1988. Morphology and foods of Arizona Catostomid fishes: *Catostomus insignis*, *Pantosteus clarki*, and their putative hybrids. Copeia 1988(2):422-433.

Collazo, T. 1991. Memo of February 20, 1991 to Stefferud, Simms, Dahlem, Brown, Abarca, Minckley, and Jakle re minutes of February 12 meeting on Aravaipa fish protection and revised memorandum of understanding. The Arizona Nature Conservancy, Tucson, AZ.

Collins, J.P., J.E. Deacon, T.E. Dowling, and P.C. Marsh. 2002. Obituary, Wendell Lee Minckley 1935-2001. Copeia 2002(1):258-262.

Cooke, R.U. and R.W. Reeves. 1976. Arroyos and environmental change in the American South-west. Clarendon Press, Oxford, England.

Corman, T.E., M. Brown, and F.J. Abarca. 1989. Report of the 1989 October Fish Count. Arizona Game and Fish Department, Phoenix, AZ.

Cullinan, S. 1990. Hydrology of Aravaipa Creek. U.S. Fish and Wildlife Service, Albuquerque, NM.

Davis, G.P., Jr. 1986. Man and wildlife in Arizona. Arizona Game and Fish Department, Phoenix, AZ.

Deacon, J.E. and W.L. Minckley. 1974. Desert fishes. Pp. 385-488 *in:* W.L. Minckley ed. Desert Biology, Volume II. Academic Press, New York, NY.

DeMarais, B.D. 1986. Morphological variation in *Gila* (Pisces: Cyprinidae) and geologic history: lower Colorado River basin. M.S. Thesis. Arizona State University, Tempe, AZ.

DeMarais, B.D. 1992. Genetic relationships among fishes allied to the genus *Gila* (Teleostei: Cyprinidae) from the American southwest. PhD Dissertation. Arizona State University, Tempe, AZ.

Desert Fishes Council. 1971. How can the Desert Fishes Council become more effective? Proceedings of the Desert Fishes Council 3:41-42.

Desert Fishes Recovery Team. 1986. Minutes of the Desert Fishes Recovery Team, April 17-18, 1986. U.S. Fish and Wildlife Service, Phoenix, AZ.

Desert Fishes Recovery Team. 1990. Minutes of the Desert Fishes Recovery Team, November 7-8, 1990. U.S. Fish and Wildlife Service, Phoenix, AZ.

Desert Fishes Recovery Team. 1991. Minutes of the February 5-6, 1991 meeting. U.S. Fish and Wildlife Service, Phoenix, AZ.

Desert Fishes Recovery Team. 1992a. Letter to U.S. Fish and Wildlife Service Regional Director, March 10, 1992. U.S. Fish and Wildlife Service, Phoenix, AZ.

Desert Fishes Recovery Team. 1992b. Minutes of the February 5-6, 1992 meeting. U.S. Fish and Wildlife Service, Phoenix, AZ.

Desert Fishes Recovery Team. 1997. Minutes of the Deceber 19, 1997 meeting. U.S. Fish and Wildlife Service, Phoenix, AZ.

Desert Fishes Recovery Team. 1998. Minutes of the June 16, 1998 meeting. U.S. Fish and Wildlife Service, Phoenix, AZ.

Desert Fishes Recovery Team. 1999. Minutes of the January 14, 1999 meeting. U.S. Fish and Wildlife Service, Phoenix, AZ.

Desert Fishes Team. 2003. Status of Federal and State-listed warm water fishes of the Gila River basin, with recommendations for management. Report 1. Desert Fishes Team, Phoenix, AZ.

Desert Fishes Team. 2004. Status of unlisted native fishes of the Gila River basin, with recommendations for management. Report 2. Desert Fishes Team, Phoenix, AZ.

Dobyns, H.F. 1981. From fire to flood: historic human destruction of Sonoran Desert riverine oasis. Ballena Press Anthropological Papers No. 20,

Douglas, M.E., P.C. Marsh, and W.L. Minckley. 1994. Indigenous fishes of western North America and the hypothesis of competitive displacement: *Meda fulgida* (Cyprinidae) as a case study. Copeia 1994(1):9-19.

Dowling, T.E. and B.D. DeMarais. 1993. Evolutionary significance of introgessive hybridization in cyprinid fishes. Nature 362:444-446.

Dowling, T.E. and P.C. Marsh. 1999. Comparative genetics of native fishes in Salt River Project canals and in upper Salt River system: roundtail chub, desert sucker, and Sonora sucker. Report to U.S. Bureau of Reclamation for contract #98-FG-32-0020, Phoenix, AZ.

Eby, L.A., W.F. Fagan, and W.L. Minckley. 2003. Variability and dynamics of a desert stream community. Ecological Applications 13(6):1566-1579.

Ellingson, C.T. 1980. The hydrology of Aravaipa Creek, southeastern Arizona. MS Thesis. University of Arizona, Tucson, AZ.

Fuller, J.E. and L. Roberts. 1985. A paleohydrologic reconstruction of the October 1983 flood discharge of Aravaipa Creek. Report to the U.S. Bureau of Reclamation, Safford, AZ.

Ginnelly, G. 1977. Statewide Fisheries Investigations. Statewide survey of aquaitc resources. Federal Aid Project F-7-R-19, Job VI, Segment 1 of continuing. Arizona Game and Fish Department, Phoenix, AZ.

Gori, D.F. 1998. Memo to Heidi Blasius (Arizona Game and Fish Department) re Aravaipa shiner survey, July 6-7, 1998. July 10, 1998. The Nature Conservancy, Tucson, AZ.

Gori, D.F. and J.R. Simms. 1997. Memo to interested parties re monitoring data: Aravaipa Creek, 16-17 October 1997. The Nature Conservancy, Tucson, AZ.

Gould, J.A. and R.P. Wilson. 1976. Map showing ground-water conditions in the Aravaipa Valley area, Graham and Pinal Counties, Arizona -- 1975. Open file report 76-107, Water Resources Investigations, US Geological Survey, Tucson, AZ.

