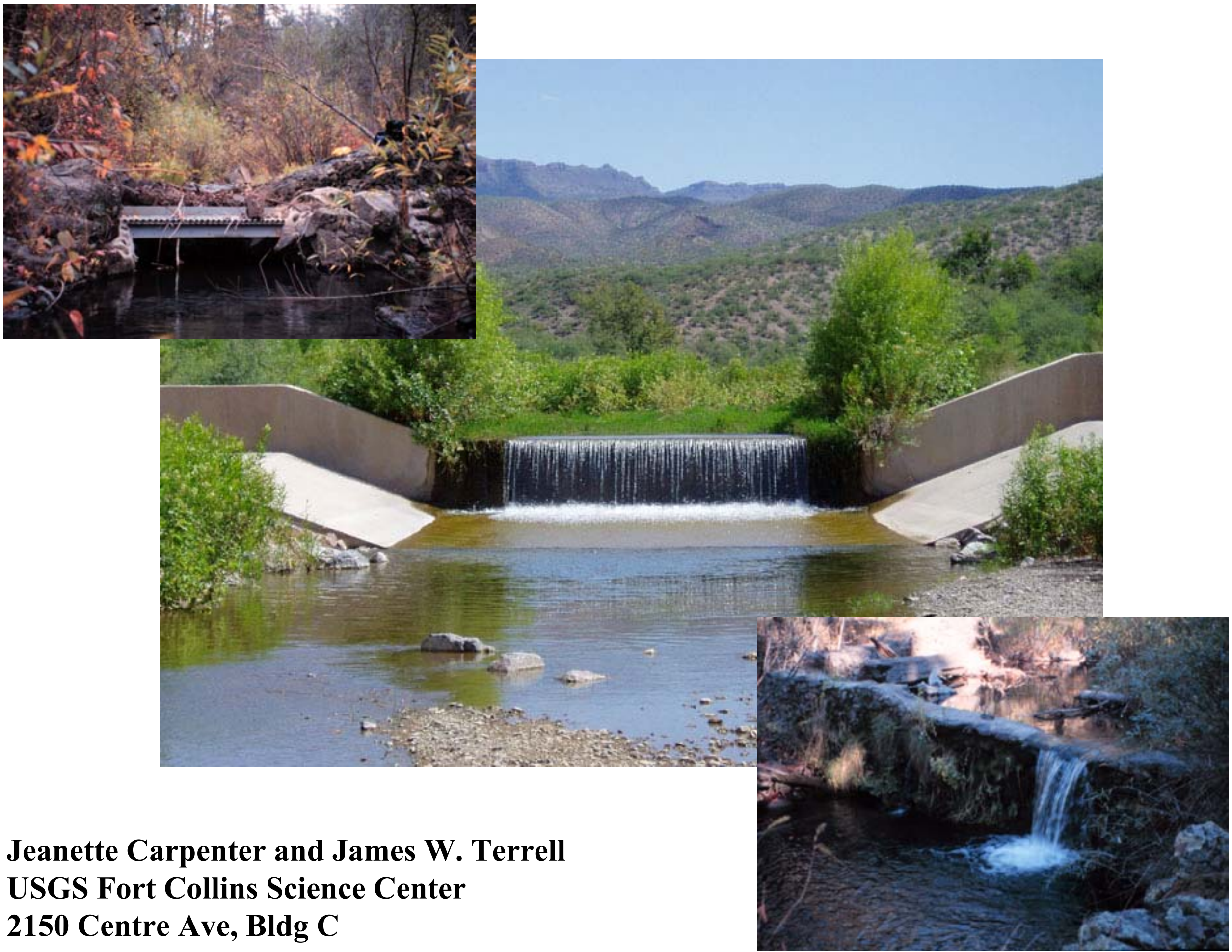
Effectiveness of Fish Barriers and Renovations for Maintaining and Enhancing Populations of Native Southwestern Fishes



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Final Report to:
U.S. Fish and Wildlife Service
Arizona Ecological Services

Interagency Agreement Number: 201814N756
CAP Fund Transfer Program Task 4-52
September 27, 2005

Cover photos (from left to right):
Snake Creek, Greenlee County, Arizona
Aravaipa Creek, Pinal County, Arizona
Bear Wallow Creek, Greenlee County, Arizona
Photographs provided by
Robert Clarkson, U.S. Bureau of Reclamation

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TABLE OF CONTENTS

List of Tables and Figures

EXECUTIVE SUMMARY

Barrier and renovation projects have allowed populations of southwestern native fish to remain free of undesirable non-natives for varied degrees of space and time. However, not all projects result in even short-term separation of native fish from non-native species. Programs to restore endangered southwestern species would benefit from an adaptive approach that recognizes species habitat requirements and effectively utilizes information from both “failed” and “successful” barrier projects previously implemented. Fishery biologists need to continue to quickly and consistently apply the lessons obtained from compromised projects by developing new protocols to increase effectiveness of later barrier construction and piscicide application.

In order to support this adaptive approach, we present information for application at the project and the program levels. At the project level, we describe successful and unsuccessful design criteria and long-term performance of 75 barrier and renovation projects implemented within the lower Colorado River, Gila River, Yaqui River, and Rio Sonoyta basins. We compiled information obtained through interviewing agency and university personnel involved with barrier and renovation projects, and conducting a thorough literature review via bibliographic databases, fishery symposia, and other internet sources. We also provide an annotated bibliography of individual papers at the regional and national level that relate to barrier and renovation projects. At the program level, to help improve the adaptive approach, we describe example criteria for measuring ecological success of restoration projects (e.g., Criterion 2 is “Ecological condition must be measurably improved”). We also provide an overview of how current optimization methods could be used to quantify the benefits of an individual renovation project over time.

Specific actions may improve the effectiveness of barriers and renovations, such as increasing thoughtful planning before-hand to insure the cost-effective use of resources over the expected physical life of an individual barrier, or monitoring fish populations before-hand as well as long-term consistent monitoring after a project is completed. Regular monitoring of the fish community not only makes it possible to evaluate the effectiveness of a project; it is also the only method for providing early detection if non-natives return. Thus success of projects may be increased when a protocol for monitoring effectiveness is developed, as well as the application of “failure analysis” techniques. Project success would benefit from increased follow-through and the existence of response plans that provide a clear course of action when an incursion occurs.

Over the long-term, barriers and renovations may improve with continued research on the biology of native and non-native species. Historically, successful fish control projects ---such as the sea lamprey control effort in the Great Lakes--- have benefited from research that focused on the biology of the target species, in order to determine potential areas of vulnerability. When choosing sites and types of barriers, we recommend that natural barriers are considered first; artificial structures that supplement natural barriers second; and purely artificial structures last. Hydrologists, engineers, and fish biologists should be included in designing and constructing artificial barriers, and in developing response plans to incursions. We found substantial evidence that barriers made from rock-filled gabions built perpendicular to flow are inherently unstable and short-lived, and frequently too porous to prevent fish passage; thus we recommend reconsidering the use of this kind of structure as a cross-channel dam. Multiple barrier configurations have several advantages and should be considered when possible. For instance, this design configuration may isolate an incursion to the reach between barriers. With regular monitoring, multiple barriers may allow faster identification as well as a stepwise approach for removing non-natives with less stress to the native fish population. Applying multiple barriers in a watershed-based approach could enhance genetic diversity.

Our review indicates multiple renovations are essential to ensure a complete kill before re-introducing natives, particularly in streams and complex habitats. Salvaging all native fish, not just the species of concern, enhances preservation of the historical fish community as a whole. On-site bioassays can be useful in confirming effectiveness of downstream detoxification, and should be used in complex streams or other situations where uniform dispersal of a piscicide is difficult. Timing of a renovation should take advantage of any life history characteristics that increase vulnerability of non-native fish, or that help protect the native species.

Although the ideal goal of barriers and renovations is to preserve long-term functioning of natural processes, it is important that we consider the importance of even temporarily saving a threatened population from extinction. When a non-native species directly jeapordizes the survival of a species, barriers and renovations are often the only feasible technology available for protecting native fish in their natural habitat. However, they require a long-term commitment to monitoring, maintenance, and re-evaluation of the role of an individual project within the context of overall program goals.

INTRODUCTION

Many recovery plans for federally listed fishes state that barrier construction and pisicide application should be considered and evaluated as a method for protecting existing populations from non-native fish contamination. Consideration of barriers is a reasonable starting point for fish recovery planning as barriers have been used as a management tool to enhance populations of native fishes throughout the southwest for decades. Renovation projects based on barriers are conceptually simple: a potential fish barrier is identified or constructed, undesirable fish in the area isolated by the barrier are removed, and the renovated area is restocked with native fish exhibiting desirable genetic characteristics. This conceptual simplicity bears little relationship to the technical and institutional challenges of actually implementing a "successful" barrier project. This report has been developed to help improve the process of planning and evaluating barrier/renovation projects.

Individual renovation projects for southwestern fishes can and have resulted in populations of native fish that are free of undesirable non-natives at the spatial scale of an individual project and time scales of up to several years. However, in general not all barrier projects result in even short-term separation of native from non-native species. Meronek et al. (1996) reviewed 250 control projects described in 131 papers: the overall "success" rate of the projects was just under 50%. Harig et al. (2000) evaluated a selected group of translocation projects involving natural and artificial barriers for greenback cutthroat trout (*Oncorhynchus clarki stomias)* east of the continental divide. They compared 14 "successful" translocations (defined by the authors as successful production of multiple year classes and the absence of undesirable species) to 23 "failed" translocations and found that about half of the failed translocations were characterized by reinvasion of non-native salmonids. Additional analyses of data on cutthroat trout translocations east of the continental divide (Harig and Fausch 2002) identified specific minimum habitat requirements that needed to be met at the patch scale in order to establish translocated cutthroat trout populations at individual project sites. Even though they are not based exclusively on southwestern fish data, information in the three review articles cited above (and numerous articles describing "failed" and "successful" renovation projects for southwestern fishes listed in the annotated bibliography of this report) indicate that programs to restore endangered southwestern species should benefit from an adaptive approach that recognizes species habitat requirements and effectively learns from both “failed” and “successful” barrier projects that have been previously implemented.

In order to support this adaptive approach, we present information for application at the project and the program levels. At the project level, we provide a detailed summary of the design criteria (which includes use of natural barriers) and long-term performance of 75 individual barrier projects implemented in the southwest US. It is important from an adaptive management point of view that practitioners maintain an updated version of this type of summary information as new projects are developed and follow-up work is conducted at previous renovation sites. We also provide an annotated bibliography of individual papers dealing with different technical aspects of barrier and renovation projects. We have a separate bibliography of abstracts obtained from the results of a key word search from the archived proceedings of the Desert Fishes Council.

To help improve the adaptive approach at the program level, where dollars must be allocated among competing projects, we provide example criteria (from the refereed literature) for measuring ecological success of restoration projects and an overview of how existing optimization methods can be used to quantify the benefits of an individual renovation project over time. There appears to be no standard, time delineated definition of “success” in use on restoration projects for southwestern fishes and our literature review uncovered little evidence of the formal application of methods to optimize cost effectiveness of multiple barrier projects over the effective life span of engineered structures. One of the suggested criteria for ecologically successful river restoration presented by Palmer et al. (2005) is that pre- and post- assessments must be completed and the data made available to the public. The material that follows in this report is intended to help meet this criterion.

METHODS

Criteria for Inclusion of Barrier and Renovation Projects

Geographic coverage

The geographic range of individual projects summarized in our review was the lower Colorado River basin, which includes the basins of the Gila, Little Colorado, Salt, Verde, Virgin, Santa Cruz, and San Pedro Rivers; we also included the Yaqui River Basin. Thus, we surveyed the literature for specific barrier and renovation projects in most of Arizona, western New Mexico, and parts of Nevada and California. It was difficult to determine how to include the spring systems in Nevada, as some valleys are historically in the Colorado River basin and others are more disjunct. We based our information on LaRivers (1994), who described the White River as discontinuous but historically in the Colorado River basin. The White River drainage includes Pahranagat Valley springs, Warm Springs Valley, Muddy River, Moapa River, and Meadow Valley Wash (which includes Eagle Valley Creek and Clover Creek). We did not include projects in Railroad Lake system, Ash Meadows, or Owens Valley. We used Silvey et al. (1984) and the EPA watershed website (http://cfpub.epa.gov/surf/locate/index.cfm) to determine drainage and sub-basin information for individual sites.

Extent and Type of Project

Projects had to be completed by 2003 in order to be included in compilations of project results. By "completed" we mean not only was the last renovation in a series of treatments completed, but also that native fish were returned to the site, and there was at least one opportunity to obtain preliminary data on the effectiveness of the project.

Non-native fish are being removed from native fish localities via mechanical and chemical means. There are mechanical removal projects that are not directly tied to barriers and are also not associated with chemical removals. For instance, purely mechanical removals are being conducted in the Grand Canyon and in the rivers and backwaters of the upper Colorado River basin. These types of mechanical removal projects are not included in this review.

Sources of Information

We used a variety of sources to compile information on barriers and renovations. We began by interviewing people from agencies and universities in Arizona and New Mexico that are involved with native fish research and management. In these interviews we discussed all of the barriers and renovations that each person knew about or was directly involved with. Often an interview with one person would lead to a new contact. Many people provided us with summaries of agency files, and/or directed us to agency reports and other unpublished works such as recovery plans for federally-listed species and monitoring reports at sites with barriers and renovations. Many of the recovery plans provide detailed information on historical attempts to apply barriers and chemically remove non-native fish.

We also considered literature related to the more general topics of river restoration, stream improvement and habitat management to provide a general ecological and management context with which to evaluate barrier projects.

Common and scientific names of fishes and taxonomic order follow Nelson et al. (2004).

Internet Databases

We accessed several databases available on the internet to locate both grey and white literature. As of September 27, 2005, the URL locations listed below were accurate and accessible.

Databases Accessed for Published Papers (these two databases require a subscription):

- CSA Illumina: http://www.csa.com/csaillumina/login.php
- Science Citation Index Expanded (via Web of Science): http://www.isinet.com/products/citation/scie/

Databases Accessed for Unpublished Reports and Proceedings:

- Proceedings of the Desert Fishes Council, 1969-2004: http://www.desertfishes.org/meetings/dfc_meet_specific.html
- Western Divison of the American Fisheries Society Annual Meetings: http://www.wdafs.org/archives/archives.htm

Other Grey Literature Databases:

- NatureServe Explorer provides species accounts: http://www.natureserve.org
- Recovery Plans were invaluable for obtaining historical accounts of barriers and renovations for rare fish. The most recent recovery plans are available from the US Fish and Wildlife Service' website: http://ecos.fws.gov/tess_public/TESSWebpageRecovery?sort=1#E
- Montana State University's Fish Passage Barrier Database: http://wildfish.montana.edu/projects/barrier/default.asp
- Nonindigenous Aquatic Species Database helped determine locations of translocations outside the range of a species, such as Apache Trout: http://nas.er.usgs.gov/queries/default.asp
- Arizona Game and Fish Department (AGFD) Heritage Data Management System: http://www.gf.state.az.us/w_c/edits/hdms_abstracts_fish.shtml
- US Fish and Wildlife Service Annual or Monthly Reports, for example: http://www.fws.gov/southwest/fishery/azfro/PDF/Monthly%20Reports/February%202003.pdf

RESULTS

Compilation of Source Material in Southwest

Twenty-eight people assisted us in compiling papers and data on barriers and renovations (Table 1). They provided information in the form of personal communications as well as providing numerous grey literature and agency reports which would have been difficult if not impossible for us to obtain without their help.

Our compilation revealed 31 native fish specifically mentioned as species of concern in barrier and renovation projects (Table 2). This represents approximately 80% of the native fish currently found within the geographic region we covered. Most of these species have recovery plans or habitat management projects associated with their recovery as federally listed species. In our compilation, 18 non-native species were mentioned as the fish targeted for removal from native fish habitat (Table 3).

There were numerous translocations of topminnows throughout the region that were discussed in a chapter of *Battle Against Extinction* (Minckley et al. 1991) and in various Recovery Plans. These translocations were in areas not clearly historical or natural, nor was it clear that renovations or barriers were involved. For instance, the revised recovery plan for Gila topminnow (USFWS 1998a) stated that there were 207 known introductions into 175 “wild locations” by 1994. The sites we included in our analysis are of seven extant natural populations of topminnow that underwent either barrier construction or chemical renovation.

The annotated bibliography (Appendix A) includes approximately 125 entries. Keywords were added to Appendix A only if they provided information not available from the title or summary of an entry. These entries include papers that discuss effectiveness of barriers and renovations at the national level, as well as all published papers, book chapters, books, recovery plans, and unpublished reports that served as the original source of data for Tables 4-8.

We included the Desert Fishes Council (DFC) proceedings abstracts as a separate bibliography (Appendix B). The DFC provides access to all their proceeding abstracts on one page of their website. This service made it very simple to search for relevant abstracts. The proceedings often provided information difficult to obtain anywhere else. For instance, each state provides a summary of the yearly status of the fishes in their region or activities that occurred that year. Thus having the DFC abstracts in chronological order makes it easier to follow the history of various barriers and renovations.

Tables 4-8 summarize information on 75 barrier/renovation projects in the southwest. These five tables also include information provided from personal communications and agency files. Table 9 provides a key of the reference numbers used in Tables 4-8 with the specific references in Appendix A. Of the 75 projects, 52 had some type of indicator of success or compromise (Table 8). Three of the 52 projects began after 2000 and had been successful for three years or less with no sign of incursion; thus they have a longevity of <3 years, which would underestimate our analysis of longevity so they were removed. Of these 49 projects, 39% (19 projects) were compromised (non-natives were found) in less than 3 years. However, 35% (17 projects) were effective at keeping natives populations free of non-natives for 10 years or more (Figure 1).

Major Published Reviews on Renovations at a Regional or National Scale

Rinne and Turner (1991): Reclamation and Alteration as Management Techniques and a Review of Methodology in Stream Renovation

In a chapter from *Battle Against Extinction*, Rinne and Turner (1991) provided an historical account and review of many barriers and renovations completed in streams of the west. Much of their review was based on contacts made with game and fish departments from 13 western states. Although piscicides were used extensively in the west, they found little documentation of techniques used or end results. Yet they were able to extract enough information to produce tables covering the history of renovations on numerous streams from 1950-1988. Most renovations during that time period were for the purpose of enhancing sport fish. The level of detail varies; however, they provided years of treatment, length of stream treated, target species and species of concern, and success of renovation for more than 30 western streams. They included a more thorough review of Arizona and New Mexico renovations and barriers, especially with respect to habitat reclamation for native trout. Most Apache trout renovations failed due to unauthorized stockings or an incomplete renovation. They also reviewed and recommended renovation procedures, such as considering impacts on non-target organisms, timing (diel and seasonal), pre-treatment sampling, and detoxification.

Hepworth et al. 2001: A review of what did and did not work after 24 years of native trout restoration in southern Utah.

Hepworth et al. (2001) presented a paper at an American Fisheries Society symposium describing what they have learned over two decades of restoration work for cutthroat trout. They concluded that there are six factors that are most important to consider when selecting sites for restoration. All six factors apply to barriers and renovations: 1) projects should be within historic distributions, 2) have good fish habitat, 3) be large enough to justify a renovation, 4) avoid major land use conflicts, 5) be feasible in terms of removing and preventing the re-invasion of nonnative fishes, 6) and have support from the general public, individuals and land use agencies.

Dawson and Kolar 2003: Integrated Management Techniques to Control Nonnative Fishes

Dawson and Kolar (2003) examined the potential of using integrated management techniques to control non-native fish for the purposes of protecting native fish of the Gila River basin. However the information they presented on pest management and piscicides is not limited to a geographical region. They discussed general information on developing an integrated pest management strategy with respect to non-native fish.

Dawson and Kolar (2003) included a historical review of renovation literature which we do not need to repeat here; instead we direct the reader to their summary, Chapter 5 of their report, titled “Successes and failures of using piscicides”. Nearly all of the fish control projects covered in their historical review were for enhancing game fish populations. We point out three substantial reviews on fish control projects that are thoroughly covered in Dawson and Kolar (2003) but which we also include in our bibliography. Lennon et al. (1971): “Reclamation of ponds, lakes, and streams with fish toxicants: A review” conducted a literature review and a survey via an internationally circulated questionnaire. This report is now available online (see citation in Appendix A). Lopinot (1975): “Summary on the use of toxicants to rehabilitate fish populations in the Midwest” covered piscicide use from 1954-1973. Lastly, Meronek et al. (1996): “A review of fish control projects” reviewed 250 projects that covered and 36 states and 3 countries.

According to Dawson and Kolar (2003), the problems most frequently found in renovation reviews included the following: 1) a lack of justification for reclamation; 2) lack of information on the biology of the target species; 3) crews that were either inexperienced or of insufficient size to handle treatment operation; 4) missing or inadequate pre-treatment and post-treatment surveys; 5) inappropriate toxicant used; and 6) insufficient application methods.

They discussed registered and unregistered piscicides, species-specific as well as general piscicides, candidate piscicides; and how to develop and register a piscicide. The time and finances needed make it highly unlikely a species-specific toxicant could be developed to selectively remove non-native fish from southwestern streams. Chemicals, however, are the most efficient method for removing non-native fish, although renovation projects in general need better planning. They recommended piscicides be viewed as one of several tools to control non-native fish within an integrated management approach that considers chemical, physical, and biological controls.

Field Studies Evaluating Renovations and Barriers

Several papers provided excellent historical accounts of various renovations and barriers in the southwest (e.g., Marsh and Minckley 1990; Rinne and Turner 1991). These studies greatly assisted us in developing Tables 4-8, but they were not field studies designed to quantitatively evaluate the effectiveness of barriers and renovations. We found few such studies, either in the southwest or at the national scale. We summarize these studies below.

Three papers evaluated electric barriers. Verrill and Berry (1995) evaluated the effectiveness of an electric barrier in preventing migration of carp and bigmouth buffalo into two lakes in Minnesota. They marked and released 1,600 fish downstream of the barrier and caught 3,376 fish caught upstream, none of which were tagged. From this evidence they concluded the barrier worked, however they also noted that in 1993, one year after their field survey, the water depth at the barrier changed from 0.5 to 2 m, and about 3 carp/hr were observed crossing the barrier. The barrier was modified to mitigate this type of incursion. Swink (1999) marked ~4200 sea lamprey, released paired groups above and below an electric barrier in Michigan, and used fyke nets to re-capture lamprey upstream. He determined the barrier was extremely effective, as only 1 downstream lamprey was caught at the lower pulsator setting (1 ms pulse width); no downstream lamprey were caught at 2 ms pulse width. He had a 24% recapture rate for lamprey released upstream, which helped validate his recapture rates. Clarkson (2004) evaluated the effectiveness of electric barriers on two canals of the Central Arizona Project. Over a 12-yr period he documented few outages, however he concluded that these outages allowed upstream movement of non-native fish. He also found evidence that grass carp moved through a working barrier, and directly observed red shiners passing safely, with no tetany, through the electrical field of an active barrier.

Thompson and Rahel (1998) evaluated a three-yr old, intact gabion barrier built to protect cutthroat trout in Wyoming. They marked and released brook trout downstream and found that fish up to 224 mm TL were circumventing the barrier because the interstitial spaces within the gabion had not filled. Baxter et al. (1999) marked and radio-tagged native fish to determine movement over a barrier built to enhance a sport fishery in Canada. The barrier had a 1.5 m vertical drop which was not sufficient to stop upstream movement during high flows. Porto et al. (1999) determined that by impacting fish movement, low-head barriers (<2 m) built to control sea lamprey cause a longitudinal decline in diversity of fish communities in Lake Ontario streams.

Instead of evaluating barriers, Hayes et al. (2003) evaluated four sampling designs for examining the effect of fish barriers on sea lamprey. Their findings and recommendations are relevant to any barrier, regardless of the target species. They concluded that a pre- and post-construction sampling design which included barrier and reference streams would provide the most meaningful information for assisting in management decisions on barriers. Their suggestions may be difficult to apply in southwestern streams because of logistic or financial limitations, however their specific addressing of assumptions made in barrier evaluation studies are certainly worth considering. They also concluded that extensive surveys and process-oriented studies should provide biologists the quality of information that should give them the most confidence in their conclusions.

Robinson et al. (2004) examined the movement of marked trout released below 13 barriers in Apache trout streams in Arizona. They found that 7 of 11 barriers had non-native salmonids above them. They noted that most failed barriers obviously needed repair or had serious design flaws, such as being too short or too porous. Thus they concluded that non-natives moved upstream by way of structurally unsound barriers, not from unauthorized human transport.

DISCUSSION

In selecting appropriate locations of barriers, we can consider what scientists have learned from designing and evaluating natural preserves (e.g., Moyle and Sato 1991). Sites considered for protection with a fish barrier are similar to a preserve and subject to the same issues of population genetics, fragmentation, and isolation. The ideal goal of barriers and renovations is to preserve long-term functioning of natural processes, which is not always possible. A potential site for a barrier or renovation should not be automatically discarded because the restoration activity would reduce the long-term natural function of the site, if at the same time these efforts would also increase the short-term survival of a specific ESU (evolutionarily significant unit).

A species can suffer local extirpations via two types of stochastic events: environmental catastrophe and a random drop in population size which goes beyond the threshold of recovery (Moyle and Sato 1991). Recent examples of the first type are the catastrophic fires that occurred within watersheds possessing significant populations of Gila trout (Propst et al. 1992; USFWS 2003) and Gila chub (Sabino Canyon, Aspen Fire in 2003). These examples underscore the importance of sustainable replicate populations of ESU's for a given species and the need for larger populations less vulnerable to stochastic events.

Adaptive Management: Gaining Knowledge Through Experience

Clarkson (2004) argued that if a barrier is not 100% effective, it is a failure. This point of view is especially understandable given that a protected population can be compromised by a few non-native fish that establish a reproducing population, or when a species is vulnerable to hybridization. However blanket declarations that a given barrier or renovation is a success or failure are of limited usefulness for guiding new projects. A project failure can be extremely valuable to future projects if proper data are collected, analyzed, and incorporated into new management decisions. As Gene Maughan said, "Little is learned from success" (Arizona Cooperative Fish and Wildlife Research Unit, personal communication, 1989). Within the field of engineering is an entire discipline of "failure analysis" which is commonly utilized by business. For example, the following recommendations were made in considering failure analysis in the realm of business (Apogee Newsletter archives, Sep 2003: http://www.adastro.com/apogee/lost.html):

> The same basic principles can apply to many business situations in which one encounters a failure--you archive the data so that no information is lost, and then you investigate the situation to understand both immediate and root causes. The objective is not to find someone to blame--it is to understand what really happened (which very often turns out to be different than what appeared to happen), to turn the failure into an opportunity for learning, to improve your organization and its practices, and to realize value from the experience.

Of course we want successful barriers and renovations to protect native fish populations. Thus it is most important that we do not repeat mistakes, but learn from them. Although many early Gila trout renovations were not successful, with each effort biologists made progress in understanding how to apply piscicides effectively to these systems (Stefferud et al. DFC 1991). As an example, the standard protocol with Arizona Game and Fish Department (AGFD) for Apache trout renovations now requires two applications of piscicide before repatriating natives, waiting a season to see if the renovation was successful, and then continuing to renovate if necessary. They repeat this procedure until they are certain of a complete kill (M. Lopez, AGFD, personal communication, 2004)

What is learned from previous barriers and renovations should be quickly applied to future projects, which has not always been the case. For instance, as early as 1983, the following recommendations for improving renovations were made available to biologists and managers (Meffe 1983; Marsh and Minckley 1990):

> "…A single treatment, even in high doses, apparently is not effective";
> "A fishless period of at least a year should be required for the entire system before topminnows are restocked";
> "..to assure long-term success, the area must be inspected frequently and managed.."

We point this out to reiterate that often the solutions learned from previous renovation efforts have been available within the literature for many years, even decades, but implementing the solutions with available personnel and monetary resources has been at times exceedingly slow.

Conflicting Perceptions: Considering a Barrier a Long-Term "Failure" vs. a Short-Term Essential Management Tool

A secondary issue of declaring a barrier or renovation a "failure" has to do with the assumptions that are made or if restoration goals have been clearly defined. If a barrier or renovation prevents re-invasion for 5 years, for example, is it a failure on the 6th year? Thus, some biologists emphasize that we should consider barriers and renovations as a delaying tactic to endangerment and extinction (e.g., Rinne and Stefferud DFC 1999). Maybe we should consider incursion inevitable. Maybe we should consider a measurable extension of the length of time that a barrier and renovation prevents or controls a non-native fish re-invasion as a measure of success. In other words, barriers are successful as short-term solutions. As Hilderbrand and Kershner (2000) concluded,

> “Isolation above barriers may be a necessary conservation tool when short-term, biotic extinction risks greatly exceed long-term risks, but removal of biotic threats and population restoration is critical. Thus, barrier construction must be viewed as a temporary solution for most jeopardized populations”.

Other authors similarly conclude that isolation may be the only alternative when non-natives are an immediate threat to survival of native fish (e.g., Novinger and Rahel 2003).

RECOMMENDATIONS

With enough money, engineering, and thoughtful planning, it is feasible to build barriers that are secure, and to conduct renovations that remove all the non-native fish. Two extensive historical reviews conclude that chemical renovations could use better planning. As noted by Lennon et al. (1971), “the better studied and more carefully executed projects have the greater number of successes.” The investment of time and energy into thoughtful planning helps insure cost-effective use of resources. Therefore we summarize the following recommendations gleaned from our qualitative analysis of the source material. We provide recommendations specific to barriers or renovations as well as general recommendations to consider with these types of projects.

Recommendations Specific to Future Barriers

Consider Natural Barriers First

Several authors recommended that natural waterfall barriers provide the best protection for native fish (e.g., Stefferud DFC 1997; Harig et al. 2000). Natural waterfalls typically have already been tested by fish; they are not as likely to wash out as artificial barriers; and they are often in relatively inaccessible areas. Rinne and Turner (1991) suggested that artificial structures that supplement natural barriers appear to be more effective than those that start from scratch. However two studies indicated even natural waterfalls have limitations. Adams et al. (2000) noted that gradients of 13% or 1.5 m vertical drops would not stop brook trout from moving upstream. Harig et al. (2000) determined that translocations above natural waterfalls that were previously fishless were less effective, as apparently fish were absent because the habitat was unsuitable.

Extended dry reaches can be an effective natural barrier. For example, the lower 6 km of Aravaipa Creek is normally dry, which apparently delayed invasion by red shiner. However, when hydrological changes connected Aravaipa Creek with the San Pedro River more frequently, red shiner invaded (R. Clarkson, US Bureau of Reclamation, personal communication, 2005). Therefore locating habitats above natural waterfalls and extended dry reaches should be considered a priority for renovation and restoration; however, the habitat upstream should be examined.

Artificial Barriers Should be Designed with the Appropriate Expertise and Information

Many barriers have been designed and constructed without all the information necessary to build the most appropriate barrier (Brown and Zale 2005). The success of artificial barriers will be increased when designed by engineers with input by hydrologists and fish biologists. Biologists provide important information not obvious to engineers, such as the necessity of splash pads and notch heights relative to the characteristics of the target species, or making sure the barrier does not produce a swim hole that would attract recreational activity. Also, barriers built to withstand decades and massive flows may have their own impacts on a stream, as they impact habitats above and below in ways similar to a small dam. For instance, Bulow et al. (1998) suggested that a possible negative effect of a concrete-capped gabion barrier in a Tennessee stream was that it impeded stream flow and created a pool immediately upstream.

Reconsider the Use of Gabion Barriers

Rock-filled wire gabions were used historically within streams for bank stabilization; therefore, they were placed parallel or diagonal to flows. Now gabions are often placed across a stream to create fish barriers, especially in headwater streams for trout recovery. However, there is growing evidence that barriers made from gabions are inherently short-term and frequently too porous to prevent fish passage.

In 2000, the Washington Department of Fish and Wildlife (WDFW) made available online fishway guidelines for the state (http://wdfw.wa.gov/hab/ahg/fishguid.pdf). These guidelines were developed for a course on salmonid habitat restoration by the USFWS National Conservation Training Center. The author made these comments about gabions:

> Gabions are not a good fish passage device because they are unstable, deteriorate, and are easily damaged. A benefit often stated of gabions is the possibility of using locally available stream gravel and cobble for fill. Fill of this type is like trying to stack marbles; the gabion deforms and quickly loses its intended shape. It may also roll as it deforms. Galvanized gabion wires do not withstand the erosion of bed material wear. Gabions used in Chico Creek (Puget Sound, Washington), with only slight bedload abrasion, failed in three years. Another drawback to the use of gabions is that debris can easily snag either breaking them or distorting the wire fabric leading to their failure.

Tappel (1986) described the history of one gabion structure built for fish passage in Alaska, and concluded that gabions should not be installed perpendicular to streamflow if water velocities might exceed 5 ft/s. He noted that this recommendation would preclude the use of gabions at waterfalls. The problems with gabions described in the guidelines by WDFW above are supported by recent research. Two studies evaluated gabion barriers by releasing marked trout downstream and found some fish successfully invaded upstream either through interstitial spaces of the gabions or around or over visibly degraded structures (Rahel and Thompson 1998; Robinson et al. 2003). Some papers noted barriers failed because the gabion wire eroded much faster than expected. For instance, House (1996) evaluated 15 full-spanning structures made of gabions, built in 1986 on an Oregon creek to improve spawning habitat but not to impede fish passage. Within two years the gabion wire had visibly eroded on most of the structures, and within 3 years the gabions had deteriorated to the point where boulders within the gabion matrix were dislodging. He concluded that gabions are a short-term restoration solution as they have life spans of approximately 10 yrs. In their recent evaluation of Apache trout barriers, Robinson et al. (2004) found trout moving upstream through interstitial spaces of what appeared to be intact gabion barriers. They questioned the continued use of gabion barriers because of their failure rate. To increase life expectancy and reduce maintenance costs, they suggested covering gabion barriers with concrete or rebuilding a solid concrete backfilled barrier. Their suggestions are supported by Bulow et al. (1988) as they determined a gabion barrier was fully functional 15 years after being capped with concrete.