Hadley, D., P. Warshall, and D. Bufkin. 1991. Environmental change in Aravaipa, 1870-1970. An ethnoecological survey. Bureau of Land Management, Cultural Resources Series No. 7, Phoenix, AZ.

Hardy, T.B., B. Bartz, and W. Carter. 1990. Instream flow recommendations for the fishes of Aravaipa Creek, Arizona. Twelve-Nine, Inc., Logan, UT.

Hastings, J.R. 1959. Vegetation change and arroyo cutting in southeastern Arizona. University of Arizona, Arid Lands Program Paper No. 3, Tucson, AZ.

Heath, W.G. 1962. Maximum temperature tolerance as a function of constant temperature acclimation in the Gila topminnow (*Poeciliopsis occidentalis*). PhD Dissertation. University of Arizona, Tucson, AZ.

Hendrickson, D.A. 1987a. Geographic variation in morphology of *Agosia chrysogaster*, a Sonoran desert cyprinid fish. PhD Dissertation. Arizona State University, Tempe, AZ.

Hendrickson, D.A. 1987b. Memo - update on nongame fish activities, August 26, 1987. Arizona Game and Fish Department, Phoenix, AZ.

Hendrickson, D.A. and W.L. Minckley. 1984. Cienegas -- vanishing climax communities of the American southwest. Desert Plants 6(3):131-175.

Holanov, S.H. 1984. The effects of current speed and food on non-catastrophic drift with reference to the ecology of Aravaipa Creek, Arizona. PhD Dissertation. University of Arizona, Tucson, AZ.

Hutton, N.H. 1853. Engineers report -- El Paso and Fort Yuma wagon road. *in* Records of the Office of the Secretary of the Interior relating to wagon roads, 1857-1881. National Archives film microcopies, no. M95, roll 3., Washington D.C. (as cited in Minckley 1981)

Jackson, W., T. Martinez, P.E. Cuplin, W.L. Minckley, B. Shelby, P. Summers, D. McGlothlin, and B. Van Haveren. 1987. Assessment of water conditions and management opportunities in support of riparian values: BLM San Pedro River properties, Arizona. Project completion report. USDI Bureau of Land Mangement, Denver, CO.

JE Fuller Hydrology and Geomorphology, I. 2000. Aravaipa Canyon Geohydrology Assessment. U.S. Fish and Wildlife Service, Phoenix, AZ.

Johnson, J.E. 1977. Letter to files, Gila topminnow survey, Arizona, 15-19 March, 1977. U.S. Fish and Wildlife Service, Albuquerque, NM.

Kepner, W.G. 1982. Reproductive biology of longfin dace (*Agosia chrysogaster*) in a Sonoran Desert stream, Arizona. MS Thesis. Arizona State University, Tempe, AZ.

King, K.A. and M. Martinez. 1998. Metals in fish collected from Aravaipa Creek, Arizona, October 1997. U.S. Fish and Wildlife Service, Phoenix, AZ.

King, K.A., M. Martinez, and M. Haberstich. 1997. Table 1. Aravaipa Creek: relative fish abundance, October 28, 1997. U.S. Fish and Wildlife Service, Phoenix, AZ.

LaBounty, J.F. 1973. Status of the spikedace (*Meda fulgida*) and loach minnow (*Tiaroga cobitis*). Proceedings of the Desert Fishes Council 5th:107.

Leach, J.B. 1858. Itinerary of the El Paso and Fort Yuma wagon road expedition. National Archives film microcopies, No. M95, roll 3., Washington, D.C. (as cited in Minckley 1981)

Leopold, L.B. 1951. Vegetation of southwestern watersheds in the nineteenth century. The Geographical Review 41:295-316.

Lowe, C.H. and W.G. Heath. 1969. Behavioral and physiological responses to temperatures in the desert pupfish, *Cyprinodon macularius*. Physiological Zoology 42:53-59.

Marsh, P.C. 1991a. Loach minnow *Tiaroga cobitis* recovery plan. U.S. Fish and Wildlife Service, Albuquerque, NM.

Marsh, P.C. 1991b. Spikedace *Meda fulgida* recovery plan. U.S. Fish and Wildlife Service, Albuquerque, NM.

Marsh, P.C., F.J. Abarca, M.E. Douglas, and W.L. Minckley. 1989. Spikedace (*Meda fulgida*) and loach minnow (*Tiaroga cobitis*) relative to introduced red shiner (*Cyprinella lutrensis*). Arizona Game and Fish Department, Phoenix, AZ.

Marsh, P.C., J.E. Brooks, D.A. Hendrickson, and W.L. Minckley. 1990. Fishes of Eagle Creek, Arizona, with records for threatened spikedace and loach minnow (Cyprinidae). Journal of the Arizona-Nevada Academy of Science 23(2):107-116.

Matter, W.J. 1991. Potential for transfer of non-native fish in Central Arizona Project canal waters to the Gila River system. Bureau of Reclamation, Phoenix, AZ.

McNatt, R.M. 1973. Status of the native Arizona fishes of Aravaipa Creek. Proceedings of the Desert Fishes Council X:116-117.

Meffe, G.K. and W.L. Minckley. 1987. Persistence and stability of fish and invertebrate assemblages in a repeatedly disturbed Sonoran desert stream. The American Midland Naturalist 117(1):177-191.

Miller, R.R. 1950. Field notes for Aravaipa Creek, May 10-11, 1950. University of Michigan Museum of Zoology, Ann Arbor, Michigan.

Miller, R.R. 1961. Man and the changing fish fauna of the American southwest. Papers of the Michigan Academy of Science, Arts, and Letters XLVI:365-404.

Miller, R.R., C. Hubbs, and F.H. Miller. 1991. Icthyological exploration of the American west: the Hubbs-Miller era, 1915-1950. Pp. 19-40 *in:* W.L. Minckley and J.E. Deacon, eds. Battle against extinction; Native fish management in the American West. University of Arizona Press, Tucson, AZ.