Paired or Multiple Barriers May be a Very Effective Strategy

Multiple barriers allow biologists to identify an invasion in the early stages. In addition, multiple barriers could isolate an incursion to the stream reach that is between barriers, which would make non-native fish removal easier and would be less disruptive to the native fish community (Meffe 1983). The nine stone bridges in Sabino Canyon acted as short-term barriers to upstream movement of green sunfish, as it took 12 yrs for this non-native to invade the reach below the ninth bridge (Dudley 1995). W.L. Minckley suggested a paired structure concept for protecting Aravaipa Creek fishes, and recommended two barriers be built that would withstand 100-yr floods (Clarkson DFC 2003). Hepworth et al. (2001) determined that the most effective barriers in Utah streams were those adjacent to other natural barriers, such as de-watered stream reaches. They concluded that single-point structures were the most vulnerable barriers, and chose to build multiple barriers if secondary obstacles were not available.

Multiple barriers provide a structural framework within the landscape that allows a more manageable, stepwise approach when eliminating an introduced species. For instance, red shiners are being eliminated from the Virgin River on a reach by reach basis, between natural and artificial barriers (Lentsch et al. 2002).

Multiple barriers also provide a stepwise approach for a watershed-based concept of native fish protection. Propst et al. (1992) described the danger of limiting protection of a species to isolated headwaters, and recommended reclaiming sub-drainages with multiple tributaries for Gila trout. Hilderbrand and Kershner (2000) described in detail a watershed-based concept for managing cutthroat trout. They recommended including confluences of tributaries so that more than one headwater population can mix.

A watershed-based approach of multiple barriers could be an additional tool for enhancing genetic diversity of southwestern fish. If barriers could be built or retrofitted so that they can be temporarily disabled when tributaries are consistently free of non-natives, then they would allow free movement of native fish. The barrier located farthest upstream can be viewed as a "temporary first" in an eventual series as more and more sections of stream are renovated. Thus over time larger segments of a river basin would provide improved habitat for natives. Eventually entire watersheds could be free of non-natives, although continued monitoring would be always necessary. If an incursion occurs downstream, the barriers could be restored to their full function. A watershed-based approach of multiple barriers would eventually allow increased gene flow as well.

Since stochastic events can eliminate small isolated populations, it may be unrealistic to assume populations above barriers will persist indefinitely (Hilderbrand and Kershner 2000). However, the importance of fragmentation and preserve size differs among species. For example, Apache trout historically had naturally fragmented, disjunct distributions long before any possible anthropogenic impacts (Dowling and Childs 1992). Even more naturally isolated are those species that have been in remote springs, such as the White River springfish (Williams et al. 1985). In considering methods for preserving genetic diversity, these disjunct populations are all the more important to protect.

Electric Barriers

Electrical barriers may be useful in areas where physical barriers (e.g., low-head dams) are not practical or desirable. Electrical barriers have been effective in controlling sea lamprey migration (Swink 1999). Two electrical barriers have been installed in Central Arizona Project canals to prevent non-native fish occurring in the Colorado River Basin from moving upstream into the Gila River basin (Clarkson 2004). However, their effectiveness is compromised by brief electrical outages; also low flows allow non-natives to bypass the barriers (Clarkson DFC 1997). Clarkson (2004) recommended that electrical barriers should still be considered in an integrated approach to managing non-native fish.

Recommendations Specific to Future Renovations

Conduct Multiple Renovations and Ensure a Complete Kill before Re-Introducing Natives

Many studies have shown that single treatments do not consistently result in a complete removal of target fish and recommend multiple renovations (Rinne and Turner 1991; Propst et al. 1992; Harig et al. 2000). Hepworth et al. (2001) noted that a single treatment was not effective in even the smallest streams. They recommended timing a second renovation one year after the first treatment. Complex waters (braided channels, marshlands, spring inflows) make a complete kill more difficult, and high gradients in streams reduce the effectiveness of antimycin (Tiffan and Bergersen 1996).

Consider Salvaging Other Species Before Renovation

Rinne and Stefferud (1999) clarified that single species management is one of the best means of delaying endangerment, however they also noted we should continue efforts for multiple-species management. Similarly, many biologists expressed concern with the method employed in many streams, where piscicides are applied after salvaging **only** the species of concern. Historically, single-target species renovations in some streams have caused declines for other sympatric fish populations (Rinne and Turner 1991). Although these un-salvaged sympatric species may not be protected by federal listing, they are often species of concern at the state or regional level and may be at risk of further decline (e.g., Sonora sucker, speckled dace). We recommend that these fish also be salvaged, both to preserve their genetic diversity as well as to preserve the historical fish community as a whole. Likewise, some renovation projects salvage benthic invertebrates to ensure that repatriated fish have a sufficient food resource.

Consider Bioassays to Improve Chances of Complete Kill

Some renovations included on-site bioassays to determine that enough piscicide was used (e.g., cages with brown trout for Apache trout renovation). Bioassays may be especially useful in complex streams and cases where the uniform dispersal of toxicants is difficult. Bioassays can also be used to ensure that downstream detoxicification is working (Rinne and Turner 1991).

Time Renovation Appropriately to Improve Chances of Complete Kill

Timing of a renovation is important to consider in terms of water chemistry and flow. Cold temperatures (Tiffan and Bergersen 1996) and high pH (Marking 1992) reduce the effectiveness of antimycin and rotenone degrades faster in high temperatures, high pH, and exposure to sunlight (Marking 1992; Finlayson et al. 2000).

General Recommendations for Barrier / Renovation Projects

Consistent, Long-Term Monitoring Is Imperative

Most reviews on fish control projects emphasized the need to monitor fish populations before-hand and to conduct long-term consistent monitoring after a project is completed. Specific monitoring guidelines depend on the species and the situation. Meronek et al. (1996)

noted that 25% of the projects they reviewed could not be evaluated because of inadequate information. They recommended that projects should include detailed rationale and objectives, and pre-treatment and long-term post-treatment study. In their review of greenback cutthroat trout populations, Harig et al. (2000) suggested that each translocated population should be monitored once every 3 years, and representative populations be monitored annually. From their analysis of six years of monitoring Gila trout, Propst and Stefferud (1997) concluded that multiyear sampling is essential to understand the range of variation possible in a natural population; they also recommend regular sampling of a reference population.

Early pre-treatment surveys may even provide the necessary information that a barrier or renovation is not necessary. In one recent case, Baxter et al. (1999) tested fish movement over a barrier and determined it was likely navigable at high flows, but despite that, the barrier was probably unnecessary as a response to controlling the target fish, two native non-game species.

Without regular monitoring of the fish community, it is impossible to evaluate the effectiveness of a project. However, the most important value of consistent monitoring is that it allows early detection of an incursion. When the presence of non-native fish is detected in the early stages, there are more alternatives and opportunities available to identify what happened and apply the best solution. For instance, if biologists can quickly determine the number and age distribution of non-natives present and the distance of stream that is contaminated, then they can also identify the likely source (e.g., determine if the barrier needs repair of if an unauthorized stocking occurred). With this information they can more quickly determine the best action to take to resolve the problem, possibly with less effort and expense. Consistent monitoring of the native fish also allows biologists to assess the health of these isolated populations, by estimating condition, recruitment success, and population size. So that future projects can be evaluated for their effectiveness, we suggest that those biologists that are planning future monitoring efforts consider the population characteristics such as those summarized in Table 8 for inclusion in their data collection.

Examine the Biology of the Target Species and Species of Concern

Lennon et al. (1971) pointed out that the success of sea lamprey control in the Great Lakes was greatly assisted by research conducted to understand the biology of the target species:

> Knowledge of the biology of undesirable fishes is a primary requisite to effective control. The weakest link in the life cycle may be the only logical target for toxicants or other control measures. The larval stage of the sea lamprey in streams is an example. Or, attacking spawning congregations of problem fishes may provide a degree of control where poisoning of an entire body of water is impractical or impossible. Furthermore, an understanding of the life history of an undesirable fish might lead to biological or other controls less drastic than poisoning.
>
> It is important, too, that we learn more about the environments in which problem fish exist and the factors which contribute to the development of problems. In some situations, the problems with undesirable species may be avoided or solved by manipulating environmental factors instead of by poisoning.

A thorough pre-treatment survey assists in developing the appropriate renovation protocol. By understanding the ecology of the target species, biologists can choose the best time and season for a renovation. For instance, treatment at night may be more effective depending on fish behavior (Rinne and Turner 1991). Rotenone and antimycin do not kill fish eggs until the egg capsule ruptures at hatching (Finlayson et al. 2000) and young-of-year may escape piscicides by selecting shallow stream margins. Therefore, a complete kill is more probable if piscicide is applied when these less vulnerable life stages are not present. Phelps et al. (DFC 2000) examined reproduction of *Gambusia affinis* and *Poecilia* spp. in Nevada and Arizona, and recommended January as the best time to treat warm springs to remove non-native poeciliids. Dawson and Kolar (2003) compared specific life history characteristics of native and non-native fish of the Gila River basin for the purpose of identifying areas of vulnerability that could possibly be used to develop control strategies. They found few areas of vulnerability for non-natives; although they also noted that non-native fish present in the Gila River basin had shorter, more distinct spawning periods.

Avoid Problem of Halfway Technologies

> “Many fishery managers viewed fish toxicants as a panacea and that a single application would correct problems and result in bountiful fishing for a long time. . . “ -Dawson and Kolar (2003)

> “Some stream habitat improvements have apparently been done for no apparent reason, as is strongly indicated by the fact that only a few have been monitored or evaluated…Long-term evaluation of projects is required to justify their continued use” (Rinne and Turner 1991).

A consistent level of frustration was evident among biologists working on native fish that there was a lack of follow-through on barrier and renovation projects. For instance, Clarkson (2004) noted “Given all this effort and expenditure toward ensuring fish-tight barriers, it is ironic that the agencies operating the electrical barriers will not support comprehensive management”. Other biologists were concerned that clear response plans are essential, so that everyone involved with a given stream that has a barrier or renovation knows what steps need to be taken when a breach occurs. For example, before a project starts, plans should be in place that answer the following questions: 1) Who is responsible for conducting regular surveys to detect for non-natives? 2) Once non-natives are found, who is responsible for taking action to remove them? 3) Is there a threshold level for non-native fish population metrics before action is taken (e.g., one non-native fish found; a specific percentage of population is non-native; is non-native species reproducing)? 4) Is there a threshold level for native fish population metrics before action is taken (e.g., population declines to a specific percentage of original stocking or an estimated effective population size; decline in genetic variation; no reproduction for a specific time period); and 5) What is the threshold level for repeating a renovation?

Recent renovations appeared successful but were compromised by a minimum of follow-through. For instance, three years after Sabino Creek was treated for green sunfish, they were found by AGFD and University of Arizona biologists in the previously-treated reach. Apparently it was unclear at that point what actions had to be taken to re-treat the creek. Before green sunfish were artificially removed, the Aspen Fire naturally re-renovated Sabino Creek in 2003.

A lack of follow-through on stream alteration projects is not a new problem. In 1936, C.M. Tarzwell described a lack of information on ecological changes brought about by stream “improvement” projects completed by the Civilian Conservation Corps and called for additional experimental work in the field and better before and after data on biological measures such as fish spawning success to evaluate the projects. Recent papers by Palmer et al. (2005) and Jansson et al. (2005) provided more explicit guidelines for measuring ecological success in the form of six criteria for evaluating river restoration: (1) a specific guiding image of what could feasibly exist at a site; (2) ecological condition must be measurably improved; (3) the system must be more self-sustaining and resilient to perturbations so that only minimal follow up maintenance is required; (4) during construction, no lasting harm inflicted; (5) pre- and post- assessment must be completed and the data made public; (6) specific hypotheses and a conceptual model of ecological mechanisms should be incorporated. Current projects in the Southwest generally meet criteria 1-4, although lack of resistance to perturbations in the form of introduced species is obviously a continuing problem. Criteria 5 and 6 are areas that could see significant improvement as pre and post assessment data are not always widely available.

Address Need For as well as Complexities Involved with Public Relations and Education

Many large-scale projects conducted to kill native fish have occurred without much publicity or concern, such as the 100's of km of streams poisoned before 1960 to remove "rough fish" in California, Arizona and New Mexico (Lennon et al. 1971; Rinne and Turner 1991). Yet some well-publicized chemical renovations that resulted in native fish kills fostered negative public opinion towards piscicides, and resulted in a range of changes in management policies. For example, piscicide treatment of the Green River in 1962 to remove "rough fish" caused a massive die-off of native cypriniformes, likely pushing these fish toward extirpation in this region (Rinne and Turner 1991). The controversy surrounding the Green River project spurred native fish biologists to work for legal protection of native fish and possibly prompted the evolution of the public's view of native fish species as a valuable resource (Pister 1991). The northern pike removal effort in Lake Davis, California was a public relations disaster for two reasons: the lake was a source of drinking water for a nearby town, and the renovation also killed all the trout, further impacting the local trout fishing economy. Most recently, public opinion has resulted in a policy of banning piscicide application in streams in New Mexico, even though there is little scientific basis for this ban (Brooks and Propst 2001). On the positive side, Moore et al. (2001) described how public hearings and media education helped improve public approval of a proposed restoration project for native brook trout in the Great Smoky Mountains.

When there is a conflict between sport fishing and rare fish in the region, barriers and renovations are more difficult to maintain. There are numerous cases of unauthorized human transplants (UHT) by anglers, and many are accidental. However, deliberate vandalism to establish non-native trout has been identified in Gila trout streams (Brooks and Propst DFC 1999). Besides enforcement, patrol, and consistent and frequent monitoring, other potential solutions to preventing or reducing UHT include restricting vehicle access and installing remote cameras (Robinson et al. 2004). These measures can be factored in as operational costs in long term planning. Specific actions that should be considered for reducing UHT include establishing well-publicized and enforced fines, and a monetary reward for information leading to the arrest and conviction of those responsible for an UHT.

The likelihood and impact of a UHT should be considered when prioritizing sites for barriers or renovations. The biologists most familiar with the biological and social conditions at a given site need to consider such factors as the attitudes of the public in the region, public access to the site, and the level of controversy surrounding the species of concern. They also need to consider the level of impact that an individual UHT will have on the species of concern. Increased education via interpretive signs in areas that are both heavily used by sport fishermen and remotely located may not be an effective practice. As a possible example, after a major renovation in 1993, Cibola High Levee Pond remained relatively free of non-natives for approximately 11 years (Mueller et al. 2003). However, shortly after a large interpretive sign that identified this pond as supporting rare native fish was placed along the levee road, numerous largemouth bass appeared in 2004 (Mueller et al. 2005).

Consider Cost Effectiveness of Restoration Action

On an annual basis, programs to recover endangered southwestern fishes are going to have to allocate dollars to several competing categories: 1) costs to operate and maintain barriers that are in place (including monitoring the fish populations to see if they meet project objectives); 2) costs to renovate undesirable populations behind barriers that are assumed to be capable of blocking natural movement of fish; and 3) the costs to construct new barriers and successfully renovate the subsequently isolated habitat. Effective dollar allocation will require measurable definitions of ecologically successful restoration, early detection of reinvasions or other forms of "failure", and a method of balancing the costs of constructing and implementing new renovation projects where success is a hoped-for outcome against the future costs of operating, maintaining, and monitoring previously constructed projects. For any given budget level, the point may eventually be reached where all available money is needed to meet operation and maintenance goals for old projects, leaving no dollars available for new projects.

New projects that result in modest gains of new habitats that are at least temporarily free of undesirable non-natives will generate future operations and maintenance costs that need to be discounted to give the present value of total project costs over the life of the project. The present value of dollars that have to be spent in the future is lower than the dollar amount to be spent in the future. The same concept of discounting used for dollars can be applied to estimate present value of endangered fish and their habitats that is expected to occur in the future as a result of a building a new barrier project. For example, 10,000 fish or 10 miles of non-native free stream that are expected to occur in the future are less valuable than having 10,000 fish or 10 miles of non-native free stream today. Operation, maintenance, construction, and monitoring costs of present and future projects must be determined in terms of today's dollars to optimize population and habitat gains per dollar spent over multiple years. Farmer et al. (1988) provided some basic guidelines for using linear programming and optimization methods to design cost effective habitat management plans. A natural resource economist should be consulted when setting discount rates for future dollar costs.

Access Sources of Information on Barriers and Renovations

We direct the readers to the annotated bibliographies (Appendices A and B) as a source for more detailed information on barriers and renovations. Most of the citations include summaries and abstracts, thus they provide a substantial information source.

During our search we found a relevant website from Montana State University's Wild Fish Habitat Initiative (WFHI). They are developing a database on barrier design, and are requesting information from those working on barriers to provide information on construction, design, effectiveness, and longevity. As of September 27, 2005, there were detailed descriptions on 34 barriers that various entities have provided, however only two of these barriers (the double barriers at Aravaipa Creek) were within the geographic range of our review. We recommend accessing this website to review the type of information the WFHI is looking for, and entering data for additional barrier projects if the data meet website standards. The website is: http://wildfish.montana.edu/projects/barrier/default.asp

Provide Additional Information To The Authors

There are large gaps in the data presented in Tables 4-8. We consistently found certain types of information difficult to obtain. Specific information on the flow rates that artificial barriers were designed to withstand was frequently missing from our information sources, as were information on designed life span, or if a barrier failed because of a problem with structural integrity or fish movement. Descriptions of native fish salvage efforts prior to the renovation were frequently unavailable. We often could not determine if monitoring was being conducted consistently on barrier and renovation projects. Also, we suspect that the following sites may have barriers or renovations but we could not locate any information: Martinez Canyon; Mineral Creek/Devil's Canyon Mine Dam (both mentioned in DRT 2003); and the east, south, and west forks of Little Colorado River. We ask the readers to contact the senior author (jeanette_carpenter@usgs.gov) if they can provide us information or direct us to reports or files that may fill these gaps, so that we can continue to develop the dataset presented in Tables 4-8.

CONCLUSIONS

Nearly 39% of the 49 southwestern barrier and renovation projects that were amenable to assessment were compromised in less than 3 years. However, 35% were effective at keeping natives populations free of non-natives for 10 years or more. Although the ideal goal of barriers and renovations is to preserve long-term functioning of natural processes, it is important that we consider the significant success of even temporarily saving an evolutionary significant unit (ESU) from extirpation. When non-natives are an immediate threat to the survival of native fish, isolating native fish with barriers and/or renovations is often the only feasible technology available to protect these populations in their native habitat. We believe that barriers and renovations will be more effective for promoting recovery of threatened and endangered fish if an adaptive management approach, as outlined in this report, is utilized.

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ACKNOWLEDGEMENTS

This project would not have been possible without the the enthusiastic help and cooperation of the people listed in Table 1, who met with us to discuss barriers and renovations, tolerated long interviews in person and on the telephone, and provided unpublished reports and files. This project was funded by the Central Arizona Project Funds Transfer Program. We thank Paul Barrett, Robert Clarkson, Lee Lamb, and David Hamilton for manuscript comments. Jeff Kantor assisted with data entry of bibliographic references.

Table 1. Personal communications.

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Kirk Young, Arizona Game and Fish Department, Phoenix, AZ

Table 2. Native fish that have barrier or renovation projects associated with their recovery. Species abbreviations are used in Tables 4-8. Status codes are based on federal and state listings; a range indicates status varies by state. Federal: E=Endangered, T= threatened, PE=Proposed Endangered. State: S1=critically imperiled, S2=imperiled, S3=vulnerable, SH=possibly extirpated.

Common Name (Status)	Scientific Name	Abbrev.	Recovery Plan
Longfin dace, Yaqui form (S3)	*Agosia chrysogaster.*	AGCH	
Mexican stoneroller (S1)	*Campostoma ornatum*	CAOR	
Bonytail (E)	*Gila elegans*	GIEL	USFWS 2002a
Gila chub (PE)	*G. intermedia*	GIIN	USFWS 2002b
Yaqui chub (E)	*G. purpurea*	GIPU	USFWS 1994a
Roundtail chub (S1 – S2)	*G. robusta*	GIRO	
Virgin River chub (E)	*G. seminuda*	GISE	USFWS 1994b
White River spinedace (E)	*Lepidomeda albivalis*	LEALB	UWFWS 1994c
Virgin River spinedace (S1)	*L. mollispinnis*	LEMO	
Little Colorado spinedace (T)	*L. vittata*	LEVI	USFWS 1998b
Spikedace (T)	*Meda fulgida*	MEFU	USFWS 1990
Moapa dace (E)	*Moapa coriacea*	MOCO	USFWS 1995
Woundfin (E)	*Plagopterus argentissiumus*	PLAR	USFWS 1994b
Moapa speckled dace (S1)	*Rhinichthys osculus moapae*	RHOSM	
Loach minnow (T)	*Tiaroga cobitis*	TICO	USFWS 1991
Yaqui sucker (SH)	*Catostomus bernardini*	CABE	
Desert sucker (S2 – S3)	*C. clarki*	CACL	
White River desert sucker (S2)	*C. clarki intermedius*	CACLIN	
Sonora sucker (S2 – S3)	*C. insignis*	CAIN	
Flannelmouth sucker (S1 – S3)	*C. latipinnis*	CALA	
Razorback sucker (E)	*Xyrauchen texanus*	XYTE	USFWS 2002c
Yaqui catfish (T)	*Ictalurus pricei*	ICPR	USFWS 1994a
Apache trout (T)	*Oncorhynchus gilae apache*	ONAP	USFWS 1983
Gila trout (E)	*O. gilae*	ONGI	USFWS 2003
Gila topminnow (E)	*Poeciliopsis occidentalis*	POOC	USFWS 1998a
Yaqui topminnow (E)	*P. occidentalis sonoriensis*	POOCS	USFWS 1998a
Hiko White River springfish (E)	*Crenichthys baileyi grandis*	CRBAG	USFWS 1998c
Moapa White River springfish (S2)	*C. baileyi moapae*	CRBAM	
Moorman White River springfish (S1)	*C. baileyi thermophilis*	CRBATH	
Desert pupfish (E)	*Cyprinodon macularius*	CYMA	USFWS 1993
Sonoyta pupfish (E)	*C. eremus*	CYER	USFWS 1993

Table 3. Non-native fish targeted in barrier and renovation projects of the southwest. Species abbreviations are used in Tables 4-8.

Common Name	**Scientific Name**	**Abbreviation**
Grass carp	*Ctenopharyngodon idella*	CTID
Red shiner	*Cyprinella lutrensis*	CYLU
Common carp	*Cyprinus carpio*	CYCA
Fathead	*Pimephales promelas*	PIPR
Golden shiner	*Notemigonus crysoleucas*	NOCR
Rainbow trout	*Oncorhynchus mykiss*	ONMY
Brook trout	*Salvelinus fontinalis*	SAFO
Brown trout	*Salmo trutta*	SATR
Mosquitofish	*Gambusia affinis*	GAAF
Bullhead spp.	*Ictalurus sp.*	BULL
Molly spp.	*Poecilia spp.*	POSP
Green sunfish	*Lepomis cyanellus*	LECY
Warmouth	*L. gulosus*	LEGU
Black crappie	*Pomoxis nigromaculatus*	PONI
Threadfin shad	*Dorosoma petense*	DOPE
Jaguar guapote	*Cichlasoma managuense*	CIMA
Convict cichlid	*C. nigrofasciatum*	CINI
Blue tilapia	*Oreochromis aureus*	ORAU

Table 4. Location, ownership, species of concern, and primary information sources for 75 barrier/renovation sites in the southwest. All sites occur on creeks unless otherwise noted. Sites with asterisks are outside range of species of concern. See Table 2 for the species codes. Italicized numbers in "Primary Sources" column are codes for references listed in Table 9; full reference details are in Annotated Bibliography (Appendix A). Trout sites are listed first. Sites are ordered by basin, sub-basin or drainage, and then alphabetically.

Site #	Site Name	Sub-basin or drainage	Land Ownership or Management [1] (State)	Native Fish of Concern	Primary Sources Used to Obtain Information in Tables 4-8 [2]
	Lower Colorado River Basin				
1	North Canyon (Coconino Co.) *	Lower Colorado	FS Kaibab (AZ)	ONAP	*1430;* AGFD files
2	Chevelon	Little Colorado	FS Apache-Sitgr. (AZ)	ONAP; LEVI	*1463; 1464; 1541; 1542*
3	Coyote *	Little Colorado	FS Apache-Sitgr. (AZ)	ONAP	*548; 1303; 1559;* AGFD files
4	Lee Valley	Little Colorado	FS Apache-Sitgr. (AZ)	ONAP	*1303; 1430;* DFC; AGFD files
5	Mineral	Little Colorado	FS Apache-Sitgr. (AZ)	ONAP	*1303; 1430; 1559;* AGFD files
	Salt River Basin				
6	Big Bonito	Big Bonito	WMAT (AZ)	ONAP	DFC; AGFD HDMS
7	Flash	Big Bonito	WMAT (AZ)	ONAP	*548* ; DFC; AGFD HDMS
8	Hurricane	Big Bonito	WMAT (AZ)	ONAP	*548; 1430;* AGFD HDMS
9	Squaw	Big Bonito	WMAT (AZ)	ONAP	DFC; AGFD HDMS
10	Bear Wallow	Black	FS Apache-Sitgr. (AZ)	ONAP	*548; 1303; 1430;* DFC; AGFD files
11	Centerfire	Black	FS Apache-Sitgr. (AZ)	ONAP	*548;* DFC; AGFD files
12	Conklin	Black	FS Apache-Sitgr. (AZ)	ONAP	*548; 1303* ; AGFD files
13	Fish	Black	FS Apache-Sitgr. (AZ)	ONAP	*548; 1303;* DFC; AGFD files
14	Snake	Black	FS Apache-Sitgr. (AZ)	ONAP	*1303;* DFC
15	WF Black River: upper	Black	FS Apache-Sitgr. (AZ)	ONAP	*1303; 1559;* AGFD files
16	WF Black River: lower	Black	FS Apache-Sitgr. (AZ)	ONAP	*1303; 1559*
17	Wildcat	Black	FS Apache-Sitgr. (AZ)	ONAP	*1430; 1559;* AGFD files
18	Hayground	Black, West Fork	FS Apache-Sitgr. (AZ)	ONAP	*1303; 1559;* AGFD files
19	Home	Black, West Fork	FS Apache-Sitgr. (AZ)	ONAP	*1303; 1430; 1559;* AGFD files
20	Stinky	Black, West Fork	FS Apache-Sitgr. (AZ)	ONAP	*548; 1303; 1559;* AGFD files
21	East Fork White River	White	WMAT (AZ)	ONAP	*548; 1559;* AGFD HDMS
22	Little Diamond	White	WMAT (AZ)	ONAP	*548*
23	Ord	White	WMAT (AZ)	ONAP	*548; 1298; 1430;* DFC
24	Paradise	White	FS Apache-Sitgr. (AZ)	ONAP	*548;* DFC
	Upper Gila River Basin				
25	Grant (Apache Co.)	Blue	FS Apache-Sitgr. (AZ)	ONAP	*1430;* NAS; AGFD files
26	KP	Blue	FS Apache-Sitgr. (AZ)	ONAP	*548; 1430; 1456;* AGFD files
27	Marijilda (Pinaleno Mts) *	Gila	FS Coronado (AZ)	ONAP	*1430;* NAS; AGFD files
28	Grant (Pinaleno Mts) *	Lower San Pedro	FS Coronado (AZ)	ONAP	*1430;* NAS; AGFD files
29	Ash (Pinaleno Mts) *	San Carlos	FS Coronado (AZ)	ONAP	*1430;* NAS; AGFD files

Table 4, continued.

Site #	Site Name	Sub-basin or drainage	Land Ownership or Management [1] (State)	Native Fish of Concern	Primary Sources Used to Obtain Information in Tables 4-8 [2]
30	Chitty	Eagle	FS Apache-Sitgr. (AZ)	ONGI or ONAP; unknown	*526; 1331; 1456*
31	Black Canyon Drainage	Gila, East Fork	FS (NM)	ONGI, MEFU, RHCO	*649; 1331; 1450; 1559;* DFC; D. Propst
32	Iron	Gila, Middle Fork	(NM)	ONGI	*1331; 1430; 1450; 1474;* DFC; D. Propst
33	Little: Upper and Lower	Gila, West Fork	(NM)	ONGI	*1331; 1450; 1474; 1559;* DFC; D. Propst
34	Upper White	Gila, West Fork	(NM)	ONGI	*1331; 1450;* DFC
35	McKnight *	Mimbres	FS & TNC allotment (NM)	ONGI	*1331; 1430; 1450; 1474; 1559;* DFC
36	Trail Canyon	Mogollon	FS Gila (NM)	ONGI	*1331; 1450; 1474; 1559;* DFC; D. Propst
37	Upper Reach of Mogollon	Mogollon	FS Gila (NM)	ONGI	*1331; 1450; 1474;* DFC; D. Propst
38	Woodrow Canyon	Mogollon	FS Gila (NM)	ONGI	*1331; 1450; 1474;* DFC; D. Propst
39	Big Dry: Upper and Lower	San Francisco	(NM)	ONGI	*1331; 1450; 1474; 1559;* DFC; D. Propst
	Lower Colorado River Basin				
40	Beal Lake	Lower Colorado	FWS NWR (AZ)	XYTE	DFC, FWS online quarterly reports
41	Cibola High Levee Pond	Lower Colorado	FWS NWR (AZ-CA)	XYTE, GIEL	*1469*
42	Imperial NWR: Duck Ponds Unit 2	Lower Colorado	FWS NWR (AZ)	XYTE	*1448;* DFC
43	Imperial NWR: Duck Ponds Unit 1	Lower Colorado	FWS NWR (AZ)	XYTE	*1448;* DFC
44	Office Cove	Lower Colorado	FWS NWR (AZ)	XYTE, GIEL	C. Minckley
45	Yuma Cove Backwater	Lower Colorado	NPS (AZ)	XYTE	DFC
	Lower Gila River Basin				
46	Tule	Agua Fria	BLM & Private (AZ)	POOC	*1304; 1468;* D. Duncan
	Rio Sonoyta Basin				
47	Quitoboquito Spring	Sonoyta	NPS (AZ)	CYER	*1462; 1463*
	Salt River Basin				
48	Seven Springs Wash	Cave	FS Tonto (AZ)	RHOS; GIIN; MEFU; RHCO	*1258; 1426; 1544*
	San Pedro and Santa Cruz River Basins				
49	Aravaipa	San Pedro	Indian Trust Land (AZ)	MEFU,RHCO,GIRO,AGCH,CAIN,CACL,RHOS	*1290; 1304;* R. Clarkson; J. Stefferud
50	O'Donnell	San Pedro	NAS & TNC (AZ)	GIIN, CAIN, AGCH	1258; DFC; H. Blasius, R. Clarkson
51	Romero	Santa Cruz	FS Coronado (AZ)	GIIN	D. Mitchell
52	Sabino	Santa Cruz	FS Coronado; Private (AZ)	GIIN	D. Mitchell & H. Blasius; DFC
53	Sonoita Ck below Cottonwood Spr.	Santa Cruz	TNC & Private (AZ)	POOC	*1304;* R. Clarkson
	Upper Gila River Basin				
54	Eagle (Phelps Dodge Div. Dam)	Eagle	FS Apache-Sitgr. (AZ)	Gila sp.; MEFU; RHCO; XYTE	*526; 1304;* P. Marsh; B. Csargo
55	Arnett	Gila	FS Tonto (AZ)	GIIN, POOC, AGCH, CACL	D. Mitchell; *662; 751; 1258; 1304*
56	Central Arizona Project barriers	Gila	BR (AZ)	19 native fishes of the Gila River Basin	*1304; 1309;* DFC

Table 4, continued.

Site #	Site Name	Sub-basin or drainage	Land Ownership or Management [1] (State)	Native Fish of Concern	Primary Sources Used to Obtain Information in Tables 4-8 [2]
57	Bylas Springs: S1	Gila	San Carlos Apache (AZ)	POOC	*55; 1296; 1304; 1468, 1470; 1472*
58	Bylas Springs: S2 = Middle	Gila	San Carlos Apache (AZ)	POOC	*55; 1296; 1304; 1468, 1470; 1472*
59	Bylas Springs: S3 = Salt Cr.	Gila	San Carlos Apache (AZ)	POOC	*55; 1296; 1304; 1468, 1470; 1472*
	Virgin River Basin				
60	Boiler Spring	Virgin	(UT)	Virgin River Basin fishes	*1451*
61	Ft Pierce Wash	Virgin	(UT)	GISE, PLAR	*1363; 1452; 1453;* J. Heinrich; M. Morvilius
62	Virgin River: AZ border to JDD [3]	Virgin	Private & Public (UT)	GISE, PLAR, LEMO, CALA, CACL, RHOS	*1363; 1452; 1453;* J. Heinrich; M. Morvilius
63	Virgin River: JDD to WFDD [4]	Virgin	Private & Public (UT)	GISE, PLAR, LEMO, CALA, CACL, RHOS	*1363; 1452; 1453;* J. Heinrich; M. Morvilius
64	Virgin River: Above WFDD	Virgin	Private & Public (UT)	GISE, PLAR, LEMO, CALA, CACL, RHOS	*1363; 1452; 1453;* J. Heinrich; M. Morvilius
65	Hot Creek Spring	White	NWMA (NV)	CRBATH, RHOSM,CACLIN	*1461; 1499;* DFC
66	Hiko Spring	White	(NV)	CRBAG	DFC
67	Sunnyside (includes Flag Spring)	White	(NV)	LEALB, RHOSM, CACLIN	J. Heinrich; DFC
68	Sunnyside (below Flag Spring)	White	NWMA (NV)	LEALB, RHOSM, CACLIN	J. Stein, B. Hobbs
	White River basin				
69	Cardy Lamb Spring	Muddy	Private (NV)	MOCO, GISE, CRBAM	J. Heinrich; DFC
70	Lower Apcar Tributary	Muddy	Private (NV)	MOCO, GISE, RHOSM, CRBAM	J. Heinrich; DFC
71	Reid/Gardner: 3 ponds	Muddy	Private power plant (NV)	GISE, RHOSM, CRBAM	J. Heinrich; DFC
72	Upper Apcar Tributary	Muddy	Private (NV)	MOCO, CRBAM	J. Heinrich; DFC
	Yaqui River Basin				
76	Black Draw	Yaqui	FWS NWR (AZ)	POOCS	*1236*
74	House Pond	Yaqui	FWS NWR (AZ)	POOCS; GIPU	*1096; 1326;* AGFD HDMS; N. King
75	West Turkey [5]	Yaqui	Private & FS (AZ)	POOCS, ICPR, CAOR, GIPU, AGCH	*1326; 1327; 1328; 1330;* DFC

[1] FS = Forest Service; WMAT = White Mtn Apache Tribe; FWS NWR = Fish and Wildlife Service Nat'l Wildlife Refuge; TNC = The Nature Conservancy; NPS = National Park Service; NAS = National Audubon Society; BR = Bureau of Reclamation; NWMA = Nevada Wildlife Management Area

[2] DFC = Desert Fishes Council abstracts (Appendix B); HDMS = AGFD's online Heritage Data Management System; NAS = USGS' online Non-indigenous Aquatic Species database

[3] JDD = Johnson Diversion Dam

[4] WFDD = Washington Fields Diversion Dam

[5] Site 75 includes entire drainage: W. Turkey creek, side canyons, and 12+ ponds

Table 5. Information specific to barrier construction, design, and repair for 75 sites in the southwest. Sites are in the same order as in Table 4.