Minckley, W.L. 1969. Attempted re-establishment of the Gila topminnow within its former range. Copeia 1969(1):193-194.

Minckley, W.L. 1972. A survey of selected physico-chemical and biologic parameters of Aravaipa Creek, Arizona. A report to The Defenders of Wildlife and the U.S. Bureau of Land Management, Safford, Arizona. Arizona State University, Tempe, AZ.

Minckley, W.L. 1973. 1973 survey of fishes of Aravaipa Creek, Graham and Pinal counties, AZ. Arizona State University, Tempe, AZ.

Minckley, W.L. 1977. Sonoran Desert, United States; area report. Proceedings of the Desert Fishes Council IX:352-353.

Minckley, W.L. 1981. Ecological studies of Aravaipa Creek, central Arizona, relative to past, present, and future uses. With 1982 addendum. USDI Bureau of Land Management, Safford, AZ.

Minckley, W.L. 1985. Native fishes and natural aquatic habitats in U.S. Fish and Wildlife Service Region II west of the continental divide. Arizona State University, Tempe, AZ.

Minckley, W.L. 1987. Fishes and aquatic habitats of the upper San Pedro River system, Arizona and Sonora. U.S. Bureau of Land Management, Denver, CO.

Minckley, W.L. 1990. Summary of red shiner survey, lower Aravaipa Creek, October 1990 with tabulation of Minckley's pre-1991 data on Aravaipa Creek spikedace and loach minnow. Arizona State University, Tempe, AZ.

Minckley, W.L. 1992. 10-11 October 1992, Arizona, Pinal Co., Aravaipa Creek at lower three stations (Wood's Ranch, Jay White Ranch, and "Sycamore Tree)." Notes taken from hard drive of his computer, May 2004. Arizona State University, Tempe, AZ.

Minckley, W.L. 1995. Data for Aravaipa Creek fish count, sampling dates: October 7-8, 1995. Arizona State University, Tempe, AZ.

Minckley, W.L. 1996. Data for Aravaipa Creek fish count, sampling dates: April 5-6, 1996. With field data sheets. Arizona State University, Tempe, AZ.

Minckley, W.L. 1998. Letter of May 19, 1998 with results of Aravaipa Creek sampling. Arizona State University, Tempe, AZ.

Minckley, W.L. 2000. Summary tables for sampling, Aravaipa Creek, Arizona (unpublished). Combined annual collections in number of fish taken; seasonal samples and annual samples. Arizona State University, Tempe, AZ.

Minckley, W.L. 2001. Untitled manuscript regarding long-term monitoring studies in Aravaipa Creek. Arizona State University, Tempe, AZ.

Minckley, W.L. and W.E. Barber. 1971. Some aspects of the biology of the longfin dace, a cyprinid fish characteristic of streams in the Sonoran desert. The Southwestern Naturalist 15(4):459-464.

Minckley, W.L. and J.E. Brooks. 1985. Transplantations of native Arizona fishes: records through 1980. Journal of the Arizona-Nevada Academy of Science 20(2):73-89.

Minckley, W.L. and B.D. DeMarais. 2000. Taxonomy of chubs (Teleostei, Cyprinidae, Genus *Gila*) in the American southwest with comments on conservation. Copeia 2000(1):251-256.

Minckley, W.L. and C.A. Karp. 1986. Aravaipa Creek fishes: October 1985. Arizona State University, Tempe, AZ.

Minckley, W.L. and G.K. Meffe. 1987. Differential selection by flooding in stream fish communities of the arid American southwest. Pp. 93-104 *in:* W.J. Matthews and D.C. Heins, eds. Community and evolutionary ecology of North American stream fishes. University of Oklahoma Press, Norman, OK.

Minckley, W.L. and J.N. Rinne. 1985. Large woody debris in hot-desert streams: an historical review. Desert Plants 7(3):142-153.

Minckley, W.L. and R. Timmons. 1993. Memo to interested parties re monitoring data: Aravaipa Creek, 6-8 July, 1993. July 10, 1993. Arizona State University, Tempe, AZ.

Minckley, W.L., A.L. Velasco, and C.R. Reimus. 1993. Memo to interested parties re monitoring data: Aravaipa Creek, 23 January and 7 February 1993. February 25, 1993. Arizona State University, Tempe, AZ.

Minckley, W.L., A.L. Velasco, and R. Timmons. 1994. Memo to interested parties re monitoring data: Aravaipa Creek, 25-26 June 1994. June 27, 1994. Arizona State University, Tempe, AZ.

Moody, T.O. 1999. Regional relationships for bankfull stage in natural channels of central and southern Arizona. Final Report. Northern Arizona University, Flagstaff, AZ.

Moody, T.O., W. Odem, and D.G. Neary. 1998. Return intervals for bankfull discharge in ephemeral and perennial streams of central and southern Arizona. Pp. 25-28 *in:* G.J. Gottfried ed. Hydrology and water resources in Arizona and the southwest. Hydrology Section, Arizona-Nevada Academy of Science, Glendale, AZ.

Moore, S.D., M.E. Wilkosz, and S.K. Brickler. 1990. The recreational impact of reducing the "laughing waters" of Aravaipa Creek, Arizona. Rivers 1(1):43-50.

Morfin, O., M.H. Conklin, T.L. Corley, J.B. Hiskey, J. Ruiz, and J.T. Chesley. 2003. The use of Pb isotopes, total metals analysis and total metals ratios to characterize Pb transport and fate in an interrupted stream, Aravaipa Creek, SE Arizona. Hydrometallurgy 2003, Proceedings of the 5th International Symposium in honor of Professor Ian Ritchie. C.A. Young, A.M. Alfantazi, C.G. Anderson, A. James, D.B. Dreising, and B. Harris (eds.) The Minerals, Metals, and Materials Society, Warrendale, PA.

Mpoame, M. 1981. Parasites of some fishes native to Arizona and New Mexico with ecological notes. PhD Dissertation. Arizona State University, Tempe, AZ.

Mpoame, M. 1982. Ecological notes on parasites of fishes from Aravaipa Creek, Arizona. Journal of the Arizona-Nevada Academy of Science 17:45-51.

Mpoame, M. and J.N. Rinne. 1983. Parasites of some fishes native to Arizona and New Mexico. The Southwestern Naturalist 28(4):399-405.

Otis, E.O., IV. 1994. Distribution, abundance, and composition of fishes in Bright Angel and Kanab Creeks, Grand Canyon National Park, Arizona. University of Arizona. MS Thesis, Tucson, AZ.

Parke, J.G. 1857. Report of explorations for railroad routes. *in* Explorations and surveys to ascertain the most practicable and economical route for a railroad from the Mississippi River to the Pacific Ocean. U.S. 33rd Congress, 2nd Session, Senate Ex. Doc. 78, Vol. 7.

Parmenter, H.L. and S.P. Platania. 2004. Captive propagation and rearing of spikedace, *Meda fulgida*. Final report to U.S. Bureau of Reclamation, Phoenix, AZ.

Propst, D.L. 2002. Systematic investigations of warmwater fish communities. FW-17-RD completion report. 1 July 1997-30 June 2002. Report to U.S. Fish and Wildlife Service. New Mexico Department of Game and Fish, Santa Fe, NM.

Reinthal, P.N. 2002. Email of November 5, 2002 to interested parties re Aravaipa, Fall 2002. University of Arizona, Tucson, AZ.

Reinthal, P.N. 2003a. Email to interested parties re Aravaipa fish sampling April 5-6, 2003. University of Arizona, Tucson, AZ.

Reinthal, P.N. 2003b. Email of October 7, 2003 to interested parties re Fall 2003 Aravaipa. University of Arizona, Tucson, AZ.

Reinthal, P.N. 2004a. Aravaipa Spring 2004. Unpublished data. University of Arizona, Tucson, AZ.

Reinthal, P.N. 2004b. Aravaipa Fall 2004. Unpublished data. University of Arizona, Tucson, AZ.

Remington, R.K. 2002. Larval fish drift of Aravaipa Creek. MS thesis. Arizona State University, Tempe, AZ.

Rinne, J.N. 1969. Cyprinid fishes of the genus *Gila* from the lower Colorado River basin. MS thesis. Arizona State University, Tempe, AZ.

Rinne, J.N. 1976. Cyprinid fishes of the genus *Gila* from the lower Colorado River basin. The Wasmann Journal of Biology 34(1):65-107.

Rinne, J.N. 1985. Physical habitat evaluation of small stream fishes: point vs. transect, observation vs. capture methodologies. Journal of Freshwater Ecology 3(1):121-131.

Rinne, J.N. 1989. Physical habitat use by loach minnow, *Tiaroga cobitis* (Pisces: Cyprinidae), in southwestern desert streams. The Southwestern Naturalist 34(1):109-117.

Rinne, J.N. 1991. Habitat use by spikedace, *Meda fulgida* (Pisces: Cyprinidae) in southwestern streams with reference to probable habitat competition by red shiner, *Notropis lutrensis* (Pisces: Cyprinidae). The Southwestern Naturalist 36(1):7-13.

Rinne, J.N. 1992. Physical habitat utilization of fish in a Sonoran Desert stream, Arizona, southwestern United States. Ecology of Freshwater Fish 1:35-41.

Rinne, J.N., P. Boucher, D. Miller, A. Telles, J. Monzingo, R. Pope, B.P. Deason, C. Gatton, and B. Merhege. 1999. Comparative fish community structure in two southwestern desert rivers. Proceedings of the symposium on interactions of native-nonnative fishes, July 13-14, 1999, Las Vegas, NV. U.S. Fish and Wildlife Service, Albuquerque, NM.

Rinne, J.N. and J. Janisch. 1995. Coldwater fish stocking and native fishes in Arizona: past, present, and future. American Fisheries Society Symposium 15:397-406.

Rinne, J.N. and E. Kroeger. 1988. Physical habitat used by spikedace, *Meda fulgida*, in Aravaipa Creek, Arizona. Proceedings of the Western Association of Fish and Wildlife Agencies Agenda 68:1-10.

Roberts, L.K. 1987. Paleohydrologic reconstruction, hydraulics, and frequency-magnitude relationships of large flood events along Aravaipa Creek. MS Thesis. University of Arizona, Tucson, AZ.

Schreiber, D.C. 1975. 1974 survey of fishes of Aravaipa Creek, Graham and Pinal counties, Arizona. University of Arizona, Tempe, AZ.

Schreiber, D.C. 1978. Feeding interrelationships of fishes of Aravaipa Creek, Arizona. Arizona State University, Tempe, AZ.

Schreiber, D.C. and W.L. Minckley. 1981. Feeding interrelations of native fishes in a Sonoran Desert stream. Great Basin Naturalist 41(4):409-426.

Sheldon, D.L. and D.A. Hendrickson. 1988. Report of the 1988 October Fish Count. Arizona Game and Fish Department, Phoenix, AZ.

Siebert, D.J. 1980. Movements of fishes in Aravaipa Creek, Arizona. Arizona State University, Tempe, AZ.

Simms, J.R. 1995a. Field notes, data sheets, and maps of Turkey Creek (Aravaipa basin) sampling, March 13, 1995. U.S. Bureau of Land Management, Tucson, AZ.

Simms, J.R. 1995b. File report on fishery inventory of Oak Grove Canyon, Graham Co. and Deer Creek, Pinal Co. July 1995. U.S. Bureau of Land Management, Tucson, AZ.

Simon, J.R., R.R. Miller, and M.H. Frost, Jr. 1943. Correspondence between the three authors regarding fish specimens from Aravaipa Creek and Tanque Verde Creek, with information on other streams. August 20, 1943, Nov. 2, 1943, Jan. 2, 1944, and Feb. 24, 1944. From collection of University of Michigan Museum of Zoology, Ann Arbor, MI.