				Barrier Construction Information						
Site #	**Site Name**	**Type of Barrier [1]**	**Original Purpose of Barrier [2]**	**Date Completed**	**Material [3]**	**Spill Height (m)**	**Splash pad?**	**Designed Lifespan (yr) and/or Flow Capacity (cfs)**	**Year and Probable Type of Failure [4]**	**Comments on Barriers and Repairs [5]**
	Lower Colorado River Basin									
1	North Canyon (Coconino Co.)	None	N/A							
2	Chevelon	?								Barrier exists?
3	Coyote	A	I	1994	G & M					
4	Lee Valley	A	I	1979	C & ID		Y		83 & '89: S & P	Rebuilt after '83 flood; repaired in '03
5	Mineral	A	I	1982	G					Natural barrier as well?
	Salt River Basin									
6	Big Bonito	A	I	1994						
7	Flash	A	I	1994?						
8	Hurricane	A	WM							Barrier exists?
9	Squaw	A	I	1994						
10	Bear Wallow	A	I	1979	G & M		N		1983: S & P	Gabion repaired in 1983; 2003
11	Centerfire	A	I	1984	G & N				P	2003: Barrier refurbished
12	Conklin	A	I	1988	CU & GR & G		Y			1998: Barrier refurbished
13	Fish	A	I	1986	G	1				2003: Barrier refurbished so ht 1.6 m
14	Snake	A	I	1988	GR & G		N			2003: Barrier repaired
15	WF Black River: upper	A	I	1996	G & M				P	
16	WF Black River: lower	A	I	1993	G & M				S	
17	Wildcat	N	N/A							
18	Hayground	A	I	1985	G					
19	Home	A	I	1980	G & M					1996: New barrier; 1998: reinforced
20	Stinky	A	I	1991	G					2003: Barrier repaired
21	East Fork White River	N	N/A							Barrier exists?
22	Little Diamond	A	I							Need information on barrier
23	Ord	A	I	1964	Log	3			1964: P	1994: repaired; 2000: gabion added
24	Paradise	A	I							1994: Barrier repaired
	Upper Gila River Basin									
25	Grant (Apache Co.)	None	N/A							
26	KP	None	N/A							
27	Marijilda (Pinaleno Mts)	None	N/A							
28	Grant (Pinaleno Mts)	None	N/A							
29	Ash (Pinaleno Mts)	None	N/A							

Table 5, continued.

				Barrier Construction Information						
Site #	Site Name	Type of Barrier [1]	Original Purpose of Barrier [2]	Date Completed	Material [3]	Spill Height (m)	Splash pad?	Designed Lifespan (yr) and/or Flow Capacity (cfs)	Year and Probable Type of Failure [4]	Comments on Barriers and Repairs [5]
30	Chitty	W	N/A	N/A					<1991: P	
31	Black Canyon Drainage	A	I	Jul-98	G & N					
32	Iron	A	I	1981	C/NR				No	Barrier struct. sound for >20 yr
33	Little: Upper and Lower	A	I	1982	C/NR				No	Barrier struct. sound for >20 yr
34	Upper White	N	N/A	N/A		10				
35	McKnight	A	I	<1970	C/NR					
36	Trail Canyon	W	N/A			2.5				
37	Upper Reach of Mogollon	W	N/A	1993		3				Natural barrier "improved" in 1993
38	Woodrow Canyon	?	?							
39	Big Dry: Upper and Lower	W	N/A			20				
	Lower Colorado River Basin									
40	Beal Lake	IBW	G							
41	Cibola High Levee Pond	IBW	G							
42	Imperial NWR: Duck Ponds Unit 2	IBW	G							
43	Imperial NWR: Duck Ponds Unit 1	IBW	G							
44	Office Cove	IBW	G							
45	Yuma Cove Backwater	IBW	G							
	Lower Gila River Basin									
46	Tule	A	I	early 1990's						By USBR
	Rio Sonoyta Basin									
47	Quitoboquito Spring	S	N/A							
	Salt River Basin									
48	Seven Springs Wash	A		<1975	C	1.5-2.0				"Non-native" is AGCH
	San Pedro and Santa Cruz River Basins									
49	Aravaipa	A (2)	R	2000	C & S	1.2-1.5	Y	100 yr / 40000 cfs		Double barriers (0.24 km apart)
50	O'Donnell	A	WM		C	3-Feb	N		No	
51	Romero	N	N/A							
52	Sabino	A	Bridges	1935-37?	C/NR	varies	varies			
53	Sonoita Ck below Cottonwood Spr.	A	I	2004	C	1.3	Y	100-yr flood	No	Need information on barrier
	Upper Gila River Basin									
54	Eagle (Phelps Dodge Div. Dam)	A	WM	1984		5				
55	Arnett	A	I	Dec 96?	G	1.5	Y	25 yr / 5194 cfs		Failed project due to stream drying
56	Central Arizona Project barriers	A	R	1989	Electric			100 yr	1989-2004	Electric Barriers- failures from elect. outages or components

Table 5, continued.

				Barrier Construction Information						
Site #	Site Name	Type of Barrier [1]	Original Purpose of Barrier [2]	Date Completed	Material [3]	Spill Height (m)	Splash pad?	Designed Lifespan (yr) and/or Flow Capacity (cfs)	Year and Probable Type of Failure [4]	Comments on Barriers and Repairs [5]
57	Bylas Springs: S1	A	I	1983-1984	C	0.7-0.8			2000: CB	Barrier refurbished in '89, '90, '00
58	Bylas Springs: S2 = Middle	A	I	1983-1984	C	0.7-0.8			CB	1990: notches reshaped for >flows
59	Bylas Springs: S3 = Salt Cr.	A	I	1983-1984	C	0.7-0.8			CB	Barrier and channel altered in '89, '90
	Virgin River Basin									
60	Boiler Spring	None	N/A							
61	Ft Pierce Wash	A	I	1997?	C					
62	Virgin River: AZ border to JDD	A	I							
63	Virgin River: JDD to WFDD	A	WM	1988 (JDD)					88 or '89: S	
64	Virgin River: Above WFDD	A	WM	1953 (WFDD)						
65	Hot Creek Spring	A	WM	1967, 1995	Dike barrier					Dike barrier in '95; multiple barriers ?
66	Hiko Spring	A	WM	early 1970's	Pipe					Irrigation Pipe
67	Sunnyside (includes Flag Spring)	A	WM	1995						"spreader dike" modified
68	Sunnyside (below Flag Spring)	A	I	<1998						Barrier completed before treatment
	White River Basin									
69	Cardy Lamb Spring	S	N/A							Spring source
70	Lower Apcar Tributary	A	I	<1998, 2000	G					1998: TB installed; '00: perm. Installed
71	Reid/Gardner: 3 ponds	IP	N/A							
72	Upper Apcar Tributary	A	I	1998						1998: TB installed
	Yaqui River Basin									
73	Black Draw	A	I		G	0.5			1986: CB	
74	House Pond	IP	N/A							
75	West Turkey	A	I		C	1.3		<100-yr flood		

Abbreviations:

[1] Type of Barrier: A = Artificial; IBW = Isolated Backwater; IP = Isolated Pond; N = Natural; S = Natural Spring; W = Waterfall

[2] Original Purpose: I = Isolate Native Fish; G = Grow-out Ponds for Native Fish; N/A = Not Applicable; R = Reduce or Prevent Movement of Exotics; WM = Water Management (e.g., diversion, dam)

[3] Barrier Material: C = Concrete; CU = Culvert; G = Gabion; GR = Grate; ID = Iron Deflector; M = Masonry; NR = Native Rock (includes Bedrock)

[4] Failure Type: CB = Channel Bypass (type of Passage); S = Structural (e.g., deteriorated gabions); P = Passage (not clearly from Channel Bypass)

[5] Comments on Barriers: DD = Diversion Dam; TB = Temporary Barrier

Table 6. Information specific to renovation projects at 75 sites in the southwest. Sites are in the same order as in Table 4. See Tables 2 and 3 for the species codes. Piscicide used for renovation: A = Antimycin-A; R = Rotenone.

Site #	Site Name	Site Renovated? (Piscicide)	Date(s) of Renovation	Number of Chemical Treatments per Renov.	Reach Length Affected (km)	Target Non-native Fish to Remove With Piscicide or Prevent with Barrier	Native Fish Salvaged? (If NO, Species harmed)	Initial Evidence of Success or Failure	
								Non-natives absent?	Report/ Survey Dates
	Lower Colorado River Basin								
1	North Canyon (Coconino Co.)	YES (R)	1963, 1967		8	ONMY		YES	1991
2	Chevelon	YES (R)	1965; 1968	2, ?, ?	>30	NOCR	NO (LEVI, GIRO)	NO	1970
3	Coyote	NO							
4	Lee Valley	YES (A)	1982, 1987, 2003		4.8	SAFO		NO	>1983
5	Mineral	YES (R)	1962		4.8	SAFO		YES	1991
	Salt River Basin								
6	Big Bonito	YES (A)							
7	Flash	YES (A)	1995			SATR			
8	Hurricane	YES (_?)	1982, 1987		8.5	ONMY		YES	1991
9	Squaw	YES (A)	1995			SATR			
10	Bear Wallow	YES (A)	1981, 1987, 2003	1, ?, ?	19.9	ONMY	<2003: NO (RHOS)	YES	1991
11	Centerfire	NO							
12	Conklin	NO							
13	Fish	NO							
14	Snake	YES (A)	2002, 2003		4				
15	WF Black River: upper	YES (A)	1996		33.8	SATR, ONMY, SAFO		YES	
16	WF Black River: lower								
17	Wildcat	YES (A)	1988		8.9	ONMY		YES	
18	Hayground	YES (A)	1989		6.4	SATR, ONMY		YES	
19	Home	YES (A)	1987		18	ONMY		YES	
20	Stinky	YES (A)	1994		4	SATR, ONMY		YES	
21	East Fork White River	?							
22	Little Diamond	?							
23	Ord	YES (A)	1977-78; 1980; 1994	2	16	SATR, SAFO		YES	1981
24	Paradise	?							
	Upper Gila River Basin								
25	Grant (Apache Co.)	YES (R)	1963, 1969		9.7	SATR, ONMY		?	
26	KP	YES (R)	1963; 1969		18	ONMY		NO	1983
27	Marijilda (Pinaleno Mts)	YES (R)	1968	2	14	ONMY, SAFO			
28	Grant (Pinaleno Mts)	YES (R)	1965		4.8	SATR, ONMY, SAFO	NO (several)		
29	Ash (Pinaleno Mts)	YES (R)	1965		6.4	SATR, SAFO			

Table 6, continued.

Site #	Site Name	Site Renovated? (Piscicide)	Date(s) of Renovation	Number of Chemical Treatments per Renov.	Reach Length Affected (km)	Target Non-native Fish to Remove With Piscicide or Prevent with Barrier	Native Fish Salvaged? (If NO, Species harmed)	Initial Evidence of Success or Failure	
								Non-natives absent?	Report/ Survey Dates
30	Chitty	?			8.05				
31	Black Canyon Drainage	NO	1995 by fire		18.2	SATR, ONMY		YES	1998
32	Iron	YES (A)	1981	1	2.9	SATR		NO	1985
33	Little: Upper and Lower	YES (A)	1982, 1998, 1999	1	14.8	SATR, ONMY x, ONMY	NO (CA spp,RHOS)	YES	<1989
34	Upper White	YES (A)	1991, 1993, 2000	?, 3, ?	8.8	ONMY & ONMY x		YES	
35	McKnight	YES (R)	1970; 1980		8.5	non-native trout	NO (CAPL)	YES	1971
36	Trail Canyon	YES (A)	1986-87, 1996-97	2, 2		ONMY & ONMY x	NO (RHOS)	YES	1989
37	Upper Reach of Mogollon	YES (A)	1986-89, 1996-97	2, 2	14.5	SATR, ONMY x	NO (RHOS)	YES	1989
38	Woodrow Canyon	YES (A)	1986-89, 1996-97	2, 2	28.8	ONMY x, ?	NO (RHOS)	?	
39	Big Dry: Upper and Lower	YES (A)	1984-1985	2	1.9	SATR, ONMY x		YES	1985-90
	Lower Colorado River Basin								
40	Beal Lake	YES (R)	2001	1		multiple species		?	
41	Cibola High Levee Pond	YES (R)	1993	1		multiple species	YES	YES	
42	Imperial NWR: Duck Ponds Unit 2	YES (R)	2002	2		multiple species		YES	2003
43	Imperial NWR: Duck Ponds Unit 1	YES (R)	2004	2		multiple species		Some	2004
44	Office Cove	YES (R)	1995-96	3 ?		multiple species	YES		
45	Yuma Cove Backwater	YES (R)	<1993			multiple species		YES	
	Lower Gila River Basin								
46	Tule	NO							
	Rio Sonoyta Basin								
47	Quitoboquito Spring	YES (R)	1969			NOCR		YES	1975-80
	Salt River Basin								
48	Seven Springs Wash	YES (R)	1970-71	2	2	AGCH		NO	1970-71
	San Pedro and Santa Cruz River Basins								
49	Aravaipa	NO				LECY, CYLU, BULL			
50	O'Donnell	YES (A)	2002			LECY		YES	
51	Romero	YES (A)	2003			LECY		YES	
52	Sabino	YES (A & R)	1999	1?	2.4	LECY		YES	
53	Sonoita Ck below Cottonwood Spr.	NO							
	Upper Gila River Basin								
54	Eagle (Phelps Dodge Div. Dam)	NO							
55	Arnett	YES (A & R)	1996	1		LECY, GAAF		YES	
56	Central Arizona Project barriers	NO							

Table 6, continued.

Site #	Site Name	Site Renovated? (Piscicide)	Date(s) of Renovation	Number of Chemical Treatments per Renov.	Reach Length Affected (km)	Target Non-native Fish to Remove With Piscicide or Prevent with Barrier	Native Fish Salvaged? (If NO, Species harmed)	Initial Evidence of Success or Failure	
								Non-natives absent?	Report/ Survey Dates
57	Bylas Springs: S1	YES (A)	1982, 1984, 2000	1,?, ?		GAAF		NO (3 trt)	
58	Bylas Springs: S2 = Middle	YES	1996, 2005			GAAF		NO	
59	Bylas Springs: S3 = Salt Cr.	YES	1984, 1997, 2005			GAAF		1984:3 yrs	1986-88
	Virgin River Basin								
60	Boiler Spring	YES (R)	1988			CIMA	No natives		
61	Ft Pierce Wash	YES (R)	2004			CYLU			
62	Virgin River: AZ border to JDD	YES (R)	1988; 1993-95; 2003-4	many		CYLU	1988: NO	NO	>Yearly
63	Virgin River: JDD to WFDD	YES (R)	1988; 1993-95; 2003-4	many		CYLU	1988: NO	NO	>Yearly
64	Virgin River: Above WFDD	YES (R)	1988; 1993-95; 2003-4	many		CYLU	1988: NO	NO	>Yearly
65	Hot Creek Spring	NO				MISA	YES	YES	1993
66	Hiko Spring	NO				MISA			
67	Sunnyside (includes Flag Spring)	YES (R)	1995, 2000	5	2.4	MISA	YES	YES	
68	Sunnyside (below Flag Spring)	YES (R)	1998						
	White River Basin								
69	Cardy Lamb Spring	YES (R)	2000	2	0.2	ORAU	YES	YES	2001
70	Lower Apcar Tributary	YES (R)	2000	1	0.6	ORAU	YES	YES	>Yearly
71	Reid/Gardner: 3 ponds	YES (R)	2003, 2004	4, 4		ORAU	YES	NO	2003-04
72	Upper Apcar Tributary	YES (R)	1998	2	1.8	ORAU	YES	YES	>Yearly
	Yaqui River Basin								
73	Black Draw	NO				GAAF			
74	House Pond	YES (?)	1980, 1984-85			GAAF			
75	West Turkey	YES (A & R)	Jun-05	2	13	multiple species		YES	2001

Table 7. Summary of historical information on effectiveness of barrier and renovation projects at 75 sites in the southwest. Sites are in the same order as in Table 4. See Tables 2 and 3 for the species codes. Italicized numbers correspond to references listed in Table 9.

Site #	Site Name	Origin Date of First Notes	First Notes	Origin Date of Second Notes	Second Notes
	Lower Colorado River Basin				
1	North Canyon (Coconino Co.)	1991	Successful: ONAP present	1996	Successful: ONAP present
2	Chevelon	1991	Trt in '60s for ONMY had no native salvage, lost last GIRO of LCRB	1970	NOCR returned 2 yrs after '68 trt
3	Coyote	1993	*548* : Pure ONAP	2004	*1303, 1559* : pure ONAP
4	Lee Valley	1991	Succeeded after 2nd trt in 1987	2004	*1303* : 1977-2001: SAFO and ONAP
5	Mineral	1991	*1430* : Successful: ONAP present	2004	*1303, 1559* : pure ONAP
	Salt River Basin				
6	Big Bonito			1995	No info after 1995 (AGFD HDMS)
7	Flash	1993	*548* : Pure ONAP	1995	No info after 1995 (AGFD HDMS)
8	Hurricane	1993	*548* : Pure ONAP	1995	No info after 1995 (AGFD HDMS)
9	Squaw				
10	Bear Wallow	1993	*548* : ONMY x present	2004	*1303:* non-native salmonids found above barrier
11	Centerfire	1988	Failed; ONMY x present	1993	*548* : ONMY x and ONAP present
12	Conklin	1993	*548* : ONMY x and ONAP present	2004	mixed ONAP
13	Fish	1993	*548* : ONMY x present	2004	*1303:* marked trout & ONMY x found above barrier
14	Snake	2004	*1303:* NO apparent movement of trout past barrier		
15	WF Black River: upper	2002	SATR above barrier	2004	*1303* : SATR above barrier; *1559* : pure ONAP
16	WF Black River: lower	1999	SATR above barrier		
17	Wildcat	1995	Pure ONAP	2004	*1559* : Pure ONAP
18	Hayground	2000	1989 renovation a success	2004	*1303* : SATR above barrier; *1559* : pure ONAP
19	Home	1991	Successful: ONAP present	2004	1990-2001: ONMY hybrids above barrier
20	Stinky	1995	Successful	2004	*1303* : SATR above barrier; *1559* : pure ONAP
21	East Fork White River	1993	*548* : Pure ONAP		
22	Little Diamond	1993	*548* : ONMY x and ONAP present		
23	Ord	1981	1st trt failed, maybe due to SAFO eggs surviving	1993	*548* : ONMY x and ONAP present
24	Paradise	1983	ONMY x present	1993	*548* : ONMY x present; ONAP absent
	Upper Gila River Basin				
25	Grant (Apache Co.)	1991	Failed; ONMY x present		
26	KP	1991	Failed; ONMY x present	1991	hybrid trout present
27	Marijilda (Pinaleno Mts)	1991	Failed; ONMY x present		
28	Grant (Pinaleno Mts)	1991	Cypriniformes spp. lost that were unknown to science	1991	ONAP present
29	Ash (Pinaleno Mts)	1991	Failed; ONMY x present		

Table 7, continued.

Site #	Site Name	Origin Date of First Notes	First Notes	Origin Date of Second Notes	Second Notes
30	Chitty	1992	Unkn. *Oncorhychus* sp. not collected before hybrid. with ONMY		
31	Black Canyon Drainage	1998	ONCL introd. in 1993 managed with intensive mechanical removal	2003	Early monitoring found UHT for quick removal
32	Iron	1981	Premature release after renov. caused high mortality	1992	*1331* : Secure but persistent SATR
33	Little: Upper and Lower	1997	established; all life stages present	2003	ONMY x in LOWER but not in UPPER
34	Upper White	?	Waterfall is popular angling spot	2003	existing
35	McKnight	1992	ONGI increased until flood 1988; restocked in 1989; stable	1997	established; all life stages present
36	Trail Canyon	1992	"cautious optimism"; all life stages of ONGI present	2003	*1331* : ONMY x recent contam.
37	Upper Reach of Mogollon	1992	all life stages of ONGI present	2003	*1331* : ONMY x recent contam.
38	Woodrow Canyon	1992	all life stages of ONGI present	2003	*1331* : ONMY x recent contam.
39	Big Dry: Upper and Lower	1992	established; all life stages present	1997	established; all life stages present
	Lower Colorado River Basin				
40	Beal Lake	2002	Apr-2002: 10k XYTE released; Nov-2002: none found		
41	Cibola High Levee Pond	1998	Recruitment occurring for both species, multiple yr-classes	2003	Recruitment of XYTE, GIEL since 2001
42	Imperial NWR: Duck Ponds Unit 2	2003	Pop. est: ~14k LEGU; 25 XYTE		
43	Imperial NWR: Duck Ponds Unit 1	2004	Pop. est: ~15k LEGU & others; ~6.6k XYTE from 10k released		
44	Office Cove				
45	Yuma Cove Backwater				
	Lower Gila River Basin				
46	Tule	1981	Re-introduced after flooding extirpated POOC	1998	*1468* : "Present in large numbers"
	Rio Sonoyta Basin				
47	Quitoboquito Spring	1987	pop est. 3143 - 7896 between 1975 - 1980		
	Salt River Basin				
48	Seven Springs Wash	1975	AGCH present		Weedman has info?
	San Pedro and Santa Cruz River Basins				
49	Aravaipa	2003	Annual monitoring conducted 1965 to present	2005	Upper barrier buried; lower barrier still functioning
50	O'Donnell	2003	POOC makes comeback after decades	2004	Natives breeding
51	Romero	Jun-03	Successful renovation	Jul-03	Pools "re-renovated" by Aspen Fire
52	Sabino	1999	Reservoir below FS-private boundary was not treated	2003	LECY moving US from untreated lake until '03 Fire
53	Sonoita Ck below Cottonwood Spr.	2001	AGFD HDMS: relatively stable and secure		
	Upper Gila River Basin				
54	Eagle (Phelps Dodge Div. Dam)	1991	*526* : natives >90% above dam, but <25% below		
55	Arnett	1996	No natives	2004	AGCH, CA spp stocked in '02 but failed: drought
56	Central Arizona Project barriers				

Table 7, continued.

Site #	Site Name	Origin Date of First Notes	First Notes	Origin Date of Second Notes	Second Notes
57	Bylas Springs: S1	1987	*1470* : GAAF were 98% in Jul 1987	1993	Pop. Collected
58	Bylas Springs: S2 = Middle	1993	GAAF present	2000	*1472* : new stock POOC in 1998; population thriving"
59	Bylas Springs: S3 = Salt Cr.	1990	*1296* : No GAAF for 3 yr after trt in '84; POOC released in '86	1996	100% GAAF; POOC extirpated
	Virgin River Basin				
60	Boiler Spring	1989	No natives; concern was CIMA entering Virgin River	1992	Pop. Extirpated (http://nas.er.usgs.gov)
61	Ft Pierce Wash				
62	Virgin River: AZ border to JDD	Oct-88	GISE not found immediately after accidental poisoning	1989	young collected for Demarais paper
63	Virgin River: JDD to WFDD	Oct-88	GISE not found immediately after accidental poisoning		
64	Virgin River: Above WFDD				
65	Hot Creek Spring	1993	DFC: Healthy numbers after MISA removed in 1992	1997	Pop. Est of 50k springfish (DFC); 4 MISA removed
66	Hiko Spring	198x	Barrier successful at keeping out MISA	1992	DFC: CRBAG stable or expanding (7450 est.)
67	Sunnyside (includes Flag Spring)	1997	Recruitment to >1200 individuals	2002	DFC: Success for 5 yrs then re-trt; LEALB increasing
68	Sunnyside (below Flag Spring)	1998	Recruitment to >2000 individuals		
	White River Basin				
69	Cardy Lamb Spring	2001	DFC: CRBAM reintroduced after successful renovation	2002	DFC: CRBAM numbers increasing
70	Lower Apcar Tributary			2002	DFC: CRBAM numbers increasing
71	Reid/Gardner: 3 ponds	2005	Non-natives present		
72	Upper Apcar Tributary	1997	DFC: MOCO declining but CRBAM numbers are steady	2002	DFC: CRBAM AND MOCO numbers increasing
	Yaqui River Basin				
73	Black Draw	1994	1986: GAAF breaching barrier		
74	House Pond	1995	AGFD HDMS: GIPU extant	2004	N. King: no GAAF
75	West Turkey	2000	GIER and AGCH reproduced immed; ICPR extant	2003	Big Tank: '01-'03: 0 AGCH, few ICPR; many age-0 PONI

Table 8. Summary of most recent information on effectiveness of barrier and renovation projects at 75 sites in the southwest. Sites are in the same order as in Table 4. See Tables 2 and 3 for the species codes. Italicized numbers correspond to references listed in Table 9. A = Absent, P = Present.

					Non-native metrics		Native Metrics						
							Population Status:				Indication of Reproduction:		
Site #	Site Name	Last Date Data Collected or Reported	Number of Years of Success [1]	Likely Cause of Breach [2]	Absent or Present? Change in numbers?	ONMY Hybrids	Increas-ing	Stable	Extant (no other info)	Decreasing or Absent	Spawning or Larvae	Recruit-ment	Multiple Year-Classes
	Lower Colorado River Basin												
1	North Canyon (Coconino Co.)	1996	37		A			ONAP					
2	Chevelon	1998	2	IR or UHT	NOCR: P				LEVI	GIRO sp lost			
3	Coyote	2004	10		A	A		ONAP					
4	Lee Valley	2004	24 *		SAFO: P	A			ONAP				
5	Mineral	2004	43		A	A		ONAP					
	Salt River Basin												
6	Big Bonito	1995			?				ONAP				
7	Flash	1995							ONAP				
8	Hurricane	1995							ONAP				
9	Squaw		?						??				
10	Bear Wallow	2004	<6	CB		P			??	RHOS			
11	Centerfire	2001	0		SATR: P	P			ONAP	RHOS			
12	Conklin	2004	0			P			ONAP				
13	Fish	2004	0		SATR: P	P			ONAP, RHOS				
14	Snake	2004	0			P			ONAP				
15	WF Black River: upper	2004	6 *	CB	SATR: P				ONAP				
16	WF Black River: lower	2001	20 *		SATR: P				ONAP				
17	Wildcat	2004	14		Absent	A			ONAP				
18	Hayground	2004	11 *		SATR: P	A			ONAP				
19	Home	2004	17			A			ONAP				
20	Stinky	2004	6	CB	SATR: P	A			ONAP				
21	East Fork White River	1995				A			ONAP				
22	Little Diamond	1993				P			ONAP				
23	Ord	1994	?	IR									
24	Paradise	2003	?		SATR: P	P			ONAP				
	Upper Gila River Basin												
25	Grant (Apache Co.)	1991	0			P							
26	KP	1991	0			P							
27	Marijilda (Pinaleno Mts)	1991	0		SAFO: P	P							
28	Grant (Pinaleno Mts)	1991	?		?				ONAP	Unk. Sp. lost			
29	Ash (Pinaleno Mts)	1991	0			P							

Table 8, continued.

					Non-native metrics		Native Metrics						
							Population Status:				Indication of Reproduction:		
Site #	Site Name	Last Date Data Collected or Reported	Number of Years of Success [1]	Likely Cause of Breach [2]	Absent or Present? Change in numbers?	ONMY Hybrids	Increasing	Stable	Extant (no other info)	Decreasing or Absent	Spawning or Larvae	Recruitment	Multiple Year-Classes
30	Chitty	1992	?	UHT		P				ON sp. lost			
31	Black Canyon Drainage	2004	5	UHT	A ?	A		ONGI	RHOS, CA spp		ONGI	ONGI	ONGI
32	Iron	2004	<12			P		ONGI			ONGI	ONGI	ONGI
33	Little: Upper and Lower	2004	7, __?		A	Lower:P		ONGI			ONGI	ONGI	ONGI
34	Upper White	2003	>3	UHT	A	A		ONGI			ONGI	ONGI	ONGI
35	McKnight	2004	10, 23		A	A		ONGI			ONGI	ONGI	ONGI
36	Trail Canyon	2003	<5			P		ONGI			ONGI	ONGI	ONGI
37	Upper Reach of Mogollon	2003	<5			P		ONGI			ONGI	ONGI	ONGI
38	Woodrow Canyon	2003	<5			P		ONGI			ONGI	ONGI	ONGI
39	Big Dry: Upper and Lower	2004	>19		A			ONGI		CACL	ONGI	ONGI	ONGI
	Lower Colorado River Basin												
40	Beal Lake	2002	0.5	HTL	5 spp: P					XYTE: A			
41	Cibola High Levee Pond	2005	10	UHT	Many MISA				GIEL, XYTE		XYTE, GIEL	until 2005	XYTE, GIEL
42	Imperial NWR: Duck Ponds Unit 2	2003	0.5	HTL or HC	Many LEGU					XYTE ~25			
43	Imperial NWR: Duck Ponds Unit 1	2004	0.1	HTL or HC	Many LEGU				XYTE~6600	XYTE			
44	Office Cove												
45	Yuma Cove Backwater		?										
	Lower Gila River Basin												
46	Tule	1998	>15		A ?		POOC				POOC	POOC	POOC
	Rio Sonoyta Basin												
47	Quitoboquito Spring	1987?	>18		NOCR: A			CYER					
	Salt River Basin												
48	Seven Springs Wash	1975 ?	<1	IR	AGCH: P				GIIN ('75)?	MEFU,RHOS,TICO			
	San Pedro and Santa Cruz River Basins												
49	Aravaipa	2005	5		More CYLU/No new spp.			probably	YES			TICO	TICO
50	O'Donnell	2004	>2	UHT	1 LECY removed in '04		POOC						
51	Romero	Jul-03	N/A										
52	Sabino	2004	3	UHT	LECY: A				GIIN		GIIN		
53	Sonoita Ck below Cottonwood Spr.							POOC					
	Upper Gila River Basin												
54	Eagle (Phelps Dodge Div. Dam)	1991 ?	>6		P				YES				
55	Arnett		N/A										
56	Central Arizona Project barriers	2004	4		CTID: P				GIRO				

Table 8, continued.

					Non-native metrics		Native Metrics						
							Population Status:				Indication of Reproduction:		
Site #	Site Name	Last Date Data Collected or Reported	Number of Years of Success [1]	Likely Cause of Breach [2]	Absent or Present? Change in numbers?	ONMY Hybrids	Increas-ing	Stable	Extant (no other info)	Decreasing or Absent	Spawning or Larvae	Recruit-ment	Multiple Year-Classes
57	Bylas Springs: S1	2000	<5	82:IR;'84:CB	99% GAAF				POOC				
58	Bylas Springs: S2 = Middle	2000	<5	IR	GAAF: P				POOC				
59	Bylas Springs: S3 = Salt Cr.	2000	<5		GAAF: P				POOC				
	Virgin River Basin												
60	Boiler Spring	1989	0	UHT	Many spp.				No natives				
61	Ft Pierce Wash												
62	Virgin River: AZ border to JDD	2005			Many CYLU								
63	Virgin River: JDD to WFDD	2005			CYLU: P				GISE,LEMO,PLAR				
64	Virgin River: Above WFDD	2005	3		CYLU: A		PLAR		GISE, LEMO		PLAR	PLAR	PLAR
65	Hot Creek Spring	2005	9		Few MISA			CRBATH					
66	Hiko Spring	2002	>25 ?		MISA: A		CRBAG?	CRBAG?		CRBAG<1300?			
67	Sunnyside (includes Flag Spring)	2005	5, 4		MISA: A		LEALB	CRBAG					
68	Sunnyside (below Flag Spring)												
	White River Basin												
69	Cardy Lamb Spring	2005	>4										
70	Lower Apcar Tributary	2005	4										
71	Reid/Gardner: 3 ponds	2005	0	UHT									
72	Upper Apcar Tributary	2005	6										
	Yaqui River Basin												
73	Black Draw	1994		CB	GAAF: P								
74	House Pond	2004	18?		A				GIPU, ??				
75	West Turkey	2003	>3	UAT	Many PONI		GIPU, AGCH		ICPR		GIPU, AGCH	GIER	GIER

[1] **Sites with asterisks were partially successful: non-native trout were found upstream but they were not introduced *Oncorhynchus species,* therefore no hybridization was possible.**

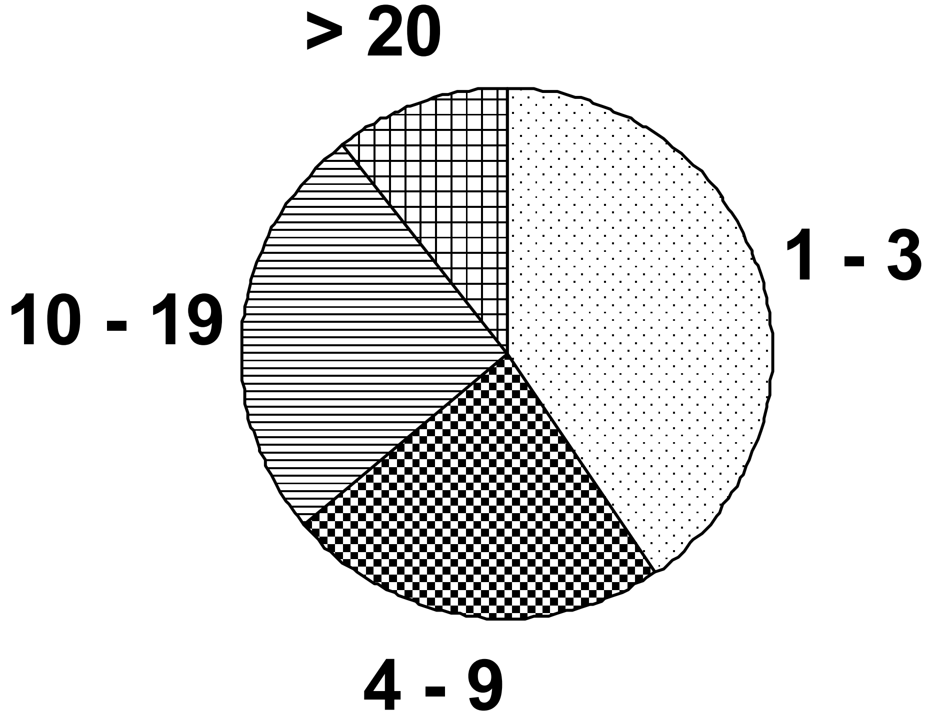
[2] **Possible Causes of Barrier / Renovation Compromise:**

CB: Channel Bypass around Barrier
HNI: Habitat not isolated from non-native source
HTC: Habitat too complex (e.g., marshy, cienegas, braided)
HTL: Habitat too large to effectively renovate
UHT: Unauthorized Human Transport
IR: Incomplete Renovation

Table 9. Sources used in Tables 4-8. References are provided in more detail in the Annotated Bibliography (Appendix A).

Reference Number in Tables 4 - 8	Reference
55	Meffe 1983
526	Marsh, Brooks, Hendrickson, and Minckley 1991
548	Carmichael et al. 1993
649	Propst 1999
662	Bizios and Tate 1995
751	Bizios 1997
1096	DeMarais and Minckley 1993
1236	Galat and Robertson 1992
1258	Desert Fishes Team 2004
1290	Eby, Fagan, and Minckley 2003
1296	Marsh and Minckley 1990
1298	Rinne, Minckley, and Hanson 1981
1303	Robinson, Avenetti, and Cantrell 2004
1304	Desert Fishes Team 2003
1309	Clarkson, R. W. 2004
1326	U.S. Fish and Wildlife Service (USFWS) 1994a
1327	Coleman 2002
1328	Coleman and Minckley 2001
1330	Coleman and Minckley 2000
1331	U.S. Fish and Wildlife Service (USFWS) 2003
1363	Demarais, Dowling, and Minckley 1993
1426	Rinne 1975
1430	Rinne and Turner 1991
1448	Brouder and Jann 2004
1450	Propst, Stefferud, and Turner 1992
1451	Marsh, Burke, Demarais, and Douglas 1989
1452	Washington County Water Conservancy District 1999
1453	U.S. Fish and Wildlife Service (USFWS) 1994b
1456	Dowling and Childs 1992
1461	U.S. Fish and Wildlife Service (USFWS) 1995
1462	Miller and Fuiman 1987
1463	Minckley 1973
1464	U.S. Fish and Wildlife Service (USFWS) 1998b
1467	U.S. Fish and Wildlife Service (USFWS) 2002a
1468	U.S. Fish and Wildlife Service (USFWS) 1998a
1469	Mueller, Carpenter, and Minckley 2003
1470	Simons 1987
1472	Schleusner 2000
1474	Propst and Stefferud 1992
1499	Williams 1991
1541	Minckley and Carufel 1967
1542	U.S. Fish and Wildlife Service (USFWS) 1987
1544	Minckley and Brooks 1985
1559	Wares, Alò, and Turner 2004

Figure 1. Longevity of barrier and renovation projects (*N* = 49). Longevity is the number of years that a project remained free of non-natives.



APPENDIX A

ANNOTATED BIBLIOGRAPHIC REFERENCES ON BARRIERS AND RENOVATIONS

Adams, S.B., Frissell, C.A., and Rieman, B.E. 2000. Movements of nonnative brook trout in relation to stream channel slope. Transactions of the American Fisheries Society 129: 623-638.
Notes: This article has a good discussion in introduction about concern of using barriers for managing native trout. A secondary objective of this study was to characterize short-term barriers.
Abstract: We provide new insights on the ability of naturalized brook trout *Salvelinus fontinalis* to ascend steep, headwater streams in the western USA. We tested hypotheses that upstream movements by brook trout are limited or absent in reaches of steep streams and are more prevalent and longer in gradually sloping streams. We compared brook trout movements in headwater streams in Idaho at sites with varied channel slopes (averages of <1–12%). After eradicating fish from 200-m stream sections, we assessed immigration of marked fish into these sections. Contrary to our hypothesis, upstream movements were more prevalent than downstream movements during the summer, even in steep streams. Marked brook trout ascended stream channels with slopes of 13% that extended for more than 67 m and 22% for more than 14 m; they also ascended a 1.2-m-high falls. Nearly vertical falls, rather than steep slopes per se, apparently inhibited upstream movements. Our hypothesis that upstream movements would decrease with increasing channel slope was partially supported; fish did not move as far upstream in steep as in gradual sites, and upstream movements through steep channels were dominated by larger fish (>135 mm total length). Immigration by marked fish smaller than 95 mm was uncommon in all sites. Slopes up to 13% do not ensure against upstream dispersal, although other mechanisms may inhibit brook trout invasion in steep channels. In very steep channels, fewer dispersing fish and slower upstream movement rates may increase the time required for successful invasion and reduce its likelihood of occurrence.

American Fisheries Society Fish Management Chemicals Subcommittee Task Force on Fishery Chemicals. 2000. Importance of rotenone as a management tool for fisheries. Fisheries 25: 22-23.
Notes: This editorial discusses how rotenone is one of few options that eradicates entire populations comared to mechanical methods that control populations. They list several rare species that would probably be extinct if it were not for rotenone. They note no public health effects have been reported from rotenone use as a piscide. The editorial discussed registration status and the reasons why rotenone use is controversial. They recommend doing environmental impact analyses or assessments on proposed projects so as to communicate better with the public. They also suggest educating the public on benefits of the restoration, and discuss their future public information program.
Abstract: No.

Baugh, T.M., Deacon, J.E., and Withers, D. 1986. Conservation efforts with the Hiko White River spring fish *Crenichthys baileyi grandis* (Williams and Wilde). Journal of Aquariculture & Aquatic Sciences 4: 49-53.
Abstract: No. Excerpts from online paper:
<u>Introduction:</u>

The White River springfish *Crenichthys baileyi grandis* (Williams and Wilde) is one of five subspecies of the genus *Crenichthys* found in spring pools and their outflows in the pluvial White River drainage of south central Nevada (Williams and Wilde, 1981). A related species, *Crenichthys nevadae* Hubbs, occurs in two locations in nearby Railroad Valley (Williams and Wilde, 1982). *Crenichthys baileyi grandis* has been restricted in historic times to Crystal Springs and Hiko Spring, Lincoln County, Nevada.

The illegal introduction of tropical aquarium fishes, including *Cichlasoma nigrofasciatum* (Gunther) (convict cichlid) and *Poecilia mexicana* Steindachner is positively correlated with the decline of *Crenichthys baileyi grandis* in Crystal Springs (Courtenay et al., in press). *C. b. grandis* was extirpated from Hiko Spring in 1967 as a consequence of the 1965 introduction of largemouth bass *Micropterus salmoides* (Lacepede) and other non-native fishes (Deacon, 1979; Courtenay et al., in press). The bass

apparently moved from a nearby reservoir into Hiko Spring via an irrigation canal. Bass disappeared from Hiko Spring in the early 1970's and modification of the connecting irrigation canal, by converting it to a pipe, appears to make it unlikely that bass will be reestablished in Hiko Spring via the canal (Courtnay et al., in press). *Gambusia affinis* (Baird and Girard) and *Poecilia mexicana* also became established in Hiko Spring in 1965 (Courtenay et al., in press; Deacon, 1979). The introduction of *Cichlasoma nigrofasciatum* into Crystal Springs occurred in the mid to late 1970's (Courtenay and Deacon, 1982).
Results and discussion:
Fish Introductions. Thirty-five juvenile *C. b. grandis* cultured in the laboratory were released into Hiko Spring on 24 January 1984 and an additional 40 fish were released on 22 March 1984. Follow-up trapping in Hiko Spring (Table 3) on March 22 and 18 July 1984 failed to demonstrate the presence of this fish. On 18 July 1984, six convict cichlids, comprising about 1.5 percent of the fish captured, were taken at Hiko Spring. These fish were apparently introduced sometime between March and July 1984. On 11 February 1985, up to 14 *C. b. grandis* were seen at one time in an area 2 X 1 X 1 m (deep) and one female was captured. It seemed apparent that the stocked springfish had successfully reproduced. Convict cichlids had also reproduced 11 February 1985.

Baxter, J.S., Birch, G.J., and Olmsted, W.R. 2003. Assessment of a constructed fish migration barrier using radio telemetry and floy tagging. North American Journal of Fisheries Management 23: 1030-1035.
Notes: The purpose of the barrier in this article was to reduce native non-sport fish within a stream. The barrier was installed, didn't work, and probably wasn't even necessary. "In hindsight this is a clear example of where a thorough review of the data prior to the initial construction....could have saved a lot of time, effort and cost". They also review marking vs. telemetry in this kind of study.
Abstract: We assessed the effectiveness of a constructed fish migration barrier in the Salmo River, British Columbia, Canada, 10 years after it was constructed. The barrier was initially installed to prevent an expected increase in upstream migration of suckers *Catostomus* spp., and northern pikeminnow *Ptychocheilus oregonensis* into the Salmo River following the creation of Seven Mile Reservoir on the Pend d'Oreille River. To determine the effectiveness of the barrier, we applied radio and Floy tags to these species in Seven Mile Reservoir to assess whether upstream migration over the barrier was occurring. After sampling below the barrier, 5 largescale suckers *C. macrocheilus* and 5 northern pikeminnow were radio-tagged, whereas 124 suckers and 11 northern pikeminnow were Floy-tagged. Radio tracking surveys confirmed that most radio-tagged suckers and northern pikeminnow made migrations only within the reservoir, but one sucker was tracked above the barrier. This movement occurred after the peak of annual discharge. During snorkel surveys conducted above the barrier, we observed five Floy-tagged suckers. The results are discussed in relation to the use of tagging methods to monitor sucker and northern pikeminnow migrations and assess the effectiveness of constructed fish migration barriers .

Beamesderfer, R.C.P. 2000. Managing fish predators and competitors: deciding when intervention is effective and appropriate. Fisheries 25: 18-23.
Abstract: Fisheries management agencies increasingly are being asked to weigh tradeoffs between game, non-game, native, and nonnative species management. Oregon recently has been considering a variety of interspecific intervention activities aimed at protecting and rebuilding depleted native fishes or improving native game fish production by managing potential predators and competitors. Activities range from reduced harvest restrictions on fish predators and competitors to more aggressive removal programs. Chemical treatment and predator hazing also have been considered for potential benefits to more desirable fish populations. This paper describes a systematic decision-making process to determine for any given case if: (1) predation or competition is likely to be important, (2) potential predators or competitors can be affected by changes in harvest or other management actions, and (3) biological benefits outweigh costs and social/ political considerations. This process is applied to several of Oregon's problems to help identify examples where intervention might prove effective and appropriate.

Bills, T.D., and L.L. Marking. 1988. Control of nuisance populations of crayfish with traps and toxicants. Progressive Fish-Culturist 50: 103-106.
Notes: This article describes how trapping can suppress crayfish populations but not likely successful for control or elimination. Bathyroid was toxic to *Pimephales promelas* for 5 weeks after introduction; possibly due to the cold temperature (10°C). For instance, rotenone is detectable for 40 d at 5°C but is undetectable after 5 d in 24°C. Also, suspended solids absorb organic chemicals, thus requiring higher concentrations in

field vs. laboratory conditions.
Abstract: Crayfish have long been a nuisance in fish-rearing ponds at fish hatcheries. The rusty crayfish (*Orconectes rusticus*) has displaced endemic species and caused serious declines of aquatic plants in some ponds and lakes in the midwestern USA. The authors attempted to evaluate the effect of intensive trapping on a crayfish population and to identify a selective chemical control agent and evaluate its effectiveness under field conditions. A crayfish population in a small pond was suppressed but not eliminated by trapping: adults were effectively harvested but efficiency diminished sharply as the population declined. Of 19 chemicals tested as possible control agents for crayfish, a synthetic pyrethroid (Baythroid) was by far the most toxic; 25 µg/ L produced a complete kill of crayfish in the pond and was also the most selective for crayfish in laboratory tests.

Bizios, L.J. 1997. Final report for the Arnett Creek native fish re-establishment project, Phase II. Heritage Grant #I94031. US Forest Service, Phoenix, Arizona.
Notes: Phase II is chemical treatment. No monitoring was done.
Abstract: No.

Bizios, L.J., and Tate, K.L. 1995. DRAFT Final report for the Arnett Creek native fish re-establishment project, Phase I. Heritage Grant #I93007. US Forest Service, Phoenix, Arizona.
Notes: Phase 1 includes: 1) designing a fish barrier; 2) installing a cattle guard (p. 15); 3) completing fish habitat inventory (p. 17). They also identified and mapped all waters in watershed to determine probability of chemical treatment to remove exotics. In the inventory, they evaluated suitability for reintroduction of multiple natives: *Agosia chrysogaster,* excellent; *Catostomus clarkii*, yes; *Gila intermedia,* doubtful; *C. insignis*, no; *Poeciliopsis occidentalis,* no.
Abstract: No.

Brooks, J.E., and Propst, D.L. 1999. Nonnative salmonid removal from the Black Canyon drainage, East Fork Gila River, June-October 1998, DRAFT.
Notes: Black Canyon has a Gila trout population above a barrier. The unauthorized stocking mentioned in this report is covered in detail in their 1999 Desert Fishes Council paper (see Appendix B). The authors successfully removed the recently-stocked non-natives by electrofishing (no chemical removal)
Abstract: No.

Brooks, J.E., and Propst, D.L. 2001. Use of antimycin-A in Gila trout recovery: response to public concerns. Pages 15-16 *in* Shepard, B. Practical Approaches for Conserving Native Inland Fishes of the West, A Symposium Sponsored by the Montana Chapter and the Western Division of the American Fisheries Society.
Notes: This paper reviews local ordinances and biologists' responses to attempted ban of Antimicyin-A; banning use impedes Gila trout recovery.
URL: http://www.fisheries.org/AFSmontana/Misc/Symposium%20Abstracts/Abstracts.pdf
Abstract: No. Excerpt from online file:

Gila trout, *Onchorynchus gilae*, is a rare salmonid restricted to headwaters of the Gila River basin of southwestern New Mexico and recently repatriated to historical range in Arizona waters. . . Recovery efforts for Gila trout since early 1970s have centered around removal of nonnative salmonids by the fish toxicant antimycin-A (trade name, *Fintrol-Concentrate*) from selected streams above natural or manmade barriers to fish movement and stocking with Gila trout. Listing as endangered, under the Endangered Species Act (ESA) of 1973, contributed to local public opposition to recovery actions. Loss of angling opportunities for nonnative trout due to stream renovations also contributed to opposition. Implementation of the National Environmental Policy Act (NEPA) by the U.S. Forest Service, provided a forum for public opposition and succeeded in delaying stream renovations as much as three years. Opposition has also included County government ordinances prohibiting use of antimycin without county approval.

Herein, we provide a case history of successful efforts to remove nonnative rainbow *Oncorhynchus mykiss* and brown *Salmo trutta* trouts from and reestablishment of Gila trout in Mogollon Creek, Grant and Catron counties, New Mexico. We also chronicle the response of State and Federal agencies to attempts of assertion of local control over recovery efforts and effects of such on recovery efforts. Support by Gila Trout Recovery Team for downlisting the species to "threatened" is discussed in relation to overall recovery objectives and lessons learned from obstacles erected by local publics and the ordinances.

. . .Agency personnel continued with planning efforts and responded to numerous public requests for information. Concurrently, County officials contracted with an independent medical microbiologist for advice on potential public health hazards of antimycin-A. After review of extensive information, it was determined by the County-contracted specialist that antimycin-A was an effective and safe fish control agent that may be used in creeks/ streams for removal of certain species of fish (Jonsson 1996).
. . .It is hoped downlisting will lessen public opposition to future recovery actions. Preliminary indications, based upon results of initial public scoping for renovation of the relatively large and hydrologically diverse West Fork Gila River, however, are that public opposition will not diminish and may increase. Much of the opposition is driven or encouraged by misleading and inaccurate information disseminated by a few vocal opponents to endangered species conservation. Nonetheless, the NEPA process will proceed and given past experience, continued agency personnel response to public and local government concerns will increase the likelihood of successful recovery of Gila trout.

Brouder, M.J. 2003. El Coronado Ranch habitat conservation plan, 2003 fish monitoring report. U.S. Fish and Wildlife Service, Peridot, Arizona.
URL: Report available from http://www.fws.gov/southwest/fishery/azfro/Project_Reports.html
Notes: This report describes survey of sites on El Coronado Ranch and on Forest Service land within the Yaqui River Basin. They monitored several fish ponds including Big Tank; and reaches of West Turkey Creek (which has a barrier).Appendix shows numbers of fish caught by species. Native fish include longfin dace (*Agosia chrysogaster*), Yaqui chub (*Gila purpurea*), and Yaqui catfish (*Ictalurus pricei*); non-native fish include numerous reproducing black crappie and one grass carp.
Abstract: No. Excerpt from Introduction:
. . .The El Coronado Ranch HCP and Implementation Agreement (USFWS 1998a; 1998b) require that monitoring and reporting on the success of conservation measures occur annually for the first five years of the permit. Coleman (2002) provided a thorough review of the biogeography of Rio Yaqui fishes in Arizona and the HCP study area (Figure 1), along with recent management efforts and results of fish monitoring conducted in 2000 and 2001. This report summarizes results of the 2003 El Coronado Ranch HCP fish monitoring effort that followed procedures outlined in the finalized El Coronado Ranch HCP Monitoring Plan (Coleman and Minckley 2003). Appendix A provides a summary table comparing this year's results with monitoring results presented in Coleman (2002). In addition to following HCP Monitoring Plan fish sampling procedures, we implemented the Arizona Fishery Resources Office's Hazardous Analysis Critical Control Point (HACCP) draft policy, which calls for the disinfection of all sampling gear (i.e., boots, waders, seines, nets, traps, etc.) used at one site prior to the use at another, in an attempt to reduce the inadvertent introductions of parasites/pathogens into uninfected waters. Lastly, this report provides recommendations for future El Coronado Ranch HCP fish monitoring and management efforts.

Brouder, M.J., and Jann, D.B. 2004. Management of native fish protected habitats on Imperial and Havasu National Wildlife Refuges, 2002-2004. Document No. USFWS-AZFRO-PA-04-016. U.S. Fish and Wildlife Service, Pinetop, Arizona.
Abstract: No. Excerpts from Executive Summary:
<u>*June 2002 to December 2003*</u>
. . . Since June 30 2002, the U.S Fish and Wildlife Service has been managing native fish protected habitats (NFPH) on Imperial and Havasu National Wildlife Refuges (NWR) under contract from U. S. Bureau of Reclamation (USBR). Primary management activities have included developing a management plan, renovating habitats prior to stocking, securing and stocking endangered razorback sucker *Xyrauchen texanus,* monitoring population and habitat characteristics, and developing management alternatives to address new challenges. In March of 2001, approximately 10,000 wild razorback sucker larvae were collected from Lake Mohave, and held at the Nevada Department of Wildlife Fish Hatchery located on Lake Mead. In October 2002, the four units of the Ducks Unlimited (DU2) habitat complex on Imperial NWR were renovated by application of Prenfish, a fish toxicant derived from rotenone. In late November 2002, monitoring revealed that not all fish had been killed in the renovation. In December 2002, another application of Prenfish was applied. Monthly monitoring in January, February, and March 2003, revealed that 2 of the 4 units still had remnant populations of warmouth *Lepomis gulosus*. No fish were observed in Unit 2, so in March 2003, the 668 surviving fingerlings from Lake Mead Fish Hatchery were stocked into the lower end of Unit 2. Also in March of 2003, 18,000 additional wild razorback sucker larvae were

collected from Lake Mohave and transported and raised at Willow Beach National Fish Hatchery and Dexter National Fish Hatchery and Technology Center. From April through June 2003, the Arizona Fishery Resources Office (AZFRO) conducted monthly monitoring of razorback sucker in Unit 2 and water quality characteristics in all units. Data indicated that fish stocked in Unit 2 were growing rapidly, but that water quality conditions, especially dissolved oxygen (DO; mg/ L) and temperature (°C), were degrading. In June 2003, warmouth were encountered during fish sampling in the lower end of Unit 2. By mid July 2003, hypoxia was approaching critical levels; however, razorback sucker were still appearing in sample catches from Unit 2. By late July 2003, anoxia dominated the entire water column at all 16 monitoring stations throughout all 4 units, and razorback sucker ceased to appear in our fish samples from Unit 2; however, warmouth were still present in our catch in increasing abundance. Data indicated that the lower end of Unit 2 had the worst water quality of all 4 units within the complex. At the end of July 2003, AZFRO opened the gates separating the units from each other, and turned on the fresh well water supply in Unit 1 with the intended goal being that any surviving razorback sucker in the lower end of Unit 2 would find their way to the small oxygen refuge being created by input of fresh water into the upper end of Unit 2. Because warmouth were now abundant in Unit 2, we believed that no harm would be done by opening Unit 2 to inflow from Unit 1. Water quality monitoring throughout all units was increased to a biweekly schedule. Data demonstrated that water quality could be significantly improved in Unit 1 and part of the upper end of Unit 2 by running the well water supply. However, water quality in most of the upper end of Unit 2, all of lower end of Unit 2, and all of Unit 3 was mostly unaffected by running the well. Furthermore, data showed that DO in Unit 1 quickly descended into anoxia whenever the well was not running; indicating that the biological oxygen demand induced by senescence of overly abundant aquatic flora and plankton communities was capable of extracting all oxygen from fresh water supplements within a biweekly sample cycle. Monthly fish sampling from late July through October 2003 in Unit 2 continued to result in the presence of warmouth and the apparent absence of razorback sucker. However in early November 2003, 3 razorback sucker were captured. By late November and early December 2003, a population survey estimated that 25 razorback sucker (± 7) had survived the poor summer water quality conditions and the warmouth population had expanded to 14,397 (± 4,122) individuals. Razorback suckers were encountered only in the upper end of Unit 2, whereas warmouth were encountered throughout the entire complex, but were in notably lower densities in the lower end of Unit 2 and in Unit 3.

January 2004 through May 2004

. . . In February 2004, Unit 1 was pumped down to approximately 20% of its volume and renovated using rotenone chemical toxicant. In March 2004, Unit 1 was refilled with water from the well, and the resulting water quality was very good. In April 2004, approximately 10,000 razorback sucker fingerlings from the 2003 Lake Mohave year-class were released into Unit 1. In May 2004, a mark-recapture population survey estimated 6,573 (95% CI = 6,326 - 6,819) razorback sucker survived the first month post-stocking.

Brown, P.J., and Zale, A.V. 2005. Barriers to prevent nonnative fish movement: a review. Page 9 *in*: 38th Annual Meeting of the Montana Chapter of the American Fisheries Society.
URL: www.fisheries.org/AFSmontana/Misc/Abstracts%202005%20MCAFS%20Annual%20Meeting.pdf
Abstract: Barriers to non-native fish movement are important tools in the conservation of native fish species. Natural and manmade barriers provide protection to some of the last populations of native fish, and barriers are frequently used to help restore a species to a larger portion of its native range. We surveyed barriers being used to prevent non-native fish movement in an effort to make a wide variety of barrier designs available to managers and researchers. Barrier design, longevity, cost, and functionality vary, and there is some indication that those designing barriers lack the information necessary to build the best barrier to meet their management needs. A wide variety of materials are used to build barriers and each has associated advantages and disadvantages. We review the major types of barrier construction, as well as noteworthy innovative designs, and discuss the advantages and disadvantages of each. The falls barrier was found to be the most common type of barrier currently used to exclude non-native fish. Results of this survey have provided an array of barrier designs and have helped to highlight gaps in the knowledge base necessary to construct effective barriers. Other types of barriers included mesh, perched culverts and velocity barriers. Knowledge gaps in the design of barriers include, the jumping performance of wild fish, knowledge of proper barrier siting, and barrier designs that can accommodate both high and low discharge. A comprehensive manual on barrier design and an understanding of the jumping ability of wild fish are necessary before barrier designers can be expected to build effective barriers.

Bulow, F.J., Webb, M.A., Crumby, W.D., and Quisenberry, S.S. 1988. Effectiveness of a fish barrier dam in limiting movement of rough fishes from a reservoir into a tributary stream. North American Journal of Fisheries Management 8: 273-275.

Notes: Relevant quote on barrier effects: "possible negative effect...is that it impedes flow, creating pond-like habitat immediately upstream".

Abstract: We evaluated the effectiveness of a fish barrier that was constructed on the Roaring River, a tributary of Cordell Hull Reservoir, Cumberland River, Tennessee. The barrier was a steel-framed, stone-filled structure covered with concrete-capped gabions, and it spanned the width of the stream. We tagged 1,056 specimens of seven rough fish species over three occasions downstream from the barrier, but never recovered any tagged fish upstream from it. The barrier seems to be effective in limiting upstream migration of rough fishes.

Carmichael, G.J., Hanson, J.N., Schmidt, M.E., and Morizot, D.C. 1993. Introgression among Apache, cutthroat, and rainbow trout in Arizona. Transactions of the American Fisheries Society 122: 121-130.

Notes: This paper has a good map of locations of Apache trout in Arizona. It shows which streams had pure Apache trout, which had hybrids, and the relative abundance of pure Apache trout compared with non-native trout.

Abstract: The Apache trout *Oncorhynchus apache* has become threatened through hybridization with introduced nonnative trouts, among other reasons. We used 10 isozyme locus polymorphisms, which were in the aggregate diagnostic for discrimination of alleles of Apache trout, rainbow trout *Oncorhynchus mykiss*, and cutthroat trout *Oncorhynchus clarki*, to assess extent and directionality of interspecific hybridization in 645 individuals from 31 wild populations within the historical range of Apache trout. Only 11 potentially unhybridized populations of Apache trout were found. Rainbow trout introgression was documented in 19 of the 31 populations, including at least two in which all individuals sampled were hybrids. In four of these introgressed populations, hybridization between cutthroat trout and Apache trout was detected; at two of these localities individuals with alleles from all three species were sampled. Apache-cutthroat hybrids were found at one locality where no rainbow trout alleles were sampled. In 19 of the 20 hybridized populations sampled, a trend of backcrossing toward Apache trout was evidenced. No pure rainbow trout or cutthroat trout were found in the population samples. Because of the extensive hybridization present, it was not possible to estimate the genetic variability extant in the Apache trout genome; only one of seven alleles detected exclusively in hybridized populations could be confidently assigned to a species of origin (rainbow trout). Apache trout recovery efforts will be confounded due to the variable conditions among populations with respect to introgression, habitat deterioration, and barriers to rainbow trout immigration.

Clarkson, R.W. 2004. Effectiveness of electrical fish barriers associated with the Central Arizona Project. North American Journal of Fisheries Management 24: 94-105.

Abstract: The Central Arizona Project (CAP) canal delivers Colorado River water into the Gila River basin. During its planning and construction, issues arose regarding the unwanted entrainment and transport of nonindigenous fishes and other aquatic biota into, through, and out of the canal. One control strategy was the emplacement of electrical fish barriers on two CAP distributary canals to prevent fishes from moving upstream into the Gila River drainage. The operation, maintenance, and effectiveness of these barriers are described for the period 1988–2000. Documented outages totaled more than 100 h, representing less than 0.001% downtime since installation. It is nearly certain that outages allowed immigration by undesired fish(es). Immigrations that occurred when the barriers were operating according to design criteria indicate that the barriers do not totally block the passage of upstream-migrating fish. The proximate sources of electrical barrier outage included component damage from lightning strikes, component breakdowns, failure to adhere to component maintenance and replacement schedules, failure to incorporate adequate protection and redundancies to certain system components, inadequate training of personnel, and unknown causes. Known outages of remote monitoring systems (which are necessary to document outages and understand the potential for undocumented barrier outages) totaled more than 400 d, representing about 3% of the period of barrier operations. The complexity of electrical barrier systems and the problems such intricacy creates for operation and monitoring may always preclude absolute effectiveness. Additional refinements to system components, personnel training, and operation procedures may reduce barrier failures but add further to that complexity. Management agencies will have to determine the cost-effectiveness of such refinements.

Coleman, S.M. 2002. El Coronado Ranch 2000 and 2001 Fish Monitoring, West Turkey Creek, Chiricahua Mtns., Cochise Co., AZ. Unpublished Report. US Fish and Wildlife Service, Ecological Services, Tucson, Arizona.
Notes: This report provides detailed information on a recent renovation and monitoring results through 2001.
Abstract: No. Excerpts from Executive Summary:

Less than two percent (1500 square kilometers) of the Rio Yaqui basin lies within the United States in Cochise County, southeastern Arizona and Hidalgo County, southwestern New Mexico. The Sulphur Springs Valley in Cochise Co., Arizona, is a closed basin that was connected to the Rio Yaqui during the Pleistocene. Historically, seven Rio Yaqui fishes were known from U.S. portions of the basin, five of which were endemic to the Rio Yaqui. One intermittent creek (West Turkey Creek) of the Sulphur Springs Valley currently contains populations of three Rio Yaqui fishes: Yaqui chub (*Gila purpurea*); longfin dace (*Agosia sp.*); and Yaqui catfish (*Ictalurus pricei*). Much of West Turkey Creek lies within the boundary of the El Coronado Ranch while the headwaters are on U.S. Forest Service allotments. The dace have survived within West Turkey Creek to the present day while the chub disappeared and was recently repatriated. Yaqui catfish were not historically found in West Turkey Creek, but ranch ponds provided readily available space for the species, which were stocked by the U.S. Fish and Wildlife Service. Native Rio Yaqui fishes in West Turkey Creek are now protected by a Habitat Conservation Plan (HCP) between the owners of El Coronado Ranch, the U.S. Forest Service, U.S. Fish and Wildlife Service, and Arizona Game and Fish Department. However, introduced non-native animals (e.g., Asian tapeworm [*Bothriocephalus acheilognathi*], bullfrog [*Rana catesbaena*], fathead minnow [*Pimephales promelas*], green sunfish [*Lepomis cyanellus*]) and drought threaten current populations.

Stream and stock tank (pond) renovations (using the piscicides antimycin and rotenone) were conducted along West Turkey Creek in 1999. A barrier was built across West Turkey Creek at the lower private property line to prevent upstream invasions. To prevent fish movement from the largest stock tank, Big Tank, an infiltration gallery was constructed at the inflow diversion ditch from West Turkey Creek. The effectiveness of the barrier and infiltration gallery is yet to be determined. Drought in 2000 threatened populations of all three fish species, particularly chub and dace in stock tanks. In response, fishes were salvaged from desiccated habitats, held in tanks on the El Coronado and then released to habitats re-watered by rains. Prior to salvage activities, the catfish population in Keith Tank suffered heavy mortality, but a circulating pump was installed to preclude future kills. Catfish density was lowered in Lisa Tank by creating another catfish population in Big Tank.

Monitoring in 2000 found dace in 2 stock tanks and one stream locality, chubs at 4 stock tanks, and catfish in 2 stock tanks. Monitoring in 2001 found dace in 1 stock tank and 3 stream localities, and catfish in 1 stock tank (but catfish were also known to exist in 2 other stock tanks, bringing the total stock tank populations to 3), and green sunfish in 1 stock tank. Reproduction of dace and chubs was apparently poor subsequent to salvage and repatriation. Catfish spawning behavior has been observed, but successful spawning and recruitment are, as yet, undocumented. Big Tank catfish are currently coexisting with introduced black crappie (*Pomoxis nigromaculatus*) that could potentially prey on catfish eggs and young.

Coleman, S.M., and Minckley, W.L. 2000. Final Report, West Turkey Creek Yaqui chub restoration. Unpublished Report. National Fish and Wildlife Foundation.
Abstract: No.

Coleman, S.M., and Minckley, W.L. 2001. Returning the natives; the renovation of West Turkey Creek. Arizona Wildlife Views March-April: 28-32.
Notes: This is a popular article on West Turkey Creek in the Yaqui River Basin.
Abstract: No.

Dawson, V.K., and Kolar, C.S. 2003. Integrated management techniques to control nonnative fishes. U.S. Geological Survey, Upper Midwest Environmental Sciences Center, La Crosse, Wisconsin.
Notes: This report summarizes detailed life history information on Gila River basin natives and non-natives in Appendix B tables. Most of the report is made up of very detailed information on piscicides. Chapter 9 covers barriers (physical control) and biological control. This report also contains a good

summary of historical reviews of fish control projects.