Stefferud, J.A. and S.E. Stefferud. 1993. The status of Gila topminnow, and results of monitoring of the fish community in Redrock Canyon, Coronado National Forest, Santa Cruz County, Arizona, 1979-present. Proceedings of the Desert Fishes Council 25:16-17.

Stefferud, J.A. and S.E. Stefferud. 2003. Systematic investigations of warm-water fish assemblages in San Pedro and Babocomari Rivers, San Pedro Riparian National Conservation Area, Arizona, 1990-2003. Report to U.S. Bureau of Land Management, Sierra Vista, AZ.

Stefferud, J.A., K.L. Young, R.W. Clarkson, C.O. Minckley, J.R. Simms, and A. Sillas. 1998. Lower Colorado River area report. Proceedings of the Desert Fishes Council 30:42-44.

Stefferud, S.E. 1983a. Status report for *Meda fulgida* Girard (spikedace). U.S. Fish and Wildlife Service, Albuquerque, NM.

Stefferud, S.E. 1983b. Status report for *Tiaroga cobitis* Girard (loach minnow). U.S. Fish and Wildlife Service, Albuquerque, NM.

Stefferud, S.E. 1999. Notes, agenda, and draft monitoring plan from January 12, 1999 meeting on Aravaipa Creek monitoring. U.S. Fish and Wildlife Service, Phoenix, AZ.

Tellman, B., R. Yarde, and M.G. Wallace. 1997. Arizona's changing rivers: how people have affected the rivers. University of Arizona, Tucson, AZ.

Tibbets, C.A. 1993. Patterns of genetic variation in three cyprinid fishes native to the American southwest. MS Thesis. Arizona State University, Tempe, AZ.

Tibbets, C.A. 1998. Evolutionary genetiics of *Agosia chrysogaster*. PhD Dissertation. Arizona State University, Tempe, AZ.

Tibbets, C.A. and T.E. Dowling. 1996. Effects of intrinsic and extrinsic factors on population fragmentation in three species of North American minnow (Teleostei:Cyprinidae). Evolution 59(3):1280-1292.

Turner, P.R. and R.J. Tafanelli. 1983. Evaluation of the instream flow requirements of the native fishes of Aravaipa Creek, Arizona by the incremental methodology. U.S. Fish and Wildlife Service, Albuquerque, NM.

U.S. Bureau of Land Management. 1987. Environmental assessment for acquired lands exotic fish removal. U.S. Bureau of Land Management, Safford, AZ.

U.S. Bureau of Reclamation. 1988. Final environmental assessment: construction of fish barriers on Aravaipa Creek. November 1998. U. S. Bureau of Reclamation, Phoenix, AZ

U.S. Fish and Wildlife Service. 1993. Memorandum of July 30, 1993 from State Supervisor to Regional Director re unregulated activities adversely affecting listed fish in Arizona. U.S. Fish and Wildlife Service, Phoenix, AZ.

U.S. Fish and Wildlife Service. 1994. Final biological opinion on the transportation and delivery of Central Arizona Project water to the Gila River Basin (Hassayampa, Agua Fria, Salt, Verde, San Pedro, middle and upper Gila Rivers, and associated tributaries) in Arizona and New Mexico. 2-21-90-F-119. April 30, 1994, amended June 22, 1995, May 6, 1998, July 24, 1998, November 4, 1999, and June 3, 2000. U.S. Fish and Wildlife Service, Albuquerque, NM.

U.S. Fish and Wildlife Service. 2001a. Background information on the Central Arizona Project and nonnative aquatic species in the Gila River Basin (excluding the Santa Cruz River Subbasin). U.S. Fish and Wildlife Service, Phoenix, AZ.

U.S. Fish and Wildlife Service. 2001b. Revised biological opinion on transportation and delivery of Central Arizona Project water to the Gila River basin (Hassayampa, Agua Fria, Salt, Verde, San Pedro, middle and upper Gila Rivers and associated tributaries) in Arizona and New Mexico and its potential to introduce and spread nonnative aquatic species. 2-21-90-F-119a. April 17, 2001. U.S. Fish and Wildlife Service, Phoenix, AZ.

U.S. Fish and Wildlife Service. 2003. Letter of June 4, 2003 to the Center for Biological Diversity regarding petition of April 2, 2003 for listing of roundtail and headwater chub. U.S. Fish and Wildlife Service, Albuquerque, NM.

U.S. Geological Survey. 2004. Monthly streamflow statistics for the nation: USGS 09473000 Aravaipa Creek near Mammoth. http://nwis.waterdata.usgs.gov/nwis/monthly/

Unmack, P.J. 1998. Email of November 2, 1998 to interested parties re Aravaipa results. Arizona State University, Tempe, AZ.

Unmack, P.J. 1999a. Email of April 20, 1999 to interested parties re Aravaipa results April 9-11, 1999. Arizona State University, Tempe, AZ.

Unmack, P.J. 1999b. Email to interested parties re Aravaipa results October 22-23, 1999. Arizona State University, Tempe, AZ.

Unmack, P.J. 2000. Email of October 23, 2000 to interested parties re Aravaipa results, October 21, 2000. Arizona State University, Tempe, AZ.

Unmack, P.J. 2001a. Email of April 30, 2001 to interested parties re Aravaipa results April 14-15, 2001. Arizona State University, Tempe, AZ.

Unmack, P.J. 2001b. Email of November 8, 2001 to interested parties re Aravaipa results November 2-4, 2001. Arizona State University, Tempe, AZ.

Unmack, P.J. 2002a. Arizona State University GIS manual for use with the lower Colorado Basin fish database.

Unmack, P.J. 2002b. Email of April 23, 2002 to interested parties re Aravaipa Creek - April 13-14, 2002. Arizona State University, Tempe, AZ.

Unmack, P.J., and W.F. Fagan. 2004. Convergence of differentially invaded systems toward invader-dominance: time-lagged invasions as a predictor in desert fish communities. Biological Invasions 6:233-143.