Abstract: Many species of native fish from the southwestern United States, including those in the Gila River basin in Arizona and New Mexico, are critically imperiled in part because of the introduction and establishment of nonnative fishes. Effective methods for eradication and control of nonnative fishes are needed to rehabilitate the imperiled native fish fauna of the Gila River basin. The objective of this report is to assess the potential of applying techniques of integrated pest management to protect imperiled native fishes in the southwestern United States from invasive nonnative species. To accomplish this, reviews of pertinent literature were conducted in selected topic areas and the information presented in a series of chapters to document findings. Subject areas of the review included (1) life-history strategies for both native and nonnative species in those waters; (2) evaluation, identification, and characteristics of successful integrated pest management programs; (3) identification of potential and existing chemicals and appropriate chemical formulations for use as general and selective piscicides; and (4) procedures and costs associated with the discovery and development of new and perhaps taxon-specific piscicides. Characteristics of native fishes of concern were compared with those of nonnative fishes, and the geographic ranges of native and nonnative fishes were mapped to identify potentially vulnerable conditions around which control strategies could be developed. The concept of chemical receptors and receptor responses are presented to help explain the basis of selective toxicity. A total of 45 chemicals were identified that have either been used as piscicides, or are currently in various stages of development. A rating system was developed that evaluates the usefulness of these chemicals in resolving problems caused by nonnative fishes. Only five of the chemicals (antimycin, rotenone, TFM, Bayluscide®, and Squoxin) achieved ratings of 75 or greater out of a possible score of 100. Chemical reclamations have not always been successful as indicated by reviews of hundreds of fish control projects with reported successes ranging from 43% to 82%. It is unlikely that the present arsenal of approved selective piscicides would be effective for controlling nonnative fishes in the southwestern United States because the fish communities are different from most areas where selective piscicides are being used, and the currently registered taxon selective piscicides target sea lampreys. A comprehensive list of formulations and associated delivery systems for applying registered piscicides are presented. The development of new chemical tools for selectively managing fish populations may be facilitated by the knowledge of the mode of action of candidate piscicides and their structure-toxicity relationships. An evaluation of the costs and benefits of chemical treatments, as well as the cost associated with the development and registration of new piscicides, are provided. Reclamation of habitats that are critically imperiled by invasive fishes may need to be implemented using general piscicides such as antimycin or rotenone. This would require that important extant native species be temporarily moved to refugia until after the treatments. In less critical situations, efforts could be directed toward development of integrated pest management techniques that include development and use of barriers, water-level manipulations, targeted overharvest, stocking of predators, sterilants, toxic baits, selective piscicides, attractants and repellants, immuno-contraceptive agents, viruses, chromosomal manipulations, gynogenesis, and transgenics.

Demarais, B.D., Dowling, T.E., and Minckley, W.L. 1993. Post-perturbation genetic changes in populations of endangered Virgin River chubs. Conservation Biology 7: 334-341.

Abstract: A 34-kilometer reach of the Virgin River, Utah-Arizona-Nevada, was poisoned with rotenone in an attempt to eradicate non-native red shiners (*Cyprinella lutrensis*), a species implicated in the decline of native fish populations in the American West. An error in detoxification resulted in lethal concentrations of piscicide passing through an additional 50 kilometers of stream. We used allozyme electrophoresis to analyze genetic variation among pre- and post-poison samples of endangered Virgin River chubs (*Gila seminuda*). Pre-poison samples indicated a single panmictic population in the river. In contrast, fish subsequently produced through natural recruitment in poisoned reaches exhibited deviations from the original pattern of genetic variation. A genetic bottleneck caused by severe reduction in the number of spawning adults was indicated.

DeMarais, B.D., and Minckley, W.L. 1993. Genetics and morphology of Yaqui chub *Gila purpurea*, an endangered cyprinid fish subject to recovery efforts. Biological Conservation 66: 195-205.

Abstract: Federally endangered Yaqui chubs *Gila purpurea* are restricted to the Rio San Bernadino, a small headwater tributary of the vast Rio Yaqui basin of Sonora, Mexico, and Arizona, Unites States. The species faced almost certain extirpation in the United States during the late 1960s when its remaining habitats went dry. Just prior to that event in 1969, individuals were successfully transplanted into nearby

Leslie Creek. Captive propagation was later used to produce fish to re-establish populations in its native range after habitats were reclaimed and protected. We present the history of conservation efforts which include numerous transfers to differing numbers of fish between captive and 'wild' stocks. We examined the effects of these recovery efforts on the genetic and phenotypic structure of populations. Genetic and morphological differentiation were respectively assessed using allozyme electrophoresis and principal components analysis. Considerable genetic stability was indicated, with observed variations attributable to documented or inferred changes in population sizes. Morphology also remained uniform, both temporally and spatially, with no evidence of changes attributable to recovery manpulations or ecophenotypic responses to novel environments. Yaqui chubs exhibit high fecundity and quickly establish large effective population sizes, life history characteristics which likely account for the minimal effects of population manipulations.

Desert Fishes Team (DRT). 2003. Status of federal and state listed warm water fishes of the Gila River basin, with recommendations for management. PEER October 15, 2003, Report Number 1.
URL: http://www.peer.org/docs/az/Gila_Fish_Status_Report.pdf.
Abstract: No. From Executive Summary:
<u>Purpose:</u> This report reviews the status of the twelve federal and state listed native warm water fishes in the Gila River basin and the post-1967 recovery and conservation actions taken by all agencies, organizations, or parties. The report includes recommendations for future actions for each species.
<u>Organization:</u> A summary for each species is given in the text. Table 1 describes historic range, known extirpations, and remaining populations of each species. Table 2 describes repatriation efforts and their success. Recovery and conservation actions are provided in Table 3. Table 4 contains recommendations for further transplants and repatriations, and recovery and conservation actions. A literature cited section completes the report—it provides examples of supporting documentation, but is not comprehensive.
<u>Conclusions:</u> Six species are extirpated from the basin, five others survive in less than 20% of their original range, and one remains in about 40% of its original range. The distribution and abundance of all listed species extant in the basin has declined since their original listing and the trend is continuing. Few successful recovery and conservation actions have occurred during the 36-year period assessed. Although repatriation has been the primary management effort, it has occurred for only a few of the species, and with limited success.
<u>Recommendations</u>: All of the federally listed species have existing and adequate biologically based recovery plans. However, few recommendations in those plans have been implemented. Additional planning for these species is unnecessary, but the other species need management plans. On-the-ground implementation of plan actions is paramount to conservation and recovery of the species. Existing recovery and conservation strategies and techniques would, if implemented, contribute substantially to stemming the decline of these fishes. Innovative strategies incorporating new knowledge and data are also important. We believe the control and removal of nonnative fishes and other aquatic flora and fauna is the most urgent and overriding need in preventing the continued decline and ultimate extinction of the native fish assemblage of the Basin.

Desert Fishes Team (DRT). 2004. Status of native fishes of the Gila River basin, with recommendations for management. PEEReview Report Number 2. Public Employees for Environmental Responsibility, Washington, DC.
Notes: This report includes information on transplant and repatriation activities, and their success.
Abstract: No. From Executive Summary:
<u>Purpose:</u> This report reviews the status of seven native warm water fishes in the Gila River basin of central Arizona, southwestern New Mexico, and northern Sonora that are not listed under the federal Endangered Species Act. These species are *Agosia chrysogaster* longfin dace, *Catostomus insignis* Sonora sucker, *C. latipinnis* flannelmouth sucker, *Elops affinis* machete, *Mugil cephalus* striped mullet, *Pantosteus clarki* desert sucker, and *Rhinichthys osculus* speckled dace. It includes post-1967 conservation actions taken by all agencies, organizations, or parties. The report provides recommendations for future conservation actions for each species.
<u>Organization:</u> A summary for each species is given in the text. Table 1 describes historical and modern range of each species. Table 2 describes repatriation efforts and their success. Restoration and conservation actions are provided in Table 3. Table 4 contains recommendations for further transplants and repatriations, and conservation actions. A literature cited section completes the report; it provides

examples of supporting documentation, but is not comprehensive.
<u>Conclusions</u>**:** One species is extirpated from the basin, four others are widespread throughout their historical range, although showing moderate decline. Two other species are occasional visitors from the Gulf of California but restricted from reaching historical range during most years. The distribution and abundance of all species present in the basin have declined in modern times. This trend continues and is accelerating. Few conservation actions have occurred during the 37-year period assessed. Although repatriation has been the primary management effort, it has occurred for only a few of the species, and with limited success. Most conservation actions have been directed at listed species, with benefits accruing to non-listed species on an incidental basis.
<u>Recommendations</u>: Development of conservation plans that include direction for removal of nonnative species, protection and monitoring of existing populations, habitat reclamation and restoration, and repatriation into suitable habitats would set the groundwork for management of these species. On-the-ground implementation of plan actions is paramount to conservation of the species. Existing conservation strategies and techniques would, if implemented, contribute substantially to stemming the decline of these fishes. There are proven techniques and processes available for conservation for native fishes, and management of these species does not depend on additional research on their biology and ecology. We believe control and removal of nonnative fishes and other nonnative aquatic flora and fauna is the most urgent and overriding need in preventing continuing decline and ultimate extinction of the native fish assemblage of the Gila River basin. Notwithstanding, innovative strategies and techniques incorporating new knowledge and data are also important and should be investigated.

Dowling, T.E., and Childs, M.R. 1992. Impact of hybridization on a threatened trout of the southwestern United States. Conservation Biology 6: 355-364.
Notes: This paper provides locations of native trout populations and good information on renovations.
Abstract: Trouts native to the American Southwest provide an excellent example of the plight of endangered fishes from this region. The native species, Apache trout and Gila trout (*Oncorhynchus apache* and *O. gilae*, respectively) have faced drastic reduction in habitat and detrimental interactions with introduced species, resulting in a dramatic decrease in numbers and sizes of populations. We used biochemical methods to identify diagnostic markers for the estimation of genetic relatedness and analysis of hybridization among native trouts and introduced cutthroat and rainbow trouts (*O. clarki* and *O. mykiss*, respectively). Restriction endonuclease analysis of mitochondrial DNA (mtDNA) indicated that Apache and Gila trout were very similar to each other, and more similar to rainbow trout than cutthroat. Diagnostic allozyme marker loci indicated that Apache trout hybridized extensively with rainbows in four populations and provided no evidence for reproductive isolation between the forms. Analysis of mtDNA, however, indicated that introduced haplotypes were rare in these same individuals, identifying a bias in the direction of gene exchange between species. The potential reproductive isolation and lack of information concerning population structure necessitate further study of Apache trout to determine the appropriate management strategy for this threatened species. This case demonstrates that extreme care must be exercised when considering elimination of any contaminated population lest the unique genetic identity of the native taxon be lost forever.

Dudley, R.K. 1995. The effects of green sunfish on distribution, abundance, and habitat use of Gila chub in Sabino Creek, Arizona. Unpublished MS thesis. University of Arizona, Tucson.
Notes: This thesis provides a figure showing movement of green sunfish upstream over time, indicating how bridges acted as barriers. It also includes a test of a mechanical removal of green sunfish.
Abstract: No.

Dunham, J.B., Adams, S.B., Schroeter, R.E., and Novinger, D.C. 2002. Alien invasions in aquatic ecosystems: Toward an understanding of brook trout invasions and potential impacts on inland cutthroat trout in western North America. Reviews in Fish Biology and Fisheries 12: 373-391.
Abstract: Experience from case studies of biological invasions in aquatic ecosystems has motivated a set of proposed empirical “rules” for understanding patterns of invasion and impacts on native species. Further evidence is needed to better understand these patterns, and perhaps contribute to a useful predictive theory of invasions. We reviewed the case of brook trout (*Salvelinus fontinalis*) invasions in the western United States and their impacts on native cutthroat trout (*Oncorhynchus clarki*). Unlike many biological invasions, a considerable body of empirical research on brook trout and cutthroat trout is available. We reviewed life

histories of each species, brook trout invasions, their impacts on cutthroat trout, and patterns and causes of segregation between brook trout and cutthroat trout. We considered four stages of the invasion process: transport, establishment, spread, and impacts to native species. Most of the research we found focused on impacts. Interspecific interactions, especially competition, were commonly investigated and cited as impacts of brook trout. In many cases it is not clear if brook trout invasions have a measurable impact. Studies of species distributions in the field and a variety of experiments suggest invasion success of brook trout is associated with environmental factors, including temperature, landscape structure, habitat size, stream flow, and human influences. Research on earlier stages of brook trout invasions (transport, establishment, and spread) is relatively limited, but has provided promising insights. Management alternatives for controlling brook trout invasions are limited, and actions to control brook trout focus on direct removal, which is variably successful and can have adverse effects on native species. The management applicability of research has been confounded by the complexity of the problem and by a focus on understanding processes at smaller scales, but not on predicting patterns at larger scales. In the short-term, an improved predictive understanding of brook trout invasions could prove to be most useful, even if processes are incompletely understood. A stronger connection between research and management is needed to identify more effective alternatives for controlling brook trout invasions and for identifying management priorities.

Finlayson, B., Somer, W., Duffield, D., Propst, D., Mellison, C., Pettengill, T., Sexauer, H., Nesler, T., Gurtin, S., Elliot, J., Partridge, F., and Skaar, D. 2005. Native inland trout restoration on national forests in the western United States: time for improvement? Fisheries 30: 10-19.

Abstract: The piscicides rotenone and antimycin are integral to successful restoration of native inland trout populations on public lands in the western United States by removing nonnative fishes that compete and hybridize with 13 species and subspecies of native trout. The U.S. Forest Service administers the greatest portion of native inland trout habitat on public lands. Piscicide use by state and federal agencies on national forests has become encumbered by redundant processes, uneven and irregular application of policies and regulations, and overlapping authorities. This has culminated in project delays and cancellations, placing native trout at continued, if not heightened, extinction risks. We reviewed the status of native trout restoration efforts on national forests in the western United States and considered issues associated with piscicide use. Central to the issue is whether piscicide applications by states require a permit from the Forest Service; those that required a permit usually invoked a redundant, federal environmental review process that precipitated the project delays. Based upon this review, we recommend that the Forest Service proceed with their proposal for a uniform standard for piscicide use by responsible government agencies on Forest Service administered lands. Doing so would streamline bureaucracy, speed future restoration efforts, and improve the status of imperiled native inland trouts without affecting environmental safeguards.

Galat, D.L., and Robertson, B. 1992. Response of endangered *Poeciliopsis occidentalis sonoriensis* in the Rio Yaqui drainage, Arizona, to introduced *Gambusia affinis*. Environmental Biology of Fishes 33:249-264.

Notes: The authors noted that *Gambusia* breached the gabion road crossing on Black Draw in 1986:

Abstract: Potential coexistence of the native Yaqui topminnow, *Poeciliopsis occidentalis sonoriensis*, with introduced mosquitofish, *Gambusia affinis*, was examined in spring pools and streams in San Bernardino National Wildlife Refuge, southeastern Arizona. *Poeciliopsis* never exceeded 12% of total poeciliid numbers in a spring pool where *Gambusia* was present. Body size, fecundity and reproductive effort of *Poeciliopsis* were significantly higher in this pool than in similar spring pools where *Gambusia* was absent. Where *Poeciliopsis* and *Gambusia* were syntopic in a stream, numbers of *Poeciliopsis* declined over 1.7 years, until none were collected. *Poeciliopsis* then increased to >60% of total poeciliid numbers following flash flooding. Persistence of *Poeciliopsis* with *Gambusia* in the spring pool appeared to be a result of compensatory increase in reproductive output, while in the stream it was associated with recurrent flash flooding and a uniform temperature springhead which provided refuge.

Gard, M. 2004. Potential for restoration of a California stream native fish assemblage. California Fish and Game 90:29-35.

Abstract: The South Yuba River has a depleted native fish fauna, with five of the expected nine native fish species absent because of past human impacts on the system. Anadromous Pacific lamprey, *Lampetra* *tridentata*, and Chinook salmon, *Oncorhynchus tshawytscha*, are excluded by a downstream barrier. Three smaller native species, riffle sculpin, *Cottus gulosus*; California roach, *Lavinia symmetricus*; and speckled dace, *Rhinichthys osculus*, were probably extirpated from the South Yuba River by the effects of hydraulic mining in the late 1800's. The fish community of the South Yuba River can be partially restored through reintroductions.

Harig, A.L., and Fausch, K.D. 2002. Minimum habitat requirements for establishing translocated cutthroat trout populations . Ecological Applications 12: 535-551.
Notes: This article is not about barriers per se but they evaluated success of translocations. They also discuss short-term vs long-term success.
Abstract: Translocation is an important management strategy in conservation programs for endangered or threatened species, including native cutthroat trout (*Oncorhynchus clarki*) in the western United States. Most subspecies of cutthroat trout have declined to <5% of their historical range, and both historical and translocated populations now persist in small isolated fragments of habitat. Success rates for translocations of fishes are generally <50%, and habitat quality or quantity are frequently cited as the cause of failure. Therefore, we conducted field surveys of stream-scale habitat and measured basin-scale habitat using a Geographic Information System for 27 streams where two subspecies of cutthroat trout were translocated in Colorado and New Mexico, to identify specific habitat attributes that contribute to the success of translocations.

We used polytomous logistic regression to develop models that predict three categories of cutthroat trout translocation success (high, low, absent) from habitat attributes at two spatial scales. Models based on stream-scale habitat attributes indicated that cold summer water temperature, narrow stream width, and lack of deep pools limited translocations of cutthroat trout. Cold summer temperatures are known to delay spawning and prolong egg incubation, which reduces the growth of fry and likely limits their overwinter survival. Furthermore, small streams with few deep pools may lack the space necessary to permit overwinter survival of a sufficient number of individuals to sustain a population. Models based on basin-scale habitat were not as effective as stream-scale habitat models for distinguishing among translocation sites with high, low, or absent population status but indicated that a minimum watershed area of 14.7 km(2) was useful as a coarse filter for separating sites with high numbers of cutthroat trout from those with low or absent status. Watersheds larger than this are expected to encompass low-elevation habitat that provides warmer summer temperatures and to have relatively wide stream channels of sufficient length to provide an adequate number of deep pools. These results indicate that the appropriate scale of habitat measurement for predicting cutthroat trout translocation success in fragmented watersheds is at the patch rather than landscape scale, which is similar to results for other salmonids and vertebrate taxa in general.

Harig, A.L., Fausch, K.D., and Young, M.K. 2000. Factors influencing success of greenback cutthroat trout translocations. North American Journal of Fisheries Management 20: 994-1004.
Notes: This paper has a very good evaluation of translocations and barriers. It is very conservative as it is based on recovery plan goals. These cutthroats are not native to Colorado River Basin; they are native east side of divide.
Abstract: Native subspecies of cutthroat trout *Oncorhynchus clarki* have declined drastically because of the introduction of nonnative salmonids, overharvesting, and habitat degradation. Conservation of most declining subspecies will include establishing new populations through translocation of genetically pure fish. Recovery of greenback cutthroat trout *O. clarki stomias* has been ongoing for 25 years, so the attempted translocations of this subspecies provide unique empirical information to guide recovery of other nonanadromous salmonids. We compared 14 translocations that successfully established populations of greenback cutthroat trout to 23 that failed to determine the factors that influenced translocation success. Of the translocations that failed, 48% were reinvaded by nonnative salmonids, 43% apparently had unsuitable habitat, and 9% experienced suppression by other factors. Reinvasion occurred most often because of failed artificial barriers or incomplete removal of nonnative salmonids in complex habitats. Of those areas that were not reinvaded, success was highest in receiving waters with at least 2 ha of habitat that had previously supported reproducing trout populations.

Hayes, D.B., Baylis, J.R., Carl, L.M., Dodd, H.R., Goldstein, J.D., McLaughlin, R.L., Noakes, D.L.G., and Porto, L.M. 2003. Biological effect of low-head sea lamprey barriers: designs for extensive surveys and the value of incorporating intensive process-oriented research. Journal of Great Lakes Research

29: 373-385.
Abstract: Four sampling designs for quantifying the effect of low-head sea lamprey (*Petromyzon marinus*) barriers on fish communities were evaluated, and the contribution of process-oriented research to the overall confidence of results obtained was discussed. The designs include: (1) sample barrier streams post-construction; (2) sample barrier and reference streams post-construction; (3) sample barrier streams pre- and post-construction; and (4) sample barrier and reference streams pre- and post-construction. In the statistical literature, the principal basis for comparison of sampling designs is generally the precision achieved by each design. In addition to precision, designs should be compared based on the interpretability of results and on the scale to which the results apply. Using data collected in a broad survey of streams with and without sea lamprey barriers, some of the tradeoffs that occur among precision, scale, and interpretability are illustrated. Although circumstances such as funding and availability of pre-construction data may limit which design can be implemented, a pre/ post-construction design including barrier and reference streams provides the most meaningful information for use in barrier management decisions. Where it is not feasible to obtain pre-construction data, a design including reference streams is important to maintain the interpretability of results. Regardless of the design used, process-oriented research provides a framework for interpreting results obtained in broad surveys. As such, information from both extensive surveys and intensive process-oriented research provides the best basis for fishery management actions, and gives researchers and managers the most confidence in the conclusions reached regarding the effects of sea lamprey barriers.

Heise, G. 1998. Building a better barrier: reconstruction of the Templeton barrier in the Golden Trout Wilderness. Outdoor California 59: 4-8.
Notes: This is "popular magazine" article about USFS constructing barrier for Golden trout on Kern River. This barrier is not in the Colorado River basin.
Abstract: No.

Hepworth, D.K., Ottenbacher, M.J., and Chamberlain, C.B. 2001. A review of what did and did not work after 24 years of native trout restoration in southern Utah. Pages 42-45 *in* Shepard, B. Practical Approaches for Conserving Native Inland Fishes of the West. Sponsored by the Montana Chapter and the Western Division of the American Fisheries Society.
Notes: This paper reviews local ordinances and biologists' responses to attempted ban of antimicyin; banning use impedes native fish recovery.
URL: http://www.fisheries.org/AFSmontana/Misc/Symposium%20Abstracts/Abstracts.pdf
Abstract: **No. Highlights from online paper:**

A review of what did and did not work after 24 years of native trout restoration in southern Utah. Conservation and recovery of native trout became a management issue in southern Utah in the 1970s after the Endangered Species Act (ESA) was passed and when several remnant populations of native Bonneville cutthroat trout *Oncorhynchus clarki utah* were identified (Behnke 1976). … Our objective in this study was to review restoration projects conducted in southern Utah since 1977 and categorize success, failures, and problems in terms of what generally did and did not work.

Methods Reviews were made of all data for known remnant populations of native trout in southern Utah, restoration projects that were completed, and restoration projects that are in progress (Tables 1 and 2)…Topics reviewed in the evaluation were: (1) genetic analyses, (2) criteria for selection of renovation projects, (3) success of renovating lakes and streams with rotenone, (4) sources of trout for re-introductions and wild brood stocks, (5) use of fish migration barriers, (6) practical consideration of metapopulations, and (7) socio-political issues.

Results and Discussion … We found six factors to be important in selecting sites for restoration of native trout populations. Restoration projects should be within historic distributions, have good trout habitat, be large enough to justify renovation efforts, avoid major land use conflicts, be feasible in terms of removing nonnative fishes and preventing their return, and have support from the general public, individuals and agencies responsible for land use management.

Even for the smallest streams selected for renovation, it was evident that a one-time treatment with rotenone could fail to remove all nonnative fishes. Second treatments, timed approximately a year after the first treatment, were generally successful in completely eradicating target species. Springs and seeps posed the greatest problem in attaining complete eradication.

…We used fish migration barriers to expand the range of native trout and decrease fragmentation (Table 2). Barriers that worked best were adjacent to other obstacles which limited fish movement such as seasonally de-watered stream segments. The most vulnerable barriers were single-point structures where nonnative fishes had a continual presence immediately downstream (N Fork North Creek, Table 2). In cases where construction of barriers with secondary obstacles was not practical, we opted to construct multiple barriers (Table 2).

…Small projects conducted in isolated (fragmented) streams were less subject to negative interventions by man in comparison to larger systems. . . Obtaining regulatory clearances to conduct recovery projects has steadily become more complex and controversial. Concern has increased that native trout could potentially be listed under the ESA. On-the-ground projects were completed by promoting cooperation among state, federal, and county governments, as well working closely with the public.

Summary and Conclusions Despite some problems and delays, over 20 restoration projects were conducted within southern Utah during the past 24 years (Table 2). . .

Hilderbrand, R.H., and Kershner, J.L. 2000. Conserving inland cutthroat trout in small streams: how much stream is enough? North American Journal of Fisheries Management 20: 513-520.

Abstract: We examined the prognosis for long-term persistence of isolated populations of cutthroat trout *Oncorhynchus clarki* and the feasibility of using barriers to protect them from nonnative salmonids. In so doing, we estimated minimum stream lengths (MSL) required by cutthroat trout populations of varying abundances and rates of population loss to emigration and mortality. Using 2,500 individuals (>75 mm) as the target population size corresponding to an effective population size, N_e, of 500we estimated that more than 8 km of stream were required to maintain a population with high fish abundances (0.3 fish/ m), and 25 km of stream were required to maintain a population of low abundance (0.1 fish/ m). Incorporating a population loss rate of 10% increased MSL to 9.3 km for the high and 27.8 km for the low abundances. Our results suggest that many isolated populations may not persist over the long term because insufficient space exists to maintain the required N_e. Barrier construction to protect cutthroat trout from nonnative salmonids may be a necessary short-term solution, but it involves a long-term risk for maintaining viable cutthroat trout populations. We propose a watershed-based framework for cutthroat trout conservation in the central and southern Rocky Mountains that emphasizes protection of strong core populations.

Holden, P.B. 1991. Ghosts of the Green River: impacts of Green River poisoning on management of native fishes. Pages 43-54 *in* Minckley, W.L., and Deacon, J.E. Battle against extinction: native fish management in the American west. University of Arizona Press, Tucson.

Notes: This chapter covers in detail the rotenone renovation of upper Green River basin in 1962 prior to the impoundment of Flaming Gorge Reservoir: it discusses the politics, rationale, opposition, operation, and aftermath (stocking of the reservoir). Species of concern were bonytail, roundtail chub, humpback chub, Colorado pikeminnow, and razorback sucker. Relevant quotes: "...poisoning without consideration for ecological consequences caused concerns for both native fishes and non-native salmonids..." (p 53); "none of the native Colorado River fishes were known to be problems in reservoirs elsewhere, and in fact might have acted as a buffer against population explosions of other non-game species in the early years following impoundment." (p 53).

Abstract: No.

Hubbs, C. 1963a. An evaluation of the use of rotenone as a means of "improving" sports fishing in the Concho River, Texas. Copeia 1963: 199-203

Abstract: **No.**

Hubbs, C.L. 1963b. Secretary Udall reviews the Green River fish eradication program. Copeia 1963: 465-466.

Notes: Secretary Udall of the Department of the Interior reviewed the 1962 Green River eradication program and issued the following directives on any future reclamations where Federal funds are involved: 1) adequate research should be undertaken on the effects of rotenone, potassium permanganate, or other fish controlling agents, under varying environmental conditions, before additional reclamations are undertaken; 2) whenever a reclamation may pose a danger to a unique species, a dominant consideration in evaluating the advisability of the project is the potential loss to the pool of genes of living material; 3) possible deleterious effects of future projects are to be evaluated by competent and disinterested parties; 4)

as followup to the 1962 event, Secretary Udall ordered the Park Service and Bureau of Sport Fisheries and Wildlife to study the impairment of fish populations in Dinosaur National Park.
Abstract: No.

Hyatt, M.W. 2004. Investigation of crayfish control technology. Final Report. Arizona Game and Fish Department, Phoenix.
Abstract: No. Excerpt from Executive Summary: North America is home to 390 native species of crayfishes, 75% of the world's total. No native crayfish occur in Arizona or the Colorado River basin of western North America; however, they have been widely introduced to this landscape and have become widespread and abundant throughout the Colorado River basin. Nonindigenous crayfishes have greatly altered North American lake and stream ecosystems, harmed fisheries, extirpated many populations of native crayfishes, and contributed to the global extinction of at least one native crayfish species. The economic cost alone of a small subset of freshwater Nonindigenous species in the United States has recently been estimated at 4.1 billion dollars annually. In Arizona, crayfish pose a serious threat to the long-term survival of many species of native fishes and amphibians. Due to the potential harmful effects to native flora and fauna, there is a need for the development of methods to control or eradicate Nonindigenous species. This report provides a complete literature review of methods that have been tested for the purpose of controlling or eradicating nonindigenous crayfishes and methods that have not been tested, but have potential. Five broad categories of control were considered: legislative, mechanical, biological, physical, and chemical. Legislative control, while in effect at both the state and national level, has been unsuccessful. Mechanical control methods include manual removal, trapping, and electrofishing. Trapping, despite being the most common method used, has failed in every case to eliminate or even control crayfish. Biological control includes the use of fish predators, diseases, and microbial insecticides. Although some cases demonstrated an inverse relationship between the presence of fish predators and crayfish numbers, in no case did fish predators eradicate a population of crayfish. Crayfish plague is lethal to non-North American crayfish, but not to North American crayfish. If a strain of this disease lethal to North American crayfish could be developed, it might prove to be an effective method of control. Physical methods include de-watering, habitat destruction, and barriers. The ability of crayfish to travel over-ground for long distances and to survive for long periods of time in their burrows during dry periods, renders physical methods useless in most cases. Chemical methods include biocides, rotenone, and pheromones. Although rotenone will kill crayfish, any dosage sufficient to cause crayfish mortality results in the death of almost all other living organisms first. Research on the potential of using pheromones as a means of control has just recently begun. Early results of these studies do not look promising, but pheromones may prove effective in helping detect low density crayfish populations. Biocides proved to be the only method with any potential for eradicating or controlling crayfish.

Joscelyn, A. 2001. Regulation of the use of fish toxicants under state and federal water quality laws. Page 21 *in* Shepard, B. Practical Approaches for Conserving Native Inland Fishes of the West. Sponsored by the Montana Chapter and the Western Division of the American Fisheries Society.
URL: www.fisheries.org/AFSmontana/Misc/Symposium%20Abstracts/Abstracts.pdf
Abstract: The federal Clean Water Act is the foundation water quality act in the United States. It sets national policy for control of water pollution, although the various states actually implement and administer many aspects of water pollution control. The essence of the Clean Water Act is found in the provision which prohibits discharge of pollutants to waters of the U.S. without a permit, and the companion provisions which allow permits only for discharge of pollutants which will not cause unnecessary degradation and, in any event, will preserve water quality standards in receiving waters.

The Clean Water Act's definition of "pollutant" is very broad. It contains no exception for discharge of toxins which are approved for use as pesticides under FIFRA, the federal law regulating approval of pesticides. This creates an apparent conflict between the Clean Water Act and FIFRA in the case of pesticides intended to kill fish, or for that matter, waterborne plants. The conflict has existed for years, but has received very little attention until lately. Recent case law is starting to provide guidance on how the conflict will be resolved by the courts.

Montana's constitution, with its guarantee of a clean and healthful environment and direction to the legislature to provide adequate remedies for protection of the environmental life support system from degradation presents another issue. While present statutes provide a mechanism for allowing the use of fish toxicants, Montana's Supreme Court has begun to provide guidance on the meaning of the constitutional provisions, which cast doubt on the validity of the statutory allowance. In this presentation, we will discuss these issues, the most current developments, and try to forecast possible outcomes.

Lanigan, S.H., and Tyus, H.M. 1989. Population size and status of the razorback sucker in the Green River basin, Utah and Colorado. North American Journal of Fisheries Management 9: 68-73.
Abstract: The status of the razorback sucker *Xyrauchen texanus* in the Green River, Utah, was evaluated with capture-recapture data collected from 1980 to 1988. The razorback sucker population in the upper Green River (river kilometers 282-555) was estimated at 948 fish (95% confidence interval, 758-1,138), based on a total of 410 fish captured (68 recaptured). Razorback suckers in the lower Green River (km 0-211) were extremely rare; their numbers were too small (13 fish captured, 1 recaptured) to allow a reliable population estimate. Gray and lower Desolation canyons separated the upper and lower Green River razorback sucker populations. These canyons and a low diversion dam appeared to be barriers to fish movement. The absence of the razorback sucker in Gray and lower Desolation canyons (km 211-282) suggested a lack of suitable habitat.

Laurent, P.J. 1995. Eradication of unwanted crayfish species for astacological management purposes. Freshwater Crayfish 8: 121-133.
Abstract: Crayfish eradication can be achieved in ponds with low concentrations (0.06 to 0.13 mg/ L) of the insecticide fenthion (commercial formulation, BAYTEX). Fenthion is highly toxic to Orconectes limosus at concentrations as low as 0.006 mg/ L. The 24-h LC50 was determined at a water temperature of 20 degree C plus or minus 0.1 degree C. Three pond were treated with fenthion without apparent injuries to vertebrates; however, among invertebrates, arthropods were affected. Even at fenthion concentrations high enough to be harmful to fish, death of crayfish occurred only after several hours of contact with the toxicant. Fenthion remains toxic to crayfish for several weeks, even at low concentrations, so restocking of treated ponds can not be undertaken immediately.

Lennon, E., Hunn, J.B., Schnick, R.A., and Burress, R.M. 1971. Reclamation of ponds, lakes and streams with fish toxicants: a review. FAO Fisheries Technical Papers 100.
Notes: Comprehensive review of chemical renovations worldwide, up to 1970. Includes short but informative historical accounts of many early renovations, including 1961 renovation of San Juan River for sportfish, at the expense of bonytail and flannelmouth sucker, and 1962 Green River renovation. From Section 4.5: “There are few unqualified successes in stream reclamation, but this is not surprising when one considers the great diversity of streams, the difficulties of attaining uniform dispersal of a toxicant throughout the confines of a stream, the problems of maintaining sufficient concentration of a toxicant and duration of exposure over long distances, and the lack of toxicants that are formulated specifically for use in streams. The art of stream reclamation is evolving more slowly than that of lake reclamation because of the greater complexities.”
Abstract: The Food and Agriculture Organization of the United Nations commissioned the U.S. Bureau of Sport Fisheries and Wildlife to prepare a review of literature on the reclamation of ponds, lakes, and streams with fish toxicants. Total or partial reclamation of small ponds, especially fish production ponds, with general or selective toxicants is a very common practice. The eradication of undesirable fishes from public lakes and streams began over 60 years ago, but accelerated within the past two decades as wild waters increasingly required fish management and as improved toxicants became available. Toxicants such as the organochlorines and organophosphates, borrowed from agriculture, are being replaced with controls that are more specific to fish or more appropriately formulated for aquatic application. Formulations of rotenone and antimycin are the most used, general fish toxicants in the United States; TFM is a successful, selective toxicant for larval sea lampreys in tributaries to the Great Lakes; and Squoxin is in advanced stages of development as a selective toxicant for squawfishes in salmonid streams on the west coast of North America.

The review of literature and a widely circulated questionnaire indicate that 27 countries, in addition to the United States, and Canada, have used or are using fish toxicants for the control of undesirable fishes. Indicated, too, is the need for much research on all aspects of reclamation -- on the biology of target fishes; on alternatives to chemical control; on safe, effective, and non-persistent toxicants; on formulations and dispensing apparatus to reach and kill target fishes with the least possible contamination of the environment; on controls that may be integrated with toxicants to enhance reclamations; and on methods and equipment for pre- and Post-treatment surveys and evaluations.

Light, T. 2003. Success and failure in a lotic crayfish invasion: the roles of hydrologic variability and habitat alteration. Freshwater Biology 48: 1886-1897.

Abstract: Yes. Highlights relevant to barriers:

. . .This paper examines the distribution, habitat relationships, and potential for spread of non-native signal crayfish (*Pacifastacus leniusculus*) in streams of the Truckee River catchment, California, U. S. A. . . . Crayfish were more likely to be found in regulated than unregulated sites, and did not occur in sites upstream of barriers, such as culverts, that separated them from reservoirs or lakes.

. . . These results suggest that natural or artificial gradient barriers and, in regulated systems, management of flow regimes to include bankfull or greater flows may help to control invasive crayfish in streams.

Ling, N. 2003. A review of the use and toxicity of rotenone for fisheries management purposes. Science for Conservation 211: 40 pp.

Notes: Includes tables of lethal concentrations of rotenone on various fish species, invertebrates, molluscs, crayfish (*Cambarus*), aquatic insects, amphibians, birds, mammals. Paper also includes discussion of bait technology (selective fish baits laced with rotenone), section on manipulating food webs and water quality (by decreasing cladoceran-eating fish) with rotenone. Also discusses advantages, disadvantages, alternatives, public health concerns, ecological safety, recommended protocol.

URL: www.doc.govt.nz/Publications/004~Science-and-Research/Science-for-Conservation/PDF/SFC211.pdf

Abstract: No. Excerpt from Introduction:

Rotenone has been used extensively in North America since the 1930s for managing freshwater fisheries and for fisheries research. The literature on rotenone is vast. Roark (1932) published a bibliography on the use of *Derris* species as insecticides and listed 475 papers. More than 1000 papers have been published on rotenone since 1990 and the literature is currently expanding at more than 100 papers per year. Recent research interest in rotenone stems mainly from biochemical interest in its highly specific action in selectively inhibiting mitochondrial activity and its possible anticancer properties. Rotenone is now recognised as the most environmentally benign of the commonly used fish poisons (piscicides or ichthyocides) and remains extremely useful for the chemical rehabilitation of fish habitats to remove noxious species and for research sampling. In response to recent public concerns about large-scale rotenone use in fisheries management, the American Fisheries Society has established a rotenone stewardship programme to provide advice on the safe use of rotenone, and to encourage good planning and public involvement in future rotenone programmes (AFS 2000).

This brief review summarises the toxicity of rotenone to aquatic and terrestrial animals and the use of rotenone in fisheries management and research. An ecological risk assessment for rotenone use in New Zealand is also provided.

Lopinot, A.C. 1975. Summary on the use of toxicants to rehabilitate fish populations in the Midwest. Pages 1-4 *in* Eschmeyer, P.H. Rehabilitation of fish populations with toxicants: a symposium. American Fisheries Society, North Central Division, St. Louis, Missouri.

Notes: Data are given by state and province: importance as management tool; if use restricted; types and amounts used in 1972; number of water bodies and acreage treated; number and miles of streams treated. Yearly data include total and mean acres treated.

Abstract: A survey on the use of fish toxicants in the Midwest showed that more than 22,000 gallons of 2-1/2% rotenone were used in 1972 to rehabilitate fish populations. During 1963-72 more than 121,000 acres of water and about 4,200 miles of streams were treated with toxicants. Data are given for each state and province in the Midwest.

Lydeard, C., and Belk, M.C. 1993. Management of indigenous fish species impacted by introduced mosquitofish: an experimental approach. Southwestern Naturalist 38: 370-373.

Notes: This paper makes an important point: even low densities of *Gambusia* had significant negative impact on native fish densities.

Abstract: The negative effects of introduced mosquitofish (*Gambusia affinis*) on native fishes of the American Southwest have been well documented. However, little experimental information is available to determine the level to which populations of Gambusia must he reduced before reintroducing native species. To simulate various options for managing indigenous fishes impacted by mosquitofish, we observed population growth of the least killifish (*Heterandria formosa*) with different starting densities of the eastern mosquitofish (*Gambusia holbrooki*) in replicate mesocosms. The presence of mosquitofish at all densities examined had a significant negative effect on population growth of least killifish. Therefore, complete removal of introduced mosquitofish appears to be the best management option for maintaining populations of native fishes.

Maceina, M.J., Slipke, J.W., and Grizzle, J.M. 1999. Effectiveness of three barrier types for confining grass carp in embayments of Lake Seminole, Georgia. North American Journal of Fisheries Management 19: 968-976.

Abstract: Three types of barriers were evaluated in Lake Seminole (13,158 ha) to determine the success of confining triploid grass carp *Ctenopharyngodon idella* in two embayments (250 and 350 ha) that were almost entirely covered with submersed macrophytes. In 1995, two different physical barriers that permitted boat passage were constructed. One had tandem V-shaped weirs placed at the entrance of a cove, and the other had two gated barriers that confined an embayment connecting two arms of the reservoir. Grass carp were radio-tagged, stocked into the confined areas ($N = 119$ for the V-shaped barrier and $N = 69$ for the gated barrier), and tracked from December 1995 through September 1997 to estimate escape rates. In addition, 18,000 triploid grass carp fitted with coded wire tags were stocked in December 1995 into the two confined areas. A low-voltage (3–4 V) electric barrier (Smith-Root, Inc.) was installed in December 1997 at one of the V-shaped funnel barriers, and an additional 84 grass carp were radio-tagged and tracked for 13 months. Based on verified locations outside the confined areas, an average of 9% of the grass carp escaped through the V-shaped, and 23% escaped through the gated barriers each year. However, based on missing fish, tag functioning rates determined from dead fish or expelled tags, and locations of fish before becoming missing, potentially up to 42% of the grass carp escaped from the V-shaped barriers and 35% escaped from the gated barriers each year. In addition, electrofishing surveys conducted in summer 1998 downstream of the tailrace in the Apalachicola River, Florida, indicated that 68% of the grass carp were escaped fish (coded wire tag present) that were stocked nearly 3 years earlier into the confined areas. After the V-shaped barrier was fitted with an electric barrier, no verified escapes occurred and with the exception of one fish, every radio-tagged grass carp was found within the confined area. Therefore, the maximum escape rate was only 1.3% per year, if this fish did indeed escape. Thus, the electric barrier and confinement structure have the potential to provide managers with a tool to confine grass carp in specific areas of large water bodies. Over many years, control of excessive aquatic macrophytes with this system is about 10% of the cost of herbicide treatments or mechanical harvesting.

Marking, L.L. 1992. Evaluation of toxicants for the control of carp and other nuisance fishes. Fisheries 17: 6-13.

Abstract: The eradication of undesirable organisms from lakes and streams began more than 80 years ago and has accelerated during the last 40 years as toxicants and technology have improved. The control of nuisance or undesired fish populations is a continuing need, and common carp, *Cyprinus carpio*, are often the target of reclamation projects. Rotenone is a registered toxicant that can be effective for control of carp, but is thought to be too expensive by some fish managers. Antimycin is also highly toxic to carp and selectively kills some other undesirable species, but is ineffective at high pH, in limited supply, and in jeopardy for reregistration. Several other toxicants have been identified, but not developed. Salicylanilide I is highly toxic to all fish species, contains no molecules or functional groups that seem to cause oncogenicity, and is detectable by analytical methods. The selectivity of GD-174 to carp was demonstrated in the laboratory and in small ponds, but not in the field. Baythroid was selectively toxic to the rusty crayfish, *Orconectes rusticus*. Development of these promising new chemicals is unlikely because private industry will not pay the high cost to register a minor-use piscicide with low market potential. New funding sources must be found to pay for the reregistration of existing fishery chemicals and the registration of new compounds.

Marsh, P.C., Brooks, J.E., Hendrickson, D.A., and Minckley, W.L. 1991. Fishes of Eagle Creek, Arizona, with records for threatened spikedace and loach minnow (Cyprinidae). Journal of the Arizona-Nevada Academy of Science 23: 107-116.

Notes: This paper provides historical information on K-P and Chitty Creeks, and historical status of native fish. The barrier is the Phelps Dodge Diversion Dam, which was not built for native fish protection but is working that way.

Abstract: The known ichthyfauna of Eagle Creek, Arizona, comprises 9 native and 11 non-native species. Reported here are records of native spikedace, *Meda fulgida*, and loach minnow, *Tiaroga cobitis*, the former encountered first in 1985, and the latter known only from a single collection in 1950 and not collected since. Evidence of impacts of alien fishes on the original Eagle Creek fauna is implied by their relative diversities and abundance above and below an artificial barrier. During intensive study in 1987, natives were abundant upstream where non-native fishes were scarce, while downstream reaches were occupied by substantial numbers of exotics contained few indigenous fish. A native headwater-dwelling trout (*Oncorhynchus* sp.) may now be replaced by introduced rainbows (O. *mykiss*).

Marsh, P.C., Burke, T.A., Demarais, B.D., and Douglas, M.E. 1989. First North American record of *Cichlasoma managuense* (Pisces: Cichlidae). Great Basin Naturalist 43: 387-389.
Notes: The authors note that it is not known if any native fish originally inhabited Boiler Spring, but the proximity to inhabited streams of the Virgin River basin was a concern. This paper describes an attempt to eliminate this non-native cichlid in 1988 with rotenone and explosives but it was unsuccessful.
Abstract: An established population of a neotropical chichlid fish, *Cichlasoma managuense*, was found in a spring pool in the Virgin River basin, Utah. Presence of this predatory species poses an additional threat to the native fish fauna of the Virgin River, which already has suffered multiple impacts of water development and introduced fishes.

Marsh, P.C., and Minckley, W.L. 1990. Management of endangered Sonoran topminnow at Bylas Springs, Arizona: Description, critique, and recommendations. Great Basin Naturalist 50: 265-272.
Notes: This paper provides a detailed overview of restoration efforts at Bylas Springs up to 1990.
Abstract: Efforts between 1982 and 1990 have failed to recover and secure three natural populations of endangered Sonoran topminnow (*Poeciliopsis o. occidentalis*) at Bylas Springs, Arizona. Flooding in the Gila River in 1977-78 allowed ingress by predatory mosquitofish (*Gambusia affinis*), and topminnows began to decline. Since that time (1) one stock has been replaced twice and is again nearly gone because of depredations by mosquitofish that resisted two eradication attempts; (2) topminnows at a second spring were extirpated through vegetation encroachment after fencing to protect the habitat from livestock; and (3) a third population was lost to mosquitofish, restocked after the nonnative was removed, and the restocked population is again in jeopardy, or extirpated, since mosquitofish reinvaded. Recommendation for a more intensive program of recovery are based on reassessments of past efforts and new suggestions for eradication and exclusion of mosquitofish.

Marsh, P.C., and Pacey, C.A. 2005. Immiscibility of native and non-native fishes. Pages 59-63 *in* Brouder, M.J., Springer, C.L., and Leon, S.C. Proceedings of two symposia: Restoring native fish to the lower Colorado River: Interactions of native and non-native fishes. July 13-14, 1999, Las Vegas, Nevada, and restoring natural function within a modified riverine environment: the lower Colorado River. July 8-9, 1998. U.S. Fish and Wildlife Service, Southwest Region, Albuquerque, New Mexico.
Abstract: Native and non-native fishes in the lower Colorado River overlap broadly in their physical habitat and resource uses, and no attribute of either use-category favors one group of fishes over another. The presence of non-native fishes alone precludes life-cycle completion by the natives. In the absence of non-natives, however, the natives thrive even in severely altered habitats. Compelling evidence supports a recommendation of segregated management of native and non-native fishes. Unabated declines of the imperiled native fish fauna demands expedient action by responsible parties to plan and implement appropriate strategies.

Martinez, A.M. 2004. An evaluation of nonnative fish control treatments in ponds along the Colorado and Gunnison Rivers, 1996-2002. Recovery Program Project Number 18/ 19.
URL: http:/ / www.r6.fws.gov/ crrip/ doc/ nnfc1996-2002.pdf.
Abstract: No. Excerpts from Executive Summary: Control of nonnative fish has been identified by the Upper Colorado River Endangered Fish Recovery Program as a primary component in the recovery of four endangered fish species. Historically 12 native fish species lived in the Colorado River in Colorado. . . . Conversely, 40 nonnative fish species have been collected in the Colorado River in Colorado; thus nonnative fish species outnumber native species by more than three to one.. . .Because riverside ponds may be chronic sources of nonnative fish to critical habitat the goal of this study was to reduce proliferation of nonnative fish species in floodplain habitats and minimize chronic escapement of nonnative fishes from

perennial ponds. The primary objective to accomplish this goal was diminution of nonnative fish abundance in riverside ponds and reduction of nonnative fish escapement from ponds. A secondary objective was to detect reinvasion of treated ponds by nonnative fish and identify nonnative fish movement through fish screens. Ultimately, the desired effect of this study was a reduction in the abundance of nonnative fishes in riverine nursery habitats.

An inventory of the study area revealed 729 potential pond sites. . . . Of the 191 ponds that were sampled and found to contain fish in the study area, 147 contained only nonnative fish (21 species) and another 43 contained both native (3 species) and nonnative fish. Only native fish species were collected in only one of the 191 ponds. The total catch from these 191 ponds was 25,393 fish, of which only 387 (1.5%) were native.

. . . 86 ponds, totaling 373.8 surface acres, received nonnative fish control treatments (reclamation, screen, water management, black plastic, and re-route irrigation water). The total cost of all treatments was $310,331. The average cost per surface acre for these treatments was $830. All fish were removed in 71 of the 86 treated ponds. Of the 71 ponds 54 were re-sampled to identify re-invasion by nonnative fish. Sixty-five percent of the 54 ponds had reinvaded. Additionally, movement of some, but not all, larval fish through screens was confirmed.. . This study, as well as others, has demonstrated that re-invasion by nonnative fish has readily occurred in most waters that have been treated using mechanical or chemical control techniques. However, re-invasion of largemouth bass was a notable exception. This fish species was present in 28 of the 54 re-sampled ponds prior to treatment but it had re-invaded only two of the 54 ponds following treatment. Similarly, minor success was observed in the 12 (22%) of the 54 re-sampled ponds that had not re-invaded at the time they were re-sampled. Limited success was also observed with regard to fish screens. Though some nonnative fish larvae passed through screen apertures as small as 0.5mm, other larvae were impinged and did not pass through some screens.

Evidence of reduction in abundance of nonnative fishes in existing riverine nursery habitats as a result of nonnative fish control in floodplain ponds on a river-reach scale is nonexistent.

Martinez, P.J. 2002. Westslope warmwater fisheries. Job Progress Report, Federal Aid Project F-325-R7. Colorado Division of Wildlife, Fort Collins.

Notes: This report discusses the barrier net set up at Highline Lake. Discusses two projects: Job No. 1: Warmwater fishery enhancement and nonnative fish control strategies. Objectives include: 1) evaluate nonnative fish control strategies; 2) Mark largemouth bass stocked into Highline Lake and monitor for fish escapement; 3) Net selection/ installation/ evaluation; 4) Develop new protocol to track non-natives in response to control efforts. Job No. 2: Trophic and bioenergetics investigations for warmwater fish management. Objectives include: 1) do stable isotope analysis to determine source of exotics in Colorado River and floodplain; 2) Start data collection for bioenergetics evaluation of smallmouth bass in Yampa; 3) estimate food web impacts of northern pike removal. Includes 7 substantial appendices, including: copies of powerpoint presentations on B) talk on GIS approach to evaluating nonnative stocking and D) studies on Highline Barrier Net; G) Grass carp in relationship to screen.

Abstract: No.

Martinez, P.J., and Nibbelink, N.P. 2004. Colorado nonnative fish stocking regulation evaluation, Final Report. Colorado Division of Wildlife and Wyoming Geographic Information Science Center to Upper Colorado River Endangered Fish Recovery Program, Denver.

Notes: No barriers are described in this report, but it reviews some chemical renovation (mostly from Martinez, A. 2004).

Abstract: No. Excerpts from Executive Summary:

In accordance with Procedures for Stocking Nonnative Fish Species in the Upper Colorado River Basin, the Colorado Division of Wildlife adopted regulations in 1999 to control the stocking of nonnative fish species below 6,500 feet in elevation in the Colorado River Basin, excluding the San Juan River Basin. The Colorado Wildlife Commission conditioned its approval of these new regulations by requiring that an evaluation be conducted to assess whether this strategy contributed to the control of target nonnative fish species within critical habitat for endangered fishes. The methodology chosen to address this question included use of a Geographic Information System (GIS) to provide a comprehensive framework for examining diverse information.

. . .The original premise in the Stocking Procedures that 6,500-feet in elevation would serve as an ecological demarcation above which few private waters would be stocked with nonnative, warmwater sport

fish appeared to be generally true, based on available data. . . .Based on available data for floodplain ponds sampled and those ponds that received treatments to control abundance or escapement of nonnative fish species within the Grand Valley reach of the Colorado River, green sunfish and largemouth bass pose the highest risk of reaching critical riverine habitat for endangered fishes.
. . .The abundance of stocked fish species (e.g. fathead minnow and largemouth bass) generally remained the same before and after treatments to control nonnative fish abundance in or escapement from floodplain ponds or to control nonnative fish density in backwaters. While there was no evident change in the backwater densities of the species examined during this study, it appeared that the highest densities of some species shifted locations from year to year, which could be a result of removal efforts dampening populations in particular locations. . . This outcome should be viewed as an opportunity to clarify the existing regulation to facilitate compliance and to improve its potential to serve as a preventative control strategy rather than a basis to eliminate or relax the existing regulation. It is increasingly evident that the prevention or control of nonnative fish before they proliferate and become problematic in rivers is likely a better strategy than removal or reclamation after the fact.

McClay, W. 2000. Rotenone use in North America (1988-1997). Fisheries 25: 15-21.

Notes: This article compares number of treatments by objective; in this time period, a very small number of treatments were done for restoration of natives or removal of non-natives: only 4% of all reported treatments. However, in terms of the amount of waters treated, 37% of the total volume of standing water and 24% of the total length of flowing water was for restoration or non-native removal.

Abstract: Rotenone has been used as a management tool by fisheries managers for more than 50 years. In recent years, a few projects have resulted in public controversy and in some states, rotenone use has been limited or temporarily prohibited. The American Fisheries Society's Task Force on Fishery Chemicals developed and implemented a Rotenone Stewardship Program for fisheries management using Federal Aid Administrative Funds. An initial survey of fish and wildlife agencies in North America was conducted to determine current trends, restrictions, and issues. The survey accounted for an estimated 87% of the rotenone used. The number of states and provinces using rotenone has changed little since 1949, but the quantity of rotenone used declined during the ten-year survey period of 1988–1997. Manipulation of fish communities to maintain sport fisheries and quantification of fish populations (sampling) were the most common uses of rotenone by North American fish and wildlife agencies. Other important uses included treatment of rearing facilities and eradication of exotic fish. The most important issues facing fish and wildlife agencies using rotenone were public acceptance and understanding of projects and environmental concerns. Responses from the survey were used to develop a manual of administrative and technical guidelines for the safe and effective use of rotenone.

McClay, W. 2002. Rotenone use in North America: an update. Fisheries 27: 19-20.

Notes: This article summaries survey questions to government agencies; 75 of 86 surveys were filled out. The article includes information such as scope of use (principal reasons were quantifying populations, manipulation, and treating rearing ponds); quantities used and water treated; issues in order of importance (public notification and education; public health; collection and disposal; and water quality.

Abstract: The American Fisheries Society (AFS) Fish Management Chemicals Subcommittee (FMCS) conducted a survey of governmental agencies in North America to determine patterns and issues relating to the use of rotenone during the period of 1988-1997 (McClay 2000). This reports a follow-up survey that covers the three-year period from 1998 to 2000.

Meffe, G.K. 1983. Attempted chemical renovation of an Arizona springbrook for management of the endangered Sonoran topminnow. North American Journal of Fisheries Management 3: 315-321.

Abstract: The Gila topminnow (*Poeciliopsis occidentialis*), an endangered poeciliid, rapidly declined in two Arizona springbrooks after colonization by non-native mosquitofish (*Gambusia affinis*). This characteristic outcome of interaction between these two species results from mosquitofish predation and generally leads to local extinction of the native fish. After removing a replacement population of topminnows, one springbrook was poisoned with Antimycin A in an attempt to remove all mosquitofish. Although mosquitofish appeared to be eliminated, and the re-introduced topminnows quickly expanded to large populations, mosquitofish again were present in the system several months later. Renovation attempts at other localities have produced similar results, and serve to illustrate difficulties involved in removing a fish species from a habitat for management purposes.

Meronek, T., Bouchard, P., Buckner, E., Burri, T., Demmerly, K., Hatleli, D., Klumb, R., Schmidt, S., and Coble, D. 1996. A review of fish control projects. North American Journal of Fisheries Management 16: 63-74.

Abstract: We searched the fisheries literature to assess the success of fish control projects. We reviewed 250 control projects from 131 papers. Usually each treated body of water was considered a project. Fish control treatments were divided into four categories: chemical applications (145), physical removal and reservoir drawdowns (70), stocking of fish (29), and any combination of chemical and physical methods (6). Success was judged by changes in standing stock, growth, proportional stock density, relative weight values, catch or harvest rates, and other benefits, such as angler satisfaction. Reduction in standing stock was the most common determinant of success. Of the 250 projects, we considered 107 (43%) to be successful, 74 (29%) to be unsuccessful, and 69 (28%) to have insufficient data to determine success. The most successful projects targeted rough fish. Total elimination was more successful (63%) than partial reduction (40%) in 221 waters. Success was not strongly related to size of water body. Success of chemical application was similar for treatment with rotenone (48%) and with antimycin (45%). Success rates for physical removal methods (nets, traps, seines, electrofishing, drawdowns, and combinations of physical treatments) ranged from 33 to 57%. Stocking certain species of fish to control others was the least successful, 7 of 29 water bodies (24%). Combined chemical and physical methods were successful in 4 of 6 projects (66%). Stocking after chemical or physical treatment may have increased success of fish control projects; 10 of 17 such projects (59%) were successful, a higher percentage than for chemical treatments, physical treatments, or stocking alone. An overall success rate of less than 50% for such a large number and wide variety of projects indicates that there is considerable room for improvement of fish control projects. The large percentage of unsuccessful projects and the complexity of factors influencing fish communities suggest that control projects should include critical evaluation of assumptions and of suspected causes of problems, explicit rationale and objectives, and pretreatment and long-term posttreatment study.

Miller, R.R. 1961. Man and the changing fish fauna of the American southwest. Papers of the Michigan Academy of Science, Arts, and Letters 46: 365-404.

Notes: This review article includes historical accounts of various rare and native fish including flannelmouth sucker, bonytail, woundfin, pupfish, Gila trout, Colorado pikeminnow, Gila topminnow, longfin dace, roundtail chub, Gila chub, spikedace, Sonora sucker, and desert sucker. Also discusses introduced species such as Gambusia, catfish, and green sunfish.

Abstract: No.

Miller, R.R., and Fuiman, L.A. 1987. Description and conservation status of *Cyprinodon macularius eremus,* a new subspecies of pupfish from Organ Pipe Cactus National Monument, Arizona. Copeia 1987: 593-609.

Notes: This paper describes in some detail the renovation of Quitoboquito.

Abstract: A new subspecies of pupfish *Cyprinodon macularius eremus* is described from Organ Pipe Cactus National Monument, Arizona. It is distinguishable from 10 other populations of the desert pupfish, *Cyprinodon macularius*, occurring throughout the natural range of that species. Especially interesting is its distinction from pupfish populations inhabiting other parts of the Rio Sonoyta basin that lie mostly in Sonora, Mexico. Remarks on conservation and management are presented both for the new pupfish and for *C. macularius* as a whole. The latter is an endangered species now surviving in Arizona only in Organ Pipe Cactus National Monument and extinct in most of its California range.

Miller, R.R., Williams, J.D., and Williams, J.E. 1989. Extinctions of North American fishes during the past century. Fisheries 14: 22-38.

Notes: This paper summarizes factors responsible for extinction. The most common are habitat loss (73%) and introduced species (68%) of the 40 taxa. Only one Arizona fish is listed: Monkey Spring pupfish.

Abstract: Extinctions of 3 genera, 27 species, and 13 subspecies of fishes from North America are documented during the past 100 years. Extinction are recorded from all areas except northern Canada and Alaska. Regions suffering the greatest loss are the Great Lakes, Great Basin, Rio Grande, Valley of Mexico, and Parras Valley in Mexico. More than one factor contributed to the decline and extinction of 82% of the fishes. Physical habitat alteration was the most frequently cited causal factor (73%).

Detrimental effects of introduced species also were cited in 68% of the extinctions. Chemical habitat alteration (including pollution) and hybridization each were cited in 38% of the extinctions, and overharvesting adversely affected 15% of the fishes. This unfortunate and unprecedented rate of loss of the fishery resource is expected to increase as more of the native fauna of North America becomes endangered or threatened.

Minckley, W.L., and Brooks, J.E. 1985. Transplantations of native Arizona fishes: records through 1980. Journal of the Arizona-Nevada Academy of Science 20:73-89.
Notes: This paper documents transplantations of 26 species and subspecies of Arizona fishes, including these species: Apache and Gila trout; Gila topminnow; Sonora, humpback chub, and Gila chub, speckled dace, longfin dace, flannelmouth sucker, bluehead sucker, pupfish, spinedace, spikedace, and Colorado pikeminnow.
Abstract: Yes, but not available electronically.

Minckley, W.L., and Carufel, L.H. 1967. The Little Colorado River spinedace, *Lepidomeda vittata,* in Arizona. Southwestern Naturalist 12:291-302.
Notes: This paper describes life history information including distribution, reproduction, diet of this threatened species. It includes one sentence on the toxaphene treatment in Little Colorado River from Lyman Reservoir in 1951. It also discusses presence of golden shiner and eradication attempt in Upper Chevelon Creek in 1965. There is no information on what species the renovation was designed to help. Rinne and Turner 1991 says it was for rainbow trout.
Abstract: Yes, but not available electronically.

Minckley, W.L., Marsh, P.C., Brooks, J.E., Johnson, J.E., and Jensen, B.L. 1991. Management toward recovery of the razorback sucker. Pages 303-357 *in* Minckley, W.L., and Deacon, J.E. Battle against extinction: native fish management in the American west. University of Arizona Press, Tucson.
Notes: This **c**hapter describes the management history of a backwater (Yuma Cove backwater) in Lake Mohave from 1984-1987. Work included chemical renovations to remove non-natives, repatriation and recruitment of razorback sucker, reinvasion by non-natives. Other topics include reproduction, predation, hybridization, genetics, and parasites.
Abstract: No.

Minckley, W.L., Marsh, P.C., Deacon, J.E., Dowling, T.E., Hedrick, P.W., Matthews, W.J., and Mueller, G. 2003. A conservation plan for native fishes of the lower Colorado River. BioScience 53: 219-234.
Abstract: The native fish fauna of the lower Colorado River, in the western United States, includes four "big-river" fishes that are federally listed as endangered. Existing recovery implementation plans are inadequate for these critically imperiled species. We describe a realistic, proactive management program founded on demographic and genetic principles and crafted to avoid potential conflicts with nonnative sport fisheries. In this program, native species would breed and their progeny grow in isolated, protected, off-channel habitats in the absence of nonnative fishes. Panmictic adult populations would reside in the main channel and connected waters, exchanging reproductive adults and repatriated subadults with populations occupying isolated habitats. Implementation of the plan would greatly enhance recovery potential of the four listed fishes.

Minckley, W.L., Meffe, G.K., and Soltz, D.L. 1991. Conservation and management of short-lived fishes: the cyprinodontoids. Pages 247-282 *in* Minckley, W.L., and Deacon, J.E. Battle against extinction: native fish management in the American west. University of Arizona Press, Tucson.
Notes: This chapter ncludes historical accounts and information such as ranges, habitats, and status of cyprinodontoid fishes of U.S., and Mexico. This includes springfish, topminnow, pupfish, poolfish, and native *Gambusia*.
Abstract: No.

Minckley, W.L., and Mihalick, P. 1981. Effects of chemical treatment for fish eradication on stream-dwelling invertebrates. Journal of the Arizona-Nevada Academy of Science 16: 79-82.
Notes: This study found dramatic short-term effects on invertebrates but longterm changes were minimal.
Abstract: Stream-dwelling invertebrates were decimated by application of 10 µg per liter of antimycin A

for fish eradication in Ord Creek, Apache County, Arizona. Three years later, numbers, biomass, and diversity of invertebrates were similar to pre-treatment conditions, but possible taxonomic changes were indicated.

Modde, T. 2005. Can habitat mitigate the impacts of non-native species on rare native fishes? Observations from the Upper Colorado River Basin. Pages 123-128 *in* Brouder, M.J., Springer, C.L., and Leon, S.C. Proceedings of two symposia: Restoring native fish to the lower Colorado River: Interactions of native and non-native fishes. July 13-14, 1999, Las Vegas, Nevada, and restoring natural function within a modified riverine environment: the lower Colorado River. July 8-9, 1998. U.S. Fish and Wildlife Service, Southwest Region, Albuquerque, New Mexico.

Abstract: Nonnative fishes are abundant throughout the Colorado River Basin and represent a threat to the continued existence of native fishes. The dominance of nonnative fishes is in large part due to modification of the natural riverine environment. In the presence of nonnative fishes, the major factors contributing to the decline of large river fish in the Colorado River Basin is recruitment. Information is provided on the results of floodplain enhancement efforts in the Upper Colorado River Basin to restore razorback sucker *Xyrauchen texanus*. When razorback sucker larvae appear in the river, inundated floodplains provide warmer temperature, velocity refuges and greater prey densities compared to main channel environments.

Failure of razorback sucker to recruit in the upper Colorado River Basin may partially be the result of failure of larvae to access historic nursery sites. Following construction of Flaming Gorge Dam, reduced spring flood flows have been insufficient in most years to connect floodplains to the river and provide access for razorback sucker larvae. If sufficient habitat is provided at critical periods, i.e. larval presence, razorback sucker recruitment may be enhanced. An example of habitat response to recruitment is illustrated by an increase in the population of Colorado pikeminnow *Ptychocheilus lucius* with the re-operation of Flaming Gorge Dam despite the overwhelming dominance of nonnative fishes.

Moore, S., Kulp, M., and Hammonds, J. 2001. Brook trout restoration, Great Smoky Mountains National Park: lessons for today. Shepard, B. Practical Approaches for Conserving Native Inland Fishes of the West. Sponsored by the Montana Chapter and the Western Division of the American Fisheries Society.

Notes: This paper emphasizes how education efforts can assist public understanding and approval for native fish recovery efforts.

URL: www.fisheries.org/AFSmontana/Misc/Symposium%20Abstracts/Abstracts.pdf

Abstract: No. Highlights from online file:

Brook trout are the only salmonid native to Great Smoky Mountains National Park. This native fish has lost approximately 75% of its range in the Park since the early 1900's. . . In 1996, we initiated the process to evaluate the use of antimycin to restore stream segments that are too large for successful renovation by electrofishing. This evaluation required compliance with the National Environmental Policy Act of 1969. The Environmental Assessment (EA) developed evaluated potential impacts to vegetation, aquatic insects, reptiles and amphibians, fish, terrestrial animals, threatened and endangered species and human impacts. This exercise was complicated because adult caddis flies had been collected in light traps that were not previously known to science. Some Park staff resisted the proposed project because they feared eradication of this caddis fly, as Sams Creek was the only locale from which it had been collected. The EA was released for public review in March 2000.

The number of negative responses initially received surprised us. Despite efforts to educate Trout Unlimited leadership and local angler groups, we soon learned that these groups remained by-and large uninformed of the proposal. Simultaneously, the local media portrayed the pilot project as the first step in eliminating all rainbow and brown trout from Park waters, which added to the confusion. As a result, we immediately undertook efforts to conduct public hearings and to educate media personnel. These efforts resulted in the project being approved by 85% of the respondents who provided comments during the public review. In retrospect, this process would have proceeded much smoother if we had broadened our education efforts to include local government bodies, civic groups, school groups and the media as the EA was being formulated.