Utah Division of Wildlife Resources. 2004. Draft range-wide conservation agreement for roundtail chub *Gila robusta*, bluehead sucker *Catostomus discobolus*, and flannelmouth sucker *Catostomus latipinnis*. Utah Department of Natural Resources, Salt Lake City, UT.

Uyeno, T. and R.R. Miller. 1973. Chromosomes and the evolution of Plagopterin fishes (Cyprinidae) of the Colorado River system. Copeia 1973(4):776-782.

Velasco, A.L. 1993a. Fish population sampling: Aravaipa Creek, Graham and Pinal Counties, Arizona, 1991-1992. The Nature Conservancy, Tucson, AZ.

Velasco, A.L. 1993b. Trip report for Anthony Velasco, Aravaipa Creek east end, 22-24 October 1993. October 25, 1993. Arizona State University, Tempe, AZ.

Velasco, A.L. 1997. Fish population response to variance in stream discharge, Aravaipa Creek, Arizona. MS Thesis. Arizona State University, Phoenix, AZ.

Vives, S.P. 1995. Spikedace and loach minnow artificial propagation, final report. Arizona Game and Fish Department, Phoenix, AZ.

Vives, S.P. and W.L. Minckley. 1990. Autumn spawning and other reproductive notes on loach minnow, a threatened cyprinid fish of the American southwest. The Southwestern Naturalist 35(4):451-454.

Voeltz, J.B. 2002. Roundtail chub (*Gila robusta*) status survey of the lower Colorado River basin. Arizona Game and Fish Department, Phoenix, AZ.

Voeltz, J.B. and R.F. Davidson. 2002. Aravaipa Creek fish monitoring and survey results from 1999 and 2000. Arizona Game and Fish Department, Phoenix, AZ.

Weedman, D.A. 1999a. Email of December 6, 1999 to interested parties re Aravaipa data summary. Arizona Game and Fish Department, Phoenix, AZ.

Weedman, D.A. 1999b. Summary of monitoring of Aravaipa Creek October 18-20, 1999. Unpublished report. Arizona Game and Fish Department, Phoenix, AZ.

Williams, C.M. 1991a. Fish movement relative to physical environment in a Sonoran desert stream. MS Thesis. Arizona State University, Tempe, AZ.

Williams, J.E. 1991b. Preserves and refuges for native western fishes: History and management. Pp. 171-189 *in:* W.L. Minckley and J.E. Deacon, eds. Battle against extinction: Native fish management in the American west. University of Arizona, Tucson, AZ.

Williams, J.E., D.B. Bowman, J.E. Brooks, A.A. Echelle, R.J. Edwards, D.A. Hendrickson, and J.J. Landye. 1985. Endangered aquatic ecosystems in North American deserts with a list of vanishing fishes of the region. Journal of the Arizona-Nevada Academy of Science 20(1):1-62.

Winn, H.E. and R.R. Miller. 1954. Native postlarval fishes of the lower Colorado River basin, with a key to their identification. California Fish and Game 40(3):273-285.

Young, K.L. 1994. Fall Fish Count Summary 1988-1993. Arizona Game and Fish Department, Phoenix, AZ.

Young, K.L. and M.A. Lopez. 1995. Fall fish count summary 1988-1994. Arizona Game and Fish Department, Technical Report 81, Phoenix, AZ.

APPENDIX 1

DOCUMENTS USED IN ARAVAIPA CREEK SAMPLING HISTORY
(for sampling not listed below, see SONFISHES database in Appendix 3)

SOURCE	SAMPLING DATE	COLLECTOR[1]	STREAM REACH[2]
Simon et al. 1943	1943, Oct. 31	Simon, Hendrickson, and Frost (UA)	L
Miller 1950	1950, May 10-11	Miller (UMMZ)	M
Minckley 2000	1963-2002 (spring & fall)	Minckley et al. (ASU)	L, M, U
Barber and Minckley 1966	1943, October 31 1950, May 10-11 1953-60 1963, April 10 1964, April 17-18; Nov. 6; Dec. 21-23 1965, Feb.27, July 22 1965, Feb. 27-28; May 1	Simon (UA) Miller (UMMZ) Lowe and Heath (UA Arnold (ASU) Minckley and Barber (ASU) Minckley and Barber (ASU) Minckley and Barber (ASU)	L M L, M, U L L, M, U floodplain pond L, M
Barber et al. 1970	1966, June July, Aug, Sept., Oct., Nov., Dec. 1967, Jan, Feb., Mar., April, May, June, July	Barber, Williams, Minckley (ASU) Barber, Williams, Minckley (ASU)	L, M, U L, M, U
Minckley 1972	1972, April 22-May 6	Minckley (ASU)	L, M, U, T
Minckley 1973	1973, April-May; Sept.	Minckley (ASU)	M, U
Schreiber 1975	1975, Nov. 9-11	Schreiber, Minckley (ASU)	L, M, U
Schreiber 1978	1975, Jan 9-10; April 18-19; July 11-12; Oct. 24-25 1976, Jan. 30-31	Schreiber (ASU)	U
Johnson 1977 Ginnelly 1977	1977, March 18	Johnson (FWS), Minckley (ASU), Ginnelly (GF)	U
Kepner 1982	1977, Sept., Oct., Nov., Dec. 1978, Jan., Feb., Mar., April, May, June, July, Aug.	Kepner (ASU)	L, U
Siebert 1980 (plus data printout)	1978, Jan., Feb., Mar., April, June, July, Aug., Sept., Oct., Nov. 1979, Feb., Mar., April, May, June, July	Siebert (ASU)	L, M, U
Turner and Tafanelli 1983	1980, May 14 1981, March 4, July 21, August 26	Turner, Tafanelli (NMSU)	U
Rinne 1985 Rinne and Kroeger 1988 Rinne 1989 Rinne 1991 Rinne 1992	1982, Dec. 1983, April, August 1984, Feb., July, Sept 1985, May	Rinne, Kroeger (USFS)	U
Bestgen 1985	1985, May 19-24	Bestgen et al. (FWS)	L
Minckley and Karp 1986	1985, Oct. 18-20	Minckley, Karp (ASU)	
Abarca 1989	1987, Mar., April, May, June, July, Aug. 1989, August	Abarca (ASU)	L