Moy, P.B. 1999. Development of an aquatic nuisance species barrier in a commercial waterway. Pederson, J, editor. First National Conference on Marine Bioinvasions January 24-27 1999. Massachusetts Institute of Technology.

URL: http:/ / massbay.mit.edu/ exoticspecies/ conferences/ 1999/ abstract8.html

Abstract: No. Excerpts from Report:

The NISA Act of 1996 authorized the Corps of Engineers to carry out a demonstration study of an aquatic nuisance species dispersal barrier in the Chicago Sanitary and Ship Canal. This location is of great interest as the century old, man-made canal is the only aquatic link between the Mississippi River and Great Lakes drainages and forms a two-way avenue for invasive species dispersal. . .To identify likely dispersal barrier methodologies the Chicago District Corps assembled a Dispersal Barrier Advisory Panel comprised of 26 federal, state, academic, regional, municipal, commercial and environmental member entities. Recognizing that 100 percent control was unrealistic, the Panel members agreed that the objective of the barrier should be to reduce, to the extent possible, the dispersal of invasive species. No migratory species traverse this man-made canal however the barrier is expected to affect the passage of native as well as invasive species. . . .The project has three phases. Phase I will target bottom dwelling species, particularly the round goby (*Neogobius melanostomus*). Phase II will target actively swimming organisms in the entire water column. Finally, Phase III will address planktonic organisms.

Construction of Phase I, which will consist of an electric barrier array, is expected to begin in Spring 1999. Laboratory and small-scale field trials currently in progress will help identify ideal field intensities and potential effect on native species. Monitoring of the project will help determine its success and effectiveness. Development of Phase II is already underway; implementation of the full water column electric barrier depends in part, upon safety and liability concerns. Other methodologies under consideration or development include infrasound, bubble screens and water jets. Though considered effective, at this time, chemical control was recommended for use only as a stopgap or emergency measure.

Mueller, G.A., and Burke, T.A. 2005. Survival of young razorback sucker in relation to stocking rates (fish/ ha) and in the presence or absence of predator communities in Lake Mohave, Arizona-Nevada. Pages 155-163 *in* Brouder, M.J., Springer, C.L., and Leon, S.C. Proceedings of two symposia: Restoring native fish to the lower Colorado River: Interactions of native and non-native fishes. July 13-14, 1999, Las Vegas, Nevada, and restoring natural function within a modified riverine environment: the lower Colorado River. July 8-9, 1998. U.S. Fish and Wildlife Service, Southwest Region, Albuquerque, New Mexico.

Abstract: Razorback suckers *Xyrauchen texanus* successfully spawn in Lake Mohave and while viable larvae are produced, no recruitment has been detected for 30 years. Wild razorback sucker larvae were stocked at rates ranging from 3,125 to 22,200 fish/ ha in ephemeral habitats located adjacent to Lake Mohave from 1993 through 1995. Suckers survived 14 of 17 stockings (82%) producing 20+ cm juveniles with survival averaging 23%. There was no correlation between survival and stocking rates (R2 = 0.06). Similar survival occurred in a permanent pond that had been recently renovated, but survival declined (91.5%, 12.1%, to 1.6%) each consecutive year (1993-1995) there after. Escalating losses were attributed to odonate nymph and crayfish competition or predation.

Non-native fish were mechanically removed from a 1.3 ha cove to determine if predator densities could be mechanically reduced to a level which would enhance stocking survival. Resident predator biomass was reduced an estimated 58% (-1,554 fish/ ha, -45 kg/ ha) or to 30-35 kg/ ha prior to stocking 10,000 juvenile (68 mm) razorbacks. In spite of their size advantage and considerable predator reductions, only 9 (0.09%) of the initial 10,000 suckers were recovered. Our stocking rate of 7,600 juveniles/ ha was effectively consumed by nonnative predators within a few weeks.

Extent of the stocking loss was sobering and exemplifies threats to naturally produced larvae throughout the Colorado River basin. Natural spawned larval in some areas of Lake Mohave may reach densities >20 larvae/ m2, however, larvae rapidly disappear and suckers >2 cm are seldom found. The rate of disappearance suggests predation may be virtually complete within 50 days and be accomplished by small or medium sized predators (cyprinids and sunfish).

Mechanical predator removal appeared to target larger predators. Largemouth bass biomass (16.9 to 7.8 ka/ ha) had not fully recovered at the time of rotenoning, however, during this same period bluegill biomass may have more than doubled (20.4 to 64.9 ka/ ha). Large predator removal may inherently increase small and medium sized predator standing to crop and possibly even further escalate predation pressure for larval fishes. Survival of early life stages appears to depend on the long-term availability of predator free nurseries. Direct manipulation of nursery habitats to artificially reduce or eliminate resident predators may be the only recourse to provide some chance for natural recruitment.

Mueller, G.A., Carpenter, J., and Marsh, P.C. 2005. Cibola High Levee Pond Annual Report 2004. Open File Report 2005-1075. US Geological Survey, Fort Collins, Colorado.
URL: www.fort.usgs.gov/products/publications/21425/21425.asp
Abstract: No. Excerpts from Summary:

This represents the fourth and last annual report of a five year study investigating the early life ecology of the bonytail and razorback sucker at Cibola High Levee Pond. The work in 2004 included: telemetry studies, collection of physical water quality measurements, zooplankton samples, netting fish, the collection of scale samples for aging, predator/ prey tank tests and a preliminary analysis of the data base.

Juvenile bonytail and razorback suckers were collected this year, demonstrating that natural recruitment occurred for both species. Young from 2004, 2003, and 2002 were all represented in our sample. Unfortunately, we discovered that largemouth bass had also spawned. Approximately 100 young bass were observed during a snorkeling trip in late July. Bass ranged in size from an estimated 5 to 50 cm and were distributed throughout the pond.

Mueller, G.A., Carpenter, J., and Minckley, C.O. 2003. Cibola High Levee Pond Draft Annual Report for FY-2002. US Geological Survey, Fort Collins, Colorado.
URL: www.fort.usgs.gov/products/publications/
Abstract: No. Excerpts from Report:

Cibola High Levee Pond (CHLP) was initially developed as a grow-out pond for bonytail and razorback sucker. CHLP was chemically renovated in 1993 and stocked until 1996 by Fish and Wildlife Service (FWS). A total of 58,300 juvenile bonytail and 14,000 razorback suckers were stocked (LaBarbara 1999; Marsh 2000). Fish were quite small: razorback suckers averaged 98 mm (57-147 mm) and bonytail averaged 66 mm (61-115 mm) in total length. All the fish were produced at Dexter National Fish Hatchery and Technology Center (22 October 1993, FWS memo).

Fish growth was monitored and as fish reached 30 cm they were PIT tagged and stocked in Lake Havasu or the Colorado River. More than 225 bonytail and 760 razorback suckers were relocated between 1993 and 1998. During a removal effort in the fall of 1998, biologists collected young of both species that were <15 cm. One 25-mm bonytail fry was collected using a floating light and dip net in April of 2000.

Novinger, D.C., and Rahel, F.J. 2003. Isolation management with artificial barriers as a conservation strategy for cutthroat trout in headwater streams. Conservation Biology 17: 772-781.
Abstract: We evaluated the effectiveness of isolation management and stocking to meet protection and enhancement goals for native Colorado River cutthroat trout (*Oncorhynchus clarki pleuriticus*) in Wyoming (U.S.A.). As a management strategy of the Wyoming Game and Fish Department, cutthroat trout were isolated upstream of artificial barriers in small headwater streams. Non-native trout that might have hybridized, competed with, or preyed upon cutthroat trout were removed from the isolated reaches, and then cutthroat trout of hatchery origin were stocked to augment populations. We monitored the abundance and body condition of cutthroat trout for 4-7 years following isolation in four streams with barriers and in two reference streams without barriers. Barriers limited new invasions by non-native trout, and removals of non-native trout greatly reduced their abundance but did not eliminate them (mainly brook trout [*Salvelinus fontinalis*]). Wild cutthroat trout persisted in low numbers upstream of barriers, but there was no evidence of enhancement of populations. Stocked cutthroat trout did not persist upstream of barriers, and many moved downstream over barriers. The body condition of wild cutthroat trout was comparable among populations upstream and downstream of barriers and in reference streams. Isolation management provided only short-term benefits by minimizing the risks of hybridization and allowed populations to persist during the study. Removal of non-native trout and stocking did not enhance wild cutthroat trout populations, however, likely because the isolated reaches lacked critical habitat such as the deep pools necessary to sustain large fish. Also, barriers disrupt migratory patterns and prevent seasonal use of headwater reaches by adult cutthroat trout. Longer-term consequences of isolation include vulnerability to stochastic processes and loss of genetic diversity. Where non-native species pose an immediate threat to the survival of native fishes, isolation in headwater streams may be the only conservation alternative. In such situations, isolated reaches should be as large and diverse as possible, and improvements should be implemented to ensure that habitat requirements are met.

Novotny, E., and Binns, N.A. 1990. How to build a gabion fish barrier. Unpublished Report. Wyoming Game and Fish Department, Lander.

Abstract: No.

Pister, E.P. 1991. The Desert Fishes Council: catalyst for change. Pages 55-68 *in* Minckley, W.L., and Deacon, J.E. Battle against extinction: native fish management in the American west. University of Arizona Press, Tucson.
Abstract: No.

Porto, L.M., McLaughlin, R.L., and Noakes, D.L.G. 1999. Low-head barrier dams restrict the movements of fishes in two Lake Ontario streams. North American Journal of Fisheries Management 19: 1028-1036.
Abstract: The Great Lakes Fishery Commission (GLFC) is considering greater use of low-head barrier dams on stream tributaries of the Laurentian Great Lakes to control populations of sea lampreys *Petromyzon marinus.* The impact of these barriers on nontarget fishes is not known. A mark-recapture study on four Lake Ontario streams examined movements of fishes in streams with (barrier) and without (reference) low-head barriers. A significantly lower proportion of fishes moved across a real barrier on barrier streams than across a hypothetical barrier on reference streams (0.15 versus 0.50, respectively). The impact of the barriers on movement was more pronounced in spring and fall than in summer. However, the likelihood of fishes moving versus not moving between sample segments on either side of a barrier location (but not across the barrier) did not differ significantly between barrier and reference streams. The upstream (longitudinal) decline in species richness was greater for barrier streams than for reference streams in each season. At both interspecific and intraspecific levels, mean total lengths of fish traversing real barriers were significantly greater than the mean total lengths of fish traversing hypothetical barriers. Our findings demonstrate that low-head barriers restrict the movements of some fishes and suggest this restriction affects assemblage structure above the barrier.

Propst, D. 1999. Project completion report, Black Canyon restoration. Grant number AP-97-205F. New Mexico Game and Fish Department, Santa Fe.
Notes: This paper describes construction of a gabion-type waterfall barrier on Black Canyon.
Abstract: No.

Propst, D.L., and Stefferud, J.A. 1992. Population dynamics of Gila trout in the Gila River drainage of the south-western United States. 37: 117-125.
Abstract: In some small, often unstable, streams of the Gila River drainage, New Mexico, Gila trout *Oncorhynchus gilae* populations fluctuated numerically seasonally and annually. Few differences were noted in length-weight and size-structure comparisons, but Fulton condition index varied significantly. Time of sample and time since disturbance (natural or human-caused) were often associated with differences in condition. Other factors may include availability of prey, cannibalism, and reproductive condition. The repeatedly sampled McKnight Creek population illustrated the resilience of Gila trout populations to natural disturbances. A scouring flood in 1988 caused a >90% reduction in numbers, but, by 1992, population structure was not substantially different from that of other streams. Likewise, juvenile/ adult ratio, density, and per cent large specimens (>200 mm total length) of most other samples were within the ranges for the McKnight Creek population. Gila trout density (no. fish min-1 electrofishing) tended to increase with higher elevation and greater drainage density (stream km catchment-1 km-2) but decreased with larger catchments. Information gained in this study demonstrates that a variety of factors must be considered when evaluating the relative well-being of Gila trout populations and illustrates the importance of larger, more hydrologically complex drainages to the long-term survival of Gila trout populations.

Propst, D.L., Stefferud, J.A., and Turner, P.R. 1992. Conservation and status of Gila trout, *Oncorhynchus gilae*. Southwestern Naturalist 37: 117-125.
Notes: This paper describes 7 streams used to translocate *O. gilae* into Arizona and New Mexico.
Abstract: Gila trout, *Oncorhynchus gilae*, formerly occurred in suitable habitat in much of the Gila River drainage, New Mexico and Arizona, but, when described in 1950, it was restricted to a few remote headwater streams in New Mexico. The Endangered Species Act of 1973 and New Mexico Wildlife Conservation Act of 1974 afforded some protection and provided impetus for efforts to conserve the species. In the past 20 years, conservation efforts focused mainly on establishing additional populations. Success of recovery has been mixed. Prior to 1989, 11 populations (five relictual and six re-established)

existed. Natural events in 1988 and 1989 eliminated one population and severely reduced two others. A fourth population (natural) may be contaminated with genes of *Oncorhynchus mykiss* and its replicate therefore may be impure. Successful conservation of *O. gilae* will require continued protection and enhancement of extant populations, re-establishment of the species in large drainages rather than small headwater streams, and modification of traditional recovery strategies.

Rahel, F. 2004. Unauthorized fish introductions: fisheries management of the people, for the people, or by the people? American Fisheries Society Symposium 44: 431-443.
Notes: This paper includes the following Section titles: The Changing Role of Management Agencies and the Public in Fish Introductions; Sources of Unauthorized Fish Introductions; Evaluating Sources of Unauthorized Fish Introductions; Creating Beachheads for Invasions; Responding to Unauthorized Introductions: Educate, Legislate, Eradicate, or Accept as Fate?
Abstract: Although agency-authorized stocking of sport and forage fishes was the most common reason for fish introductions in the past, unauthorized introductions are now a major reason for the spread of nonnative fishes. Of 62 unauthorized fish introductions documented in Wyoming during 1973-2002, half (50%) involved the deliberate and illegal release of species by the public. These illegal introductions involved 23 taxa and included sport fish, baitfish, and aquaria fish. Colonization events involving the unwanted movement of fishes into new water bodies constituted 34% of unauthorized introductions and involved 13 species. Inadvertent introductions whereby species were introduced unknowingly, often as contaminants in authorized fish stockings, constituted 8% of unauthorized introductions. The remaining 8% of unauthorized introductions involved cases where the source of the nonnative fish was unknown. Options for reducing the number of unauthorized introductions include educating the public about the negative consequences of unplanned fish introductions and enacting legislation that restricts the public's access to species deemed undesirable if released into local water bodies. Because control or eradication of nonnative fishes is expensive, logistically difficult, and sometimes controversial, it will be feasible in only a limited number of situations. In most cases, we will have to accept unauthorized introductions as potentially leading to permanent additions to the regional fish fauna.

Rinne, J.N. 1975. Changes in minnow populations in a small desert stream resulting from natural and artificially induced factors. Southwestern Naturalist 20: 185-195.
Notes: The renovations described in this creek, Cave Creek, did not work. The objective was to remove longfin dace (introduced into this creek, though native in Arizona); they came back strong.
Abstract: Population dynamics and standing crops of minnows were examined in a small Upper Sonoran stream, Arizona, between 1969 and 1971. Statistics varied from year to year, largely attributable to hardiness of the respective species, increased streamflow, and flooding. Consistent yearly patterns of change in length and weight, and in most cases, biomass of all three species occurred; however, condition (K) failed to display parallel trends among species. Total biomass of fishes was comprised predominantly of one cyprinid in this small stream in the arid Southwest.

Rinne, J.N. 1985. Variation in Apache trout populations in the White Mountains, Arizona. North American Journal of Fisheries Management 5: 146-158.
Abstract: Six hundred and forty-four trout from 46 streams in the White Mountains of east central Arizona were examined meristically and morphometrically to determine the presence of the native Apache trout (*Salmo apache*). Evidence for a wider range of morphometric characters than given in the type description of the species was substantiated. Patterns of variation were corroborated by stocking histories and probable behavior of stocked, catchable hatchery rainbow trout (*Salmo gairdneri*). Based on combinations of three meristic characters, classifications are given for stream populations of trout in the White Mountains for use in the management of this threatened species of fish.

Rinne, J.N., and Minckley, W.L. 1985. Patterns of variation and distribution in Apache trout (*Salmo apache*) relative to co-occurrence with introduced salmonids. Copeia 1985: 285-292.
Abstract: Examination of Apache trout (*Salmo apache*) populations in the White Mountains, Arizona, indicated wider ranges of morphological and meristic variation than in the type description, greater genetic purity of stocks on Fort Apache Indian Reservation than on Apache-Sitgreaves National Forest, and distributional patterns that primarily reflect stocking of nonnative rainbow trout (*S. gairdneri*).

Rinne, J.N., Minckley, W.L., and Hanson, J.N. 1981. Chemical treatment on Ord Creek, Apache County, Arizona to reestablish the Arizona trout. Journal of the Arizona-Nevada Academy of Sciences 16: 74-78.

Notes: Threatened Apache trout were being replaced in Ord Creek by nonnative brown and brook trout. Chemical renovation of the stream was proposed and conducted. First treatment was in August 1977, and in September 1978 intensive sampling revealed only brook trout fry; there were no adult Apache trout. The upper reach was re-treated in September 1978 and appeared effective. A survey in 1981 (which may have been angling only) found only adult Apache trout The authors conclusions: multiple treatments may be necessary: timing and habitat complexity may have contributed to initial failure.

Abstract: Arizona trout (*Salmo apache*), a threatened species, was being displaced in Ord Creek, Apache County, Arizona, by introduced brown trout (*S. trutta*)and brook trout (*Salvelinus fontinalis*). The stream was treated with Antimycin A after removal of a stock of the native species. Procedures, and the effects of the ichthyotoxin, are reviewed. *Salmo apache* was reintroduced, but a year after treatment only young-of-the-year brook trout were present. Another treatment in 1978 succeeded in eradicating the nonnative species, and the Arizona trout introduced in October 1980 are surviving in the stream.

Rinne, J.N., Riley, L., Bettaso, R., Sorenson, R., and Young, K. 2004. Managing southwestern native and nonnative fishes: can we mix oil and water and expect a favorable solution? American Fisheries Society Symposium 44: 445-466.

Notes: This paper has good summary information on management of natives and non-natives with some case history information by river and by fish. Paper provides relative proportion data, increase of exotics vs decrease of natives over time, and tables of historic and current abundance/ presence.

Abstract: The native fish fauna of the Southwest has become markedly reduced in range and numbers over the past century. Dramatic changes in aquatic habitats and the introduction of nonnative fishes are related to their demise. Major southwestern river systems such as the Colorado, Rio Grande, Gila, and Verde presently contain nonnative, primarily sport fish assemblages, in combination with rare, declining, and listed native species. The Arizona Game and Fish Department in collaboration with federal and private agencies is responsible for managing both of these fish groups in a representative state, Arizona. Two questions can be offered: "Is it desirable, and possible, to sustain both fish groups in the waters of Arizona?" and further, "Is it possible to sustain both fish groups in the same river, stream, lake for spring?"

Currently, the Arizona Game and Fish Department propagates primarily coldwater species; however, a half a dozen species, including the threatened Apache trout *Oncorhynchus gilae apache*, Colorado pikeminnow *Ptychocheilus lucius*, razorback sucker *Xyrauchen texanus*, Gila topminnow *Poeciliopsis occidentalis*, and desert pupfish *Cyprinodon nevadensis*, are also reared in hatcheries and refugia habitats. Repatriation programs for these same species are ongoing in Arizona. A critical component for recovery of these rare, native species will be to sustain secure habitats for their repatriation. Cooperative programs with the U.S. Forest Service, U.S. Bureau of Land Management, and U.S. Bureau of Reclamation seek available habitats for restoration of native fishes. The management activities of many agencies over the last century have contributed to the hydrological and biological state of southwestern river systems. Cooperation among these same agencies will be necessary to conserve and enhance native fishes while sportfishing continues. The answer to the above two questions are (1) "Yes, both groups are being managed under department mission statements"; and (2) "No, efforts to do so should in the same habitats are not recommended and should not be attempted.".

Rinne, J.N., and Stefferud, J.A. 1999. Single versus multiple species management: native fishes in Arizona. Forest Ecology and Management 114: 357-365.

Notes: This paper is not directly about barriers but related to barrier evaluation in terms of historical summary of native Arizona trout, and using barriers and renovations for single vs multiple species.

URL: Available on www.sciencedirect.com

Abstract: The question of single vs. multiple species management of threatened and endangered fishes is discussed using examples from Arizona, where efforts to conserve native fishes have largely taken a single species, ‘real' approach. Such a strategy has been dictated by multiple factors including: (1) the interaction between climate and topography – interaction that legislates regional hydrology, (2) marked alteration of historic hydrology by dams, diversion, and groundwater mining, and (3) introduction of non-native species of fishes. However, opportunities for multiple and perhaps ‘ideal' species management must be continually embraced, despite the increased complexity of the task. In either case, conservation of native fish communities is inseparable from conservation of habitats and will require sustaining the few remaining un-dammed, free-flowing rivers in the State and managing rivers or drainage basins to incorporate (1) sustainable riparian-stream habitats and security of habitats, (2) an ecosystem, watershed or river basin approach, and (3) a cooperative (i.e. interagency), long-term, and vigilant approach.

Rinne, J.N., and Turner, P.R. 1991. Reclamation and alteration as management techniques, and a review of methodology in stream renovation. Pages 219-244 *in* Minckley, W.L., and Deacon, J.E. Battle against extinction: native fish management in the American West. University of Arizona Press, Tucson.
Notes: This chapter provides tables of 1) habitat enhancement, alteration and renovations that were considered in recovery plans; 2) summary of many western streams that were poisoned between 1950-1988 (most for sport fish enhancement); and 3) streams poisoned for Apache Trout, 1962-1988. Many Arizona renovation projects were conducted between 1950 and 1989. Sections include: improvement structures, barriers, reclamation (poisoning) of streams; extent and results of piscicide use; evaluation of habitat improvements and renovations; renovation procedures: review and recommendations (piscicides; probabilities of total fish removal; piscicide selection and concentrations; effects on other organisms; detoxicants; considerations for renovation projects {temporal-spatial concerns; pretreatment surveys; piscicide application; detoxification}); conclusions.
Abstract: No.

Robinson, A.T., Avenetti, L.D., and Cantrell, C. 2004. Evaluation of Apache trout habitat protection actions. Technical Guidance Bulletin No. 7. Project F-14-R. Arizona Game and Fish Department, Research Branch, Phoenix.
URL: Available from http://www.azgfd.gov/w_c/research.shtml
Notes: This report evaluates barrier effectiveness, and provides information on chemical renovations. Definition of failure: non-native salmonids found above barrier. They determined failure by 1) historical evaluation and 2) marking salmonids below barriers and looking for marked salmonids above barriers. Results: 64% barrier failure rate, mostly due to barrier needing repair or reconstruction. Conclusions: They question effectiveness of gabion barriers due to failure rate. Passage through interstitial spaces considered a problem; they suggest a possible solution would be to cover gabion barriers with concrete or create a solid concrete backfilled barrier (longer life, less maintenance). Problems: equipment to remote areas; higher cost. Methods to reduce angler transport: restricting vehicle access, regulation changes, education, law enforcement, remote cameras.
Abstract: No.

Saunders, D.L., Meeuwig, J.J., and Vincent, A.C. 2002. Freshwater protected areas: strategies for conservation. Conservation Biology 16: 30-41.
Abstract: Freshwater species and habitats are among the most threatened in the world. One way in which this growing conservation concern can be addressed is the creation of freshwater protected areas. Here, we present three strategies for freshwater protected-area design and management: whole-catchment management, natural-flow maintenance, and exclusion of non-native species. These strategies are based on the three primary threats to fresh waters: land-use disturbances, altered hydrologies, and introduction of non-native species. Each strategy draws from research in limnology and river and wetland ecology. Ideally, freshwater protected areas should be located in intact catchments, should have natural hydrological regimes, and should contain no non-native species. Because optimal conservation conditions are often difficult to attain, we also suggest alternative management strategies, including multiple-use modules, use of the river continuum concept, vegetated buffer strips, partial water discharges, and eradication of exotic species. Under some circumstances it may be possible to focus freshwater conservation efforts on two key zones: adjacent terrestrial areas and headwaters.

Schleusner, C. 2000. Tusidugihalen, "hot spring" (S1) and the endangered Gila topminnow habitat improvement and renovation project. Document No: USFWS-AZFRO-SC-00-007. U.S. Fish and Wildlife Service, Pinetop, Arizona.
URL: Available from http://www.fws.gov/southwest/fishery/azfro/Project_Reports.html
Notes: This report describes both a renovation and a barrier built at the S1 spring at Bylas. It provides good basic information on the springs.
Abstract: No.

Simons, L.H. 1987. Status of the Gila topminnow (*Poeciliopsis occidentialis occidentialis*) in the United States. A special report on Project E-1. Arizona Game and Fish Department, Phoenix.
Notes: This report explains the difference between "wild" vs "natural" populations, provides detailed information on each location, and describes chemical renovations to remove *Gambusia affinis*.
Abstract: No.

Sloat, M.R. 1999. The use of artificial migration barriers in the conservation of resident stream salmonids. Unpublished report.
Abstract: Fishery managers attempting to rehabilitate populations of rare salmonids often barricade streams to prevent upstream movement of non-native competitors. Migration barriers play an important role in the preservation of native fish species by preventing colonization of remaining habitats by non-native fishes. However, barriers may also create problems for native fish populations by fragmenting fish populations, reducing gene flow, and increasing the chance of extinction through stochastic events. The extent of published literature addressing on-the-ground implementation, as well as the ecological consequences of management by isolation does not reflect this management action's widespread occurrence. I provide a review of basic barrier design criteria, as well as a critical evaluation of the use of artificial migration barriers in the conservation of resident stream salmonids.

Swink, W.D. 1999. Effectiveness of an electrical barrier in blocking a sea lamprey spawning migration on the Jordan River, Michigan. North American Journal of Fisheries Management 19: 397-405.
Abstract: Mark-recapture studies indicated that a pulsed-DC electrical barrier set to a 2-ms pulse width and 10 pulses/ s completely blocked the spawning migration of sea lampreys *Petromyzon marinus* in the Jordan River, Michigan. Capture efficiency of fyke nets averaged 24% for four groups, about 300 tagged sea lampreys each, released upstream of the barrier; no unmarked sea lampreys and none of the 1,194 sea lampreys tagged and released downstream of the barrier were captured in the fyke nets while the barrier was energized. At a lower pulsator setting (1-ms pulse width; 10 pulses/ s), 1 of 900 sea lampreys released below the barrier was recaptured in the nets. Sea lampreys from downstream were captured in the fyke nets after the barrier was de-energized, indicating that the barrier should remain in operation later than mid-July. Both sea lampreys and teleosts exposed to the electrical field were stunned but exhibited no apparent damage at either barrier setting. The pulsed-DC electrical barrier should help reduce the use of chemical lampricides for controlling sea lampreys in some Great Lakes streams and would be particularly suited for streams where even the smallest low-head barrier would create an unacceptably large impoundment.

Tappel, P.D. 1986. Limitations on the use of gabions to improve fish passage. North American Journal of Fisheries Management 6: 131-132.
Notes: This paper provides recommendations on gabions, but note the author's objective is to improve fish passage, not impede it.
Abstract: Gabions are used frequently to improve aquatic habitat and rehabilitate damaged fish habitat in low-gradient streams. However, gabions should not be installed perpendicular to the stream flow if water velocities are expected to exceed 5 ft/s. This recommendation would preclude the use of gabions to improve fish passage at waterfalls. Also, gabions installed below culverts should be placed well downstream of the culvert. Weirs constructed of reinforced concrete and/ or large boulders could be used as alternatives to gabions to provide for fish passage.

Thompson, P.D., and Rahel, F.J. 1998. Evaluation of artificial barriers in small Rocky Mountain streams for preventing the upstream movement of brook trout. North American Journal of Fisheries Management 18: 206-210.
Notes: This paper represents one of the few studies that evaluated barriers by marking and recapturing fish.
Abstract: Artificial barriers are important management tools for protecting populations of native fishes from encroaching nonnative species. We evaluated the effectiveness of gabion and culvert barriers in preventing upstream movement of brook trout *Salvelinus fontinalis* in four small Rocky Mountain streams that contained native populations of Colorado River cutthroat trout *Oncorhynchus clarki pleuriticus*. A rock-filled gabion in one stream and a road culvert in a second stream appeared to block upstream movement of brook trout; no fish marked and released downstream of the barriers were subsequently found

upstream of the barriers. However, in a third stream, 18 of 86 brook trout marked and placed downstream of a rock-filled gabion barrier were later found upstream of the barrier during 3 years of evaluation. These fish ranged in length from 81 to 224 mm total length, so all size-classes were able to navigate past the structure. One brook trout moved upstream past the gabion twice, the second time during low flows when all water was percolating through the structure. We concluded that brook trout were able to move upstream through the rocks in this gabion barrier because fine sediments had not filled in all the interstitial spaces. Attention should be given to preventing movement of fish through gabion-type barriers, not just over or around them. In the fourth stream, 1 of 48 marked brook trout was found upstream from a road culvert barrier. Because this barrier appeared to be functioning properly during our study, we suspect this fish was moved upstream by an angler.

Tiffan, K.E., and Bergersen, E.P. 1996. Performance of antimycin in high-gradient streams. North American Journal of Fisheries Management 16: 465-468.
Abstract: A variety of low- to high-gradient streams in Colorado and Montana were treated with the fish toxicant antimycin (Fintrol) to evaluate its efficacy in relation to stream gradient. In general, a dose of 8 µg/L delivered for 8 h effectively killed brook trout *Salvelinus fontinalis* and rainbow trout *Oncorhynchus mykiss* over an elevation drop of 6075 m where pH was low (=7.0) and water temperature was warm (=10°C). Colder water temperatures and higher pHs reduced the effectiveness of antimycin.

Tilmant, J.T. 1999. Management of non-indigenous fish in the U.S. National Park system. Paper presented at the 129th Annual Meeting of The American Fisheries Society. Charlotte, NC.
Abstract: Our nation's national parks and monuments have been set aside for the important and often unique natural and cultural resources they possess. They are designated as part of the national park system for the protection and conservation of their resources, “unimpaired for both present and future generations.” Under such purposes and mandates, the managers of National Parks are concerned with the maintenance of natural processes, conservation of natural biodiversity, and the functioning of native ecosystems. The widespread and intensive introductions of non-native fish species that has occurred across all areas of the United States is greatly affecting the ability of park managers to maintain and protect the natural functioning of park ecosystems. This is particularly true with regards to fish species that represent a high recreational and economic value and are continuing to be propagated through new releases outside of parks. The National Park Service has established management policies calling for the removal and control of non-native species that are impacting natural areas, and over $2 million is spent annually on restoration of native and control of non-native aquatic species in National Park Service areas. Impacts from the introduction of non-indigenous species, and the hatchery propagation of native species, range from native species displacement, to population reductions, to new disease and parasite infestations, to genetic change and loss. The National Park Service is seeking new and more effective ways of controlling and removing non-indigenous species and is continually faced with new issues of concern. However, often control and restoration activities cannot be accomplished because of the political and economic importance of the non-indigenous species or because of State and Federally supported stocking programs.

U.S. Bureau of Reclamation (USBR). 2004. Preliminary habitat assessment; establishing a native fish refugium at Butler Lake Imperial National Wildlife Refuge, Arizona. U.S. Bureau of Reclamation Lower Colorado Region, Boulder City, Nevada.
Notes: Quote from Page 28: "current conditions are inadequate to support a self-sustaining population of the targeted native fish species..".
Abstract: No, however there is an Executive Summary but it is not available electronically.

U.S. Fish and Wildlife Service (USFWS). 1980. Determination that the bonytail chub (*Gila elegans*) is an endangered species. Final Rule. Federal Register 45: 27710-27713.
Abstract: No.

U.S. Fish and Wildlife Service (USFWS). 1983. Arizona Trout (Apache Trout) Recovery Plan. Albuquerque, New Mexico.
Abstract: No. Excerpt from Executive Summary:
Arizona trout were recognized as a unique species many years before they were officially described in 1972. Their distribution is centered in the White Mountains of east Central Arizona, on lands administered

by the White Mountain Apache Tribe and adjacent Apache-Sitgreaves National Forest. The principle reason for the decline of this native trout is loss of habitat and genetic swamping by introduced rainbow trout. Recovery efforts center around 1) developing good methods of identifying pure populations of Arizona trout, 2) protecting those populations and their habitats, 3) reintroducing Arizona trout into historic waters after the nonnative species have been eliminated, and 4) developing and implementing land management plans for the protection of Arizona trout habitats. This revised Arizona Trout Recovery Plan supercedes the original plan signed in 1979. It incorporates new data, including restoration work on several streams on Indian and Forest Service lands and preliminary research on determining Arizona trout purity. The common name Arizona trout was originally used to describe *Salmo apache*, but the newest American Fisheries Society publication of Common and Scientific Names of Fishes (Robins, et al. 1980) uses Apache trout. This change has not been utilized in this publication, but will be made in future revisions.

U.S. Fish and Wildlife Service (USFWS). 1987. Endangered and threatened wildlife and plants: final rule to determine *Lepidomeda vittata* (Little Colorado River spinedace) to be a threatened species with critical habitat. Federal Register 52(179):35034-35041.

Abstract: No. Excerpt from online document:

In upper Chevelon Creek, golden shiners were present in such large numbers in 1965 that the Arizona Game and Fish Department treated the stream with a piscicide (fish toxicant) in an unsuccessful attempt to eradicate them, This treatment was considered necessary because the golden shiner competes with young game fish. particularly trout (Minckley 1973). Since the Little Colorado spinedace is “troutlike in its behavior and habitat requirements” (Miller 1963). it is quite likely that the golden shiner is also a significant competitor with the Little Colorado spinedace (Minckley and Carufel 1967).