DOCUMENTS USED IN ARAVAIPA CREEK SAMPLING HISTORY
(for sampling not listed below, see SONFISHES database in Appendix 3)

SOURCE	SAMPLING DATE	COLLECTOR[1]	STREAM REACH[2]
Marsh et al. 1989	1987, May 20-22	Marsh, Minckley, Douglas (ASU)	L, M
Bagley 1987	1987, July-August	Bagley (GF)	stock tanks
Sheldon and Hendrickson 1988	1988, Sept 24-25; Oct. 4	Multiple parties (OFC)	U, L
Williams 1991a (plus data printout)	1989, Feb., Mar., April, May, June, July, Aug., Sept., Oct., Nov., Dec. 1990, Jan., Feb., Mar., June	Williams (ASU)	L, M, U
Corman et al. 1989	1989, Oct. 7, Nov. 19	Multiple parties (OFC)	U, L
Young 1994 Abarca 1990	1990, Sept. 29-30	Multiple parties (OFC)	L, M, U
Minckley 1990	1990, Oct. 20	Minckley (ASU)	L, M, U
Brown 1990	1990, Nov., 6	Brown, Lupke, Snell (AGFD, TNC)	M, U
Brown 1991	1991, Feb.	Brown (GF)	U
Velasco 1993a	1991, Feb. 9-10, Mar. 9-10, April 12-14, May 10-12, June 7-9, July 12-14, Aug. 9-11, Sept. 13-15, Oct. 12-13, Nov. 9-10, Dec. 9-21 1992, Jan 17-19, Feb. 8-9, Mar. 13-15, April 11-12, May 18-20, June 12-13,	Velasco, Minckley (ASU)	L, M, U
Young and Lopez 1995	1991, Oct. 4	Simms, Bammann (BLM)	T
Abarca 1991	1991, Oct. 11-12	Abarca et al. (GF)	floodplain ponds
Bettaso et al. 1995 Bettaso 1992a Bettaso 1992b Bettaso 1992c Bettaso 1992d	1992, July 11-12, Aug. 10-12, Nov. 10-12, Dec. 8-10	Bettaso et al. (GF)	L, M, U
Minckley 1992 Minckley 2000	1992, Oct. 10-11	Minckley (ASU)	L, M, U
Minckley et al. 1993	1993, Jan. 23, Feb. 7	Minckley et al. (ASU)	L, M, U
Bettaso et al. 1995 Bettaso 1993a Bettaso 1993b Bettaso 1993c Bettaso 1993d Bettaso 1993e Velasco 1993b	1993, Feb. 16-17, Mar. 9-11, May 19-21, June 15-16, Aug., Oct. 23-24, Nov.	Bettaso et al. (GF)	L, U (Feb.) L, M, U
Minckley and Timmons 1993	1993, July 6-8	Minckley et al. (ASU)	L, U
Bettaso et al. 1995	1994, April 4-7	Bettaso et al. (GF)	L, M, U

DOCUMENTS USED IN ARAVAIPA CREEK SAMPLING HISTORY (for sampling not listed below, see SONFISHES database in Appendix 3)			
SOURCE	SAMPLING DATE	COLLECTOR[1]	STREAM REACH[2]
Arizona Game and Fish Department 1995	1994, May	Arizona Game and Fish	L
Minckley et al. 1994	1994, June 25-26	Minckley et al. (ASU)	L, M, U
Simms 1995a	1995, Mar. 13	Simms, Robles (BLM)	T
Simms 1995b	1995, Oct.	Simms, Robles (BLM)	T
Minckley 1995	1995, Oct. 7-8	Minckley et al. (ASU)	L, M, U
Bettaso 1995	1995, Nov. 13-14	Bettaso et al. (GF)	L
AGFD 2004 Beatson pers com., July 14, 2004	1996, Jan. 5	Beatson (ACVF)	U
Minckley 1996	1996, April 5-6	Minckley et al. (ASU)	L, M, U
Minckley 2000	1996, Oct. 19	Minckley et al. (ASU)	L, M, U
AGFD 2004	1996, Nov. 14	Simms (BLM)	U
Gori and Simms 1997	1997, Oct. 16-17	Gori, Simms (TNC, BLM)	L, M, U
King et al. 1997	1997, Oct. 28	King, Martinez (FWS)	U
Minckley 1998	1998, April 10-11	Minckley et al (ASU)	L, M, U
Blasius 1998a	1998, June 9-10	Blasius (GF)	M, U
Gori 1998, Blasius 1998b	1998, July 6-7	Blasius, Gori (GF, TNC)	L, M, U
Unmack 1998	1998, Oct./Nov.	Minckley, Unmack (ASU)	L, M, U
Unmack 1999a	1999, April 9-11	Minckley, Unmack (ASU)	L, M, U
Voeltz and Davidson 2002 Weedman 1999a Weedman 1999b	1999, Oct. 18-20	Weedman et al. (GF)	L, M, U
Unmack 1999b	1999, Oct. 22-23	Minckley, Unmack (ASU)	L, M, U
AGFD 2004 Beatson pers com., July 14, 2004	1999, Dec. 20	Beatson (ACVF)	L
Remington 2002	2000, March-April	Remington (ASU)	L
Unmack 2000	2000, Oct. 21	Minckley, Unmack	L, M, U
Bettaso 2000	2000, Nov. 27-29	Bettaso et al. (GF)	L, M, U
Unmack 2001a	2001, April 14-15	Minckley, Unmack (ASU)	L, M, U
Clarkson 2001	2001, July 5	Clarkson (BR)	L

DOCUMENTS USED IN ARAVAIPA CREEK SAMPLING HISTORY (for sampling not listed below, see SONFISHES database in Appendix 3)			
SOURCE	SAMPLING DATE	COLLECTOR[1]	STREAM REACH[2]
Unmack 2001b	2001, Nov. 2-4	Minckley, Unmack (ASU)	L, M, U
Unmack 2002b	2002, April 13-14	Unmack, Reinthal (ASU, UA)	L, M, U
Childs 2004	2002, August 22 2002, September 3, 8	Childs (GF) Widmer, et al. (UA)	L U
Clarkson 2002	2002, Oct. 4	Clarkson (BR)	L
Reinthal 2002	2002, Oct. 18-21	Reinthal et al. (UA)	L, M, U
Carveth 2004	2002, Mar. 14, 21 2002, July 9, 22 2002, Aug. 9, 13, 19 2003, April 16 2003, June 23, 29	Carveth et al. (UA)	M,U L,M,U L,M,U L M,U
Reinthal 2003a	2003, April 5-4	Reinthal et al. (UA)	L, M, U
Reinthal 2003b	2003, Sept. 27-28	Reinthal et al. (UA)	L, M, U
Clarkson 2003	2003, Oct. 15	Clarkson (BR)	L
Reinthal 2004a	2004, April 16-18	Reinthal et al. (UA)	L, M, U
Clarkson 2004 (unpub. data)	2004, Sept. 28	Clarkson (BR)	L
Reinthal 2004b	2004, Oct 1-3	Reinthal et al. (UA)	L, M, U

[1] ACVF = Arizona Conservation Voters Habitat Fund
ASU = Arizona State University
BLM = U.S. Bureau of Land Management
BR = U.S. Bureau of Reclamation
FWS = U.S. Fish and Wildlife Service
GF = Arizona Game and Fish Department
NMSU = New Mexico State University
OFC = October (or Fall) Fish Count
TNC = The Nature Conservancy
UA = University of Arizona
USFS = U.S. Forest Service

[2] L= lower reach; M= middle reach; U=upper reach; T=tributary (see definitions in Methods section of text)

APPENDIX 2

ARAVAIPA CREEK SAMPLING EVENTS SUMMARY 1964-2003 (2004 was not included as it was only a partial year)																
		NUMBER OF SAMPLING EVENTS[1]														
YEAR	# OF MONTHS WITH SAMPLING EVENTS	TOTAL	ASU	UA	MISC. UNIV.	AGFD	OFC	FWS	USFS	BLM	TNC	BR	ACVF	MULTI	# OF MONITOR-ING EVENTS[2]	# OF RED SHINER SEARCH EVENTS
1964	6	6	6												1	
1965	5	6	5	1											2	
1966	9	10	9	1												
1967	10	10	10													
1968	0	0														
1969	2	3	2		1											
1970	3	3	2		1										2	
1971	1	1			1											
1972	4	4	4												4	
1973	5	5	5												4	
1974	3	3	3												3	
1975	5	7	7												3	
1976	5	6	5			1									2	
1977	8	10	8			1		1							2	
1978	11	12	12												2	
1979	9	9	9												3	
1980	5	5	4		1										3	
1981	6	6	3		3										3	
1982	5	5	4						1						4	
1983	5	6	4						2						3	
1984	6	6	3						3						3	
1985	3	3	2					1							2	
1986	4	4	3						1						3	
1987	7	9	9												3	
1988	5	7	4			1	2								4	
1989	11	17	13			2	2								3	
1990	8	10	7			1	1							1	4	2
1991	11	13	11			2									11	
1992	11	12	7		1	4									11	
1993	11	13	4			9									11	1
1994	4	5	3			2									4	
1995	5	5	4			1									2	1
1996	4	4	2							1			1		2	
1997	4	6	3			1		1		0.5	0.5				4	
1998	6	6	4			1.5					0.5				2	2
1999	4	5	3			0.33				0.33	0.33		1		3	
2000	4	5	4			1									3	
2001	3	3	2									1			3	
2002	7	10	1	6		2						1			3	
2003	4	4		3								1			3	
TOTAL	229	264	191	11	8	29.8	5	3	7	1.8	1.3	3		1	125	6

ARAVAIPA CREEK SAMPLING EVENTS SUMMARY 1964-2003														
	ASU	UA	MISC. UNIV.	AGFD	OFC	FWS	USFS	BLM	TNC	BR	ACVF	MULTI	# OF MONITOR-ING EVENTS[2]	# OF RED SHINER SEARCH EVENTS
percent of sampling events per collector	72%	4%	3%	17%	2%	1%	3%	0.7%	1%	1%	1%	0.4%		
average number of sampling events per year per collector	4.8	0.3	0.2	0.7	0.1	0.1	0.2	0.0	0.0	0.1	0.1	0.0		
mode number of sampling events per year per collector	4.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0		
median number of sampling events per year per collector	4.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0		

5.7 average number of months per year in which there has been sampling
5.0 mode of months per year in which there has been sampling
5.0 median of months per year in which there has been sampling
6.5 average number of sampling events per year
6.0 mode of number of sampling events per year
6.0 median of number of sampling events per year

	# OF MONITORING EVENTS	# OF RED SHINER SEARCH EVENTS
monitoring and red shiner search as percent of sampling events	47%	2.3%
average monitoring events per year	3.1	
mode of sampling events per year	3.0	
median of sampling events per year	3.0	

See Appendix 1 for abbreviation definintions.

[1]If there was a SONFISHES record and a document record for the same entity in the same month, it was considered as one event. However, if the same entity had a monitoring event (from a document but not from SONFISHES) and a non-monitoring event in the same month, those were counted as two events.

Years with a #, meaning that there is data in Minckley's table, but no document or SONFISHES record, it was counted as one event total per year for each reach with a # – but only if there were no events for ASU in other reaches (assuming that data for the # reach was probably taken in the same month as data for a documented reach.

[2]May overestimate number of events due to double count if an ASU monitoring in one reach was recorded in one month and another reach in a separate month.

APPENDIX 3

ARIZONA STATE UNIVERSITY
SONFISHES DATABASE ENTRIES FOR ARAVAIPA CREEK

(Only a sample printed page for this appendix has been provided with this draft. The complete appendix is approximately 150 pages. The complete Excel file is on the attached disk.)