Another important factor in the decline of the Little Colorado spinedace has been the use of piscicides (fish toxicants) in the streams of the Little Colorado River drainage. Most of the major game fish streams of the drainage have been subjected to poisoning, with such chemicals as rotenone and toxaphene, in generally unsuccessful attempts to rid these streams of “trash” fish such as carp, suckers, chubs, and shiners and thereby improve the streams for game fish (Miller 1963). The Little Colorado River was treated from Lyman Resewoir downstream for approximately 10 miles in 1951, and Chevelon Creek was treated twice in 1965 (Mickley and Carufel 1967), and again several years later. These treatments undoubtedly significantly reduced both the populations and range of the Little Colorado spinedace.

U.S. Fish and Wildlife Service (USFWS). 1990. Spikedace Recovery Plan. Albuquerque, New Mexico.

Abstract: No. Excerpt from Executive Summary:

Current Species Status**:** The spikedace is a threatened fish which has been extirpated from most of its historic range in the Gila River Basin. It is presently found only in the upper Gila River in New Mexico, and in Aravaipa and Eagle creeks and the upper Verde River in Arizona. All existing populations are under threat.

U.S. Fish and Wildlife Service (USFWS). 1993. Desert Pupfish Recovery Plan. Phoenix, Arizona. 67 pp.

Notes: This Recovery Plan is for *Cyprinodon macularis*. Since this report was published, the Quitoboquito form has been determined to be it's own species, *C. eremus.* The Quitoboquito renovation is mentioned. Appendix on Page 38 provides full list of known transplants in California, Arizona, and Mexico. However, we could find no information on possible renovations that may have been associated with these transplants.

Abstract: No. Excerpts from Executive Summary:

Current Species Status: Listed as endangered throughout its range. Composed of two subspecies in the U.S.: a Colorado River form and a Quitobaquito form. Natural populations of the Colorado River form have been extirpated from Arizona, restricted to three natural locations in California and the non-natural irrigation drains around the Salton Sea. The Colorado River form also occupies certain restricted locations of the Colorado River Delta in Sonora and Baja California, Mexico. The Quitobaquito form persists in a single, modified spring at Organ Pipe Cactus National Monument, Arizona. Distribution of a third, undescribed form in Rio Sonoyta of Sonora, Mexico is unknown, but believed to be quite limited.

Habitat Requirements and Limiting Factors: . . . Does not cope effectively with introduction of non-native fish. Habitat loss, habitat modification, pollution, and competition and predation from nonnative fish threaten the species’ survival.

Recovery Criteria: Secure, maintain and replicate all naturally occurring extant populations. Re-establish replicate populations in the most natural, identifiable habitats within the probable historical range.

Each replicated population will not be considered established until the population has persisted for a minimum of ten years. Protection and establishment of refugium populations of Quitobaquito and Rio Sonoyta forms.

U.S. Fish and Wildlife Service (USFWS). 1994a. Fishes of the Rio Yaqui Recovery Plan. USDI Fish and Wildlife Service, Albuquerque, New Mexico. 48 pp.

Notes: This report also discusses the following non-endangered fishes: Yaqui form of longfin dace (*Agosia chrysogaster ssp.*), roundtail chub (*G. robusta*), Mexican stoneroller (*Campostoma ornatum*), and Yaqui sucker (*Catostomus bernardini*).

Abstract: No. Excerpts from Executive Summary:

Current Status: Four Yaqui fish species are included in this plan, two listed as endangered, the Yaqui chub (*Gila purpurea*) (USFWS 1984) and Yaqui topminnow (*Poeciliopsis occidentalis sonorensis*) (USFWS 1967), and two threatened species, the Yaqui catfish (*Ictalurus pricei*) (USFWS 1984), and the beautiful shiner (*Cyprinella formosa*) (USFWS 1984). All formerly occurred throughout the Rio Yaqui Basin in USA and Mexico. Current distribution in Mexico is imperfectly known. USA populations are limited primarily to the San Bemardino/ Leslie Canyon NWR and West Turkey Creek, Cochise County, Arizona. Beautiful shiner and Yaqui catfish also occurred in the Mimbres River in New Mexico.

Habitat Requirements and Limiting Factors: In the United States, Yaqui fishes are heavily dependent on artesian wells and spring flows on San Bernardino NWR (SBNWR). Three stream sections, Leslie Creek, West Turkey Creek and Black Draw, contain Yaqui fishes. Water development and pumping of underground aquifers constitute the greatest threat to survival of Yaqui fishes, followed closely by introduction of non-native organisms.

Recovery Criteria: Although present in the US, these populations will not continue to persist unless they are managed intensively. Also, populations and habitats need to be stabilized in Mexico before delisting can be considered.

U.S. Fish and Wildlife Service (USFWS). 1994b. Virgin River Fishes Recovery Plan. Salt Lake City, Utah.

Notes: Pages 15-16 of this report describe the history and details of chemical renovations in the Virgin River.

Abstract: No. Excerpts from Executive Summary:

Current Species Status**:** The woundfin, *Plagopterus argentissimus*, and Virgin River chub, *Gila seminuda*, are listed as endangered. These fish presently occur in the mainstem Virgin River in Utah, Arizona, and Nevada. The Virgin River chub also has been recently described in the Moapa (Muddy) River in Nevada. The woundfin historically occurred in the Salt River, Arizona; the Gila River near Yuma, Arizona; the Colorado River near Yuma, Arizona; and the Moapa River, Nevada, but it no longer occurs in these rivers. Both the woundfin and Virgin River chub have declined in the Virgin River, especially in the reaches downstream of Washington Fields Diversion near St. George, Utah. The Virgin River chub also may have declined in the Moapa River.

Recovery Criteria**:** Downlisting. The woundfin may be downlisted to threatened status when (1) Virgin River flows essential to survival of all life stages are protected, (2) degraded Virgin River habitat from Pah Tempe Springs (also called La Verkin Springs) to Lake Mead is upgraded and maintained to allow continued existence of all life stages at viable population levels, and (3) barriers to upstream migration of introduced fishes are established, red shiner (*Notropis lutrensis*) is eliminated, and other nonnative species which present a major threat to the continued existence of the fish community are reduced.

Virgin River chub have recently been described in the Moapa River in Nevada. Virgin River chub are listed as endangered in the Virgin River, Utah, Arizona, and Nevada; they are not currently listed in the Moapa River, Nevada. If the fish is not listed in the Moapa River, downlisting criteria will be identical to those discussed above for the woundfin. If the Virgin River chub is listed in the Moapa River, recovery criteria that address the fish in both rivers will be developed in the future.

U.S. Fish and Wildlife Service. 1994c. White River Spinedace, *Lepidomeda albivallis*, Recovery Plan, Portland, Oregon. 45 pp.

Abstract: No.

U.S. Fish and Wildlife Service (USFWS). 1995. Recovery plan for the aquatic and riparian species of the Muddy River Ecosystem. Portland, Oregon.

Notes: Also includes information on the endangered Virgin River chub (*Gila seminuda*), and the state-listed Moapa speckled dace (*Rhinichthys osculus moapae*) and Moapa White River springfish (*Crenichthys baileyi moapae*).
Abstract: No. Excerpts from Executive Summary:
Current Species Status: The Moapa dace (*Moapa coriacea*) was listed as endangered on March 11, 1967 (32 Federal Register 4001). It occupies approximately 9.5 kilometers (6 miles) of stream habitat in five thermal headwater spring systems and the main stem of the upper Muddy (= Moapa) River, Clark County, Nevada. Critical habitat has not been designated. A range-wide survey documented 3,841 adult Moapa dace in August 1994. The Muddy River ecosystem is also inhabited by seven aquatic species of special concern (three fish, two snails, and two insects).
Recovery Criteria: Moapa dace will be considered for reclassification from endangered to threatened when: 1) Existing instream flows and historical habitat in three of the five occupied spring systems (Apcar, Baldwin, Cardy Lamb, Muddy Spring, Refuge ({Moapa Valley NWR}) and the upper Muddy River have been protected through conservation agreements, easements, or fee title acquisitions; 2) 4,500 adult Moapa dace are present among the five spring systems and the upper Muddy River; and 3) the Moapa dace population is comprised of three or more age classes, and reproduction and recruitment are documented from three spring systems. Moapa dace will be considered for delisting provided that all reclassification criteria have been met and when: 1) 6,000 adult Moapa dace are present among the five spring systems and the upper Muddy River for 5 consecutive years; 2) 75 percent of the historical habitat in the five spring systems and the upper Muddy River provides Moapa dace spawning, nursery, cover, and/ or foraging habitat; and 3) nonnative fishes and parasites no longer adversely affect the long-term survival of Moapa dace. These recovery criteria are preliminary and may be revised on the basis of new information (including research specified as recovery tasks).
….Species of Special Concern**:** In addition to Moapa dace, three other endemic minnows are present in the Muddy River ecosystem: Virgin River chub (*Gila seminuda*), Moapa speckled dace (*Rhinichthys osculus moapae*), and Moapa White River springfish (*Crenichthys baileyi moapae*).

U.S. Fish and Wildlife Service (USFWS). 1997. Razorback sucker (*Xyrauchen texanus*) Recovery Plan. Denver, Colorado.
Notes: There is a supplement of recovery goals available at the USFWS Endangered species website.
Abstract: No. Excerpts from Executive Summary:
Current Status**:** The razorback sucker, *Xyrauchen texanus* (Abbott), was listed as endangered on October 23, 1991 (56 FR 54957). A final rule designating critical habitat was published on March 21, 1994 (59 FR 13374). An endemic fish of mainstream rivers in the Colorado River basin, the razorback sucker was once abundant and widely distributed. It now occurs only in remnant populations in a few lakes and river reaches. The largest extant population occurs in Lake Mohave, Arizona, and the largest riverine population occurs in the Green and Yampa rivers, near Vernal, Utah.
Habitats and Limiting Factors**:** Razorback sucker populations have been declining for much of this century. . . Predation by nonnative fishes and loss of habitat are primary reasons for the virtual failure of recruitment in razorback sucker populations.
Recovery Objectives**:** Protection and expansion of three existing populations, and establishment of five new ones from remnant stocks or reintroductions.

U.S. Fish and Wildlife Service (USFWS). 1998a. Gila Topminnow *Poeciliopsis occidentalis occidentalis*, Revised Recovery Plan. Albuquerque, New Mexico.
Notes: This Recovery Plan includes the following historical information on renovations:
...Topminnows were extirpated from one of the original 10 localities, Salt Creek by mosquitofish (Marsh and Minckley 1990) but the stream was renovated and restocked with Gila topminnows from Middle Spring. Subsequently, mosquitofish were found in the stream and it was again renovated and restocked, this time with topminnows from Bylas Spring.
...Bylas Springs has been unsuccessfully poisoned twice to remove mosquitofish (Meffe 1983; Brooks 1985; Marsh and Minckley 1990). Another attempt at renovation of Bylas Springs was done by the Service's Arizona Fishery Resource Office and has so far been successful.
...Salt Creek has also been renovated and restocked with topminnow originally from Bylas Spring (USFWS nd).
...Physical and chemical renovations have taken place at Bylas Spring, Salt Creek, Hassayampa River

Preserve, Roper Lake State Park, and Boyce-Thompson Arboretum. These efforts have had limited success (Meffe 1983; Bagley et al. 1991). Renovations were temporarily successful at Bylas Spring, Salt Creek, Roper Lake State Park, and Boyce-Thompson Arboretum. However, Bylas Spring, Hassayampa River Preserve, and Boyce-Thompson currently support topminnow populations coexisting with nonnatives. Salt Creek was recently renovated a second time and has been re-stocked with topminnow held at the ASU Animal Resources Center originally from Bylas Spring.
...Renovation and reintroductions have recently occurred at Middle Spring and Salt Creek.
...When habitat renovation is considered, several factors should be taken into account including population origin (natural vs. reestablished), immediacy of threat, status of replicate populations of the same lineage, and probability of short and long-term success. Some factors negatively affecting success include poor organization and execution of renovation, potential recontamination by the public or from nearby populations in the watershed, habitat complexity and size, and lack of barriers to fish migration.

Abstract: No. Excerpts from Executive Summary:

Current Species Status**:** The Sonoran topminnow, *Poeciliopsis occidentalis*, includes two subspecies, the Gila topminnow, *Poeciliopsis o. occidentalis*, and the Yaqui topminnow, *Poeciliopsis o. sonoriensis*. . . .In the United States, the species currently occurs in the Gila River drainage, Arizona, particularly in the upper Santa Cruz River, Sonoita and Cienega creeks, and the middle Gila River. The Gila topminnow is restricted to 14 natural localities in Arizona. In Mexico, the species occurs in the Río Sonora, Río de la Concepción, and Santa Cruz River but are not listed under the Endangered Species Act.

U.S. Fish and Wildlife Service (USFWS). 1998b. Little Colorado River spinedace, *Lepidomeda vittata* Recovery Plan. Albuquerque, New Mexico. 51 pp.

Abstract: No. Excerpt from Introduction:

The Little Colorado River spinedace (spinedace), *Lepidomeda vittata,* is currently restricted to north flowing tributaries of the Little Colorado River in Apache, Coconino and Navajo counties of eastern Arizona . . . The other species of spinedace occur in extreme northwest Arizona *(L. mollispinis)* and in Nevada and Utah *(L. albivallis* and *L. altivelis,* Miller and Hubbs 1960; Minckley 1973; LaRivers 1962).

The spinedace was included in the U.S. Fish and Wildlife Service's (USFWS) "Review of Vertebrate Wildlife for Listing as Endangered or Threatened Species" (USFWS 1982). At that time, the species was considered a category one species, indicating that the USFWS had substantial information on hand to support a proposal to list the species as endangered or threatened. On 12 April 1983, the USFWS was petitioned by the Desert Fishes Council to list the spinedace. This petition was found to contain substantial scientific or commercial information and a notice of the finding was published on 14 June 1983 (USFWS 1983). After review and evaluation of the petition's merits, the USFWS found the petitioned action warranted. A notice of finding was published on 13 July 1984 and the species was proposed for listing on 22 May 1985 (USFWS 1984, 1985). The spinedace was listed as threatened in 1987 (USFWS 1987). Areas designated as Critical Habitat includes 31 miles of East Clear Creek, Coconino County, from its confluence with Leonard Canyon upstream to Blue Ridge Reservoir and from the upper end of Blue Ridge Reservoir to Potato Lake; eight miles of Chevelon Creek, Navajo County, from the confluence with the Little Colorado River upstream to the confluence of Bell Cow Canyon; and five miles of Nutrioso Creek, Apache County, from the Apache- Sitgreaves National Forests boundary upstream to Nelson Reservoir Dam (USFWS 1987).

U.S. Fish and Wildlife Service (USFWS). 1998c. Recovery plan for the aquatic and riparian species of Pahranagat Valley. Portland, Oregon. 82 pp.

Notes: This recovery plan covers three endangered fish: Pahranagat roundtail chub (*Gila robusta jordani*); White River springfish (*Crenichthys baileyi*), and the Hiko White River springfish (*Crenichthys baileyi grandis*). It also discusses Pahranagat spinedace (described as extinct) and the **state-**listed White River desert sucker (*Catostomus clarki intermedius*), and Pahranagat speckled dace (*Rhinichthys osculus velifer*).

Abstract: No. Excerpts from Executive Summary:

Current Status: The Pahranagat Valley in Lincoln County, Nevada, supports three native, endangered species. The Pahranagat roundtail chub is found in approximately 3.5 kilometers (2.2 miles) of the Pahranagat Creek and 2.5 kilometers (1.6 miles) of the main ditch, but historically occurred in over 30 kilometers (18.4 miles) of the creek. The White River springfish occupies the spring pool of Ash Spring in considerable numbers, but historically occurred in the spring pool and throughout its outflow. Hiko White River springfish are present in Hiko Spring and in Crystal Spring and its outflow. The population in Hiko

Spring is stable, but the Crystal Spring population is in danger of extirpation. . .

U.S. Fish and Wildlife Service (USFWS). 1999. Biological opinion, West Turkey Creek native fish renovation project. Phoenix, Arizona.
Notes: This report includes sections describing the proposed action (using antimycin-A in entire drainage of West Turkey Creek after removing natives); the status of Yaqui chub; the environmental baseline; the effects of the action; historical information on Ruckers Canyon; cumulative effects; incidental take; and conservation recommendations.
Abstract: No.

U.S. Fish and Wildlife Service (USFWS). 2002a. Bonytail (*Gila elegans*) recovery goals: amendment and supplement to the Bonytail Chub Recovery Plan. U.S. Fish and Wildlife Service, Mountain-Prairie Region (6), Denver, Colorado.
Abstract: No.

U.S. Fish and Wildlife Service (USFWS). 2002b. Endangered and threatened wildlife and plants: listing the Gila chub as endangered with critical habitat; proposed rule. Federal Register 67(154): 51947-51985.
Abstract: No. Excerpt from article relevant to renovations:

AGFD has several conservation projects in progress for helping to improve the status of the Gila chub. In cooperation with the Coronado National Forest, they recently completed a renovation project on Sabino Canyon to remove green sunfish and help improve the suitability of the existing Gila chub population. Two other projects that are in the planning stages and moving toward implementation are Bog Hole Wildlife Area and O'Donnell Canyon. Bog Hole Wildlife Area is a stock tank (pond) that was illegally stocked with nonnative green sunfish. Removal of these nonnatives is planned in addition to stocking tanks upstream that have potential Gila chub habitat. The second project is O'Donnell Canyon, where Gila chub are relatively abundant although nonnative green sunfish pose a threat. Removal of nonnative green sunfish is also required for this site. This project site is located in the Canelo Hills Preserve which is partially owned by TNC. This stream renovation project is a coordinated effort between TNC, the Service, the FS, and Region V of the Arizona Game and Fish Department. Both Larry Creek and Lousy Canyon have been stocked with Gila chub in an effort to reestablish them into suitable habitat.

U.S. Fish and Wildlife Service (USFWS). 2002c. Razorback sucker (*Xyrauchen texanus*) Recovery Goals: amendment and supplement to the Razorback Sucker Recovery Plan. U.S. Fish and Wildlife Service, Mountain-Prairie Region (6), Denver, Colorado.
Abstract: No.

U.S. Fish and Wildlife Service (USFWS). 2003. Gila trout (*Oncorhynchus gilae*) recovery plan. U.S. Fish and Wildlife Service, Albuquerque, New Mexico.
Abstract: No. Excerpts from Executive Summary:

<u>Current Species Status</u> Gila trout, native to streams of the Mogollon Plateau of New Mexico and Arizona, is listed as endangered throughout its range. In 1975, the known distribution of the species consisted of only five relict populations restricted to headwater stream habitats in the upper Gila River drainage in New Mexico (Main Diamond Creek, South Diamond Creek, McKenna Creek, Spruce Creek and Iron Creek). At the time of listing, no detailed genetic investigations of the few extant populations had been undertaken. Thus, each of the five known occurrences was considered a pure population and essential to recovery. A sixth relict population in Whiskey Creek was discovered in 1992. In 1996 and 1997, it was discovered that the McKenna Creek and Iron Creek populations were hybridized with rainbow trout. Replication of these two hybrid populations is not a component of recovery of Gila trout because Gila *x* rainbow hybrid trout are not recognized as a species or subspecies pursuant to the Endangered Species Act and published listing rules for the species.

Currently, there are 14 populations of Gila trout in the wild. Additionally, the Mora National Fish Health and Technology Center maintains a captive population of Gila trout that represents the Main Diamond lineage. The downlisting criteria described in the 1993 recovery plan revision have been achieved. All of the relict populations are self-sustaining in the wild. All pure populations have been replicated in a sufficient number of drainages to prevent extirpation of any lineage from a natural or human-caused event. The Main Diamond Creek population was restored to its original habitat following its loss in the wild from the 1989 Divide Fire. Replicates of the Main Diamond Creek population persist in McKnight Creek, Sheep Corral Canyon, lower Little Creek, upper White Creek, and Black Canyon. Similarly, the South Diamond Creek population was restored to its original habitat following its loss in the wild from the 1995 Bonner Fire. The South Diamond Creek population is replicated in the Mogollon Creek drainage, which includes a portion of the main stem of Mogollon Creek, Trail Canyon, Woodrow Canyon, and South Fork Mogollon Creek. The Whiskey Creek population is replicated in upper Little Creek and the Spruce Creek population is replicated in Big Dry Creek, Dude Creek, and Raspberry Creek. The total population size of Gila trout in the wild was estimated to be approximately 37,000 in 1998.

Actions Needed Actions needed to achieve the objective of this plan include: 1) establishing additional populations of Gila trout, including restoring the species in entire watersheds and recombining lineages; 2) protecting populations and habitat; 3) continuing to obtain information needed to address important conservation issues; and, 4) continuing to provide information and conduct coordination regarding recovery of the species.

Verrill, D.D., and Berry, Jr. C.R. 1995. Effectiveness of an electrical barrier and lake drawdown for reducing common carp and bigmouth buffalo abundances. North American Journal of Fisheries Management 15: 137-141.

Notes: Carp is an introduced species but bigmouth is native to Minnesota.

Abstract: An overabundance of common carp *Cvprinus carpio* and bigmouth buffalo *Ictiobus cyprinellus* in North and South Heron lakes, Minnesota, has hindered production of food plants for waterfowl. These shallow (maximum depth, 1.5 m), turbid lakes are partially drawn down each winter. Common carp were radio-tracked in both lakes during the winters of' 1991 and 1992 to monitor their movements and survival. Four of six radio-tagged fish died during the first winter because of low water, but all of an additional 12 radio-tagged common carp survived the second winter. The fish overwintered in water 28–50 cm deep under about 40 cm of ice cover. To assess the ability of an electrical barrier across the outlet stream to prevent migration into the Heron lakes basin, 1,600 common carp and bigmouth buffalo were marked with dart tags and released downstream from the barrier. No tagged fish were among the 3,376 fish caught upstream from the barrier. Catches of the two species per unit gillnetting effort in South Heron Lake were lower in August 1992 than in August 1991, suggesting that lake-level drawdown and the electrical barrier reduced both populations.

Wares, J.P., Alò, D., and Turner, T.F. 2004. A genetic perspective on management and recovery of federally endangered trout (*Oncorhynchus gilae*) in the American Southwest. Canadian Journal of Fisheries and Aquatic Sciences 61: 1890–1899.

Abstract: The native trout of New Mexico and Arizona have been managed for conservation for almost 80 years and are currently listed under the US Endangered Species Act. Management of these populations has improved the outlook for these species. However, because of a history of non-native salmonids being stocked in the region, genetic analysis of the remaining populations is necessary to ensure that each population is as representative as possible of ancestral populations of Gila (*Oncorhynchus gilae*) and Apache (*Oncorhynchus gilae apache*) trout. Here we provide a multilocus genotypic assessment of 19 populations of native southwestern trout that strongly indicates that management has maintained the genetic integrity of these species, while restoring each species to a number of historically occupied streams.

Washington County Water Conservancy District. 1999. Virgin River Management Plan. St. George, Utah.

URL: http://wcwcd.state.ut.us/WebPage/ReportsPlanAgreements/VRMP/TitlePage.html

Notes: This report describes history and ownership of the Virgin River by reach.

Abstract: No. Excerpts from online paper relevant to barriers and renovations:

Page 26:

5. Washington Fields Diversion to Johnson Diversion (Reach 5)

. . .This reach is about six miles long and is privately owned except for three-quarters of a mile of public land (see Figure 3).

The Johnson diversion serves as a fish barrier to prevent non-native fish from moving upstream. This has been effective in the past. However, red shiners (a non-native fish) have now been identified in this reach. This reach was treated to remove non-native fish in 1995 and results appear to be successful.

Page 28:

6. Johnson Diversion to St. George Sewer Plant (Reach 6)

. . .This reach receives return flows from the agricultural areas and provides good habitat for both Virgin River chub and woundfin. . . . This reach is about eight miles long and is privately owned except for a mile of State Trust land (Figure 3).

Native fish species have been heavily impacted by the introduction of non-native fish species to the river. The red shiner is the dominant fish in much of this reach (Figure 3). Although this reach was treated in 1993 to remove the non-native fish, the effort was {not} successful and this reach is still dominated by non-native fish species. The treatment greatly reduced the native fish species which have not fully recovered from its effects. Major flaw in the failed treatment was the inability to treat side drainage. It is planned treat the river again in 1998.

Page 29:

7. St. George Sewer Plant-Arizona State Line (Reach 7)

. . .This reach starts at the St. George regional sewer treatment plant. . . This reach is important habitat for Virgin River chub and woundfin. This reach is heavily impacted by introduction of non-native fish species. The red shiner is the dominant fish in much of reach. A fish barrier constructed by the WCWCD is located at the start of the narrows above the Arizona State line. After the barrier was constructed, this reach was treated to remove the non-native fish. The effort was not successful and the reach is dominated red shiner. The treatment greatly reduced the native fish species and numbers remain relatively low. . .There are plans to this reach of river again to remove red shiners and other non-native fish.. . . This reach is estimated to be seven miles long.

Page 35:

3. Winsor Diversion - Seep Ditch (Reach 3)

. . .This reach contains all of the Santa Clara River from Winsor diversion to Seep Ditch diversion. This reach is estimated to be over 13 miles long. The reach contains 4 miles Shivwits Band Paiute Indian Reservation, 2 miles public land, and 7 miles of private land (See Figure 4. . .This reach starts at the Winsor Dam diversion . . . The diversion is a tall rock and concrete structure which is a barrier to fish movement upstream. Virgin spinedace are not present in parts of this reach because it is currently dewatered in some sections for part of the year.

Page 42:

2. Chute Falls to Wilson Diversion (Reach 2)

. . .This reach starts at Chute Falls and goes to the Wilson diversion. Chute Falls is a natural barrier to prevent movement of fish up stream. La Verkin Creek up to Chute Falls has identified as Virgin spinedace habitat. . . This reach is 4 miles long. It contains 2 miles private land and 2 miles of public land (Figure 5)..

Abstract: No. Excerpts from Executive Summary:

Washington County is growing at an unprecedented rate. The population has tripled in the past 20 years. From 1990 to 1995 the population increased 28 percent or an average of 5.6 percent per year. . . .The future growth of the Virgin River Basin is dependent upon proper development of water from the Virgin River and its tributaries. The river areas are habitats for a large number of wildlife, including six native fish.

. . .This plan is prepared by the sponsors to develop an integrated approach to the sound development and management of the Virgin River and its tributaries.. . .This plan along with the Virgin River Resource Management and Recovery Program (VRRMRP), was prepared in conjunction with the U.S. Fish and Wildlife Service, will provide the necessary actions for improvement of the wildlife species listed under the Endangered Species Act and allow for water development. The VRRMRP develops base line conditions and mitigation banking for native species.

. . .Actions being considered include:

F. Restoration of native fish habitat by providing year-long instream flows in river

L. Discontinuing water diversions on lower La Verkin Creek with cooperation of property owners, to enhance spinedace habitat.

Williams, J.E. 1991. Preserves and refuges for native western fishes: history and management. Pages 171-189 *in* Minckley, W.L., and Deacon, J.E. Battle against extinction: native fish management in the American west. University of Arizona Press, Tucson.

Notes: This chapter includes historical accounts of multiple species; disucsses conservation, restoration/ barriers, and information on Aravaipa Creek (AZ) and Hot Creek Spring (NV).

Abstract: No.

Williams, J.E., Bowman, D.B., Brooks, J.E., Echelle, A.A., Edwards, R.J., Hendrickson, D.A., and Landye, J.J. 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: 1-62.
Abstract: Habitat degradation and the introduction of exotic species are endangering an increasing number of fishes and other aquatic organisms in the desert areas of North America. We identify 164 fishes from North American deserts as endangered, vulnerable, rare or of indeterminate status. Forty-six of these fishes are herein considered endangered. Additionally, 18 recently extinct fishes are recorded from the region. Fifteen ecosystems are identified as providing habitat for 83 of these vanishing fishes. These highly significant aquatic ecosystems, with locations given parenthetically, are: Cuatro Cienegas (Coahuila), Gila River (New Mexico, Arizona and Sonora), Rio Grande (New Mexico, Texas, Chihuahua, Coahuila, Nuevo Leon and Tamaulipas), Pecos River (New Mexico and Texas), Railroad Valley (Nevada), Colorado River (Colorado, Utah, New Mexico, Arizona, Nevada, California, Baja California del Norte and Sonoma), Green River (Wyoming, Colorado and Utah), Pahranagat Valley (Nevada), Parras Valley (Coahuila), La Media Luna (San Luis Potosi), Ash Meadows (Nevada), Upper White River (Nevada), Moapa River (Nevada), Rio Yaqui (Arizona, Chihuahua and Sonora), and Upper Klamath Basin (Oregon and California). A discussion of these ecosystems and their vanishing fishes, amphibians, reptiles and invertebrates are provided. Protection of remaining natural habitats and communities within these areas provide the best opportunity for long-term survival of the constituent rare organisms.

Wydoski, R.S. 2005. Habitat enhancements for native Colorado River fishes. Pages 21-55 *in* Brouder, M.J., Springer, C.L., and Leon, S.C. Proceedings of two symposia: Restoring native fish to the lower Colorado River: Interactions of native and non-native fishes. July 13-14, 1999, Las Vegas, Nevada, and restoring natural function within a modified riverine environment: the lower Colorado River. July 8-9, 1998. U.S. Fish and Wildlife Service, Southwest Region, Albuquerque, New Mexico.
Notes: This paper includes the following sections: Human Alteration of Colorado River Responses of Native Fishes to Alteration of Colorado River (includes larval survival and recruitment; predation and competition by non-natives; starvation and reduced growth of larvae); importance of floodplain habitats to warmwater riverine fishes; potential habitat enhancement strategies (limitations; management of streamflow, water quality, floodplain; importance of cover to Colorado River fishes; experience with reconnection of floodplain habitats with main channels; Use of fishways (e.g. Redlands div. dam); fish screens; management of non-native fish (chemical, biological, mechanical control); fish nurseries for augmentation and restoration stocking; factors to consider in Aquatic Habitat Enhancement Projects (biological, chemical, physical, human); Application of a Systems Approach; Epilogue. Gives table of relative abundance on native vs. non-natives in upper Colorado River Basin; Appendix 1 reviews habitat use of razorbacks, pikeminnow, humpback, and bonytail by age; Appendix 2 reviews migration and movements of these 4 species.
Abstract: Yes, but not available electronically.

Young, M.K. 2001. Pheromonal attraction: the potential for selective removal of nonnative species. Page 28 *in* Shepard, B. Practical Approaches for Conserving Native Inland Fishes of the West. Sponsored by the Montana Chapter and the Western Division of the American Fisheries Society.
URL: http://www.fisheries.org/AFSmontana/Misc/Symposium%20Abstracts/Abstracts.pdf
Abstract: Introductions of non-native species are believed to be the greatest threat to the persistence and recovery of many subspecies of cutthroat trout (Young 1995). For example, brook trout *Salvelinus fontinalis* have invaded and replaced populations of cutthroat trout *Oncorhynchus clarki* regardless of habitat conditions. To maintain or restore populations of cutthroat trout to such streams, biologists often attempt to remove brook trout by using toxicants (Gresswell 1991) such as rotenone or antimycin, or by using repeated electrofishing passes (Thompson and Rahel 1996). Both techniques rarely completely eradicate the target species, even after repeated treatments, and for toxicants, concerns have been raised about its effects on water quality and nontarget species. Electrofishing has the added disincentive of being extremely labor intensive. Consequently, an alternative technique that is less arduous, less controversial, and more species-specific than either poisoning or electrofishing is needed.

A common approach to pest control in the agricultural industry is the use of pheromones to attract reproductively active individuals to traps. Pheromones are a hormonal chemical signal, often released to attract mates or synchronize mating. Salmonids also appear to release and detect pheromones that influence behavior before and during spawning (Newcombe and Hartman 1973). Consequently, I hypothesized that pheromones could be used to attract and trap brook trout to remove them from streams.

To test this hypothesis, crews deployed hoop nets in separate streams in Wyoming in September 1999 and 2000 as brook trout began to spawn. Each treatment net was seeded with a reproductively mature male or female brook trout and control nets were left empty. All nets were checked daily. Catches of reproductively mature brook trout were nonrandom ($P < 0.003$); nets seeded with reproductively mature males caught many more fish than expected by chance alone (cf. Sveinsson and Hara 1995). A limited test in 2000 with 8-10 male-seeded nets removed 25% of adult brook trout from a 1.7-km reach in 8 d.

These tests appear to confirm that brook trout use pheromonal communication, and that selectively trapping large numbers of adults is feasible. Future field and laboratory tests will explore the potential to manipulate this attraction to selectively remove brook trout from streams containing cutthroat trout. Though the technique may not immediately eliminate large populations of brook trout, it could suppress recruitment, eliminate brook trout during early stages of an invasion, or be used to assess the success of removal projects by other methods.

Because pheromonal communication seems commonplace among salmonids, exploiting this behavior may reduce threats to rare or federally listed species from invasions by nonnative salmonids without jeopardizing populations of rare species. Alternative applications include capturing rare salmonids (e.g., greenback cutthroat trout *O. c. stomias* or bull trout *S. confluentus*) when they are mature to allow biologists to more efficiently collect eggs and milt to establish particular broodstocks, or perhaps to induce mature fish to migrate to particular locations by releasing the pheromone from those sites. However, much remains to be learned about pheromonal attraction in salmonids. The identity of the behaviorally effective pheromone in most salmonid species is unknown, and patterns of attraction appear to differ between *Oncorhynchus* and *Salvelinus*.

Young, M.K., and Harig, A.L. 2001. A critique of the recovery of greenback cutthroat trout. Conservation Biology 15: 1575-1584.

Abstract: There are no examples of recovery of fish listed under the U.S. Endangered Species Act, but the number of federally threatened greenback cutthroat trout (*Oncorhynchus clarki stomias*) populations is approaching the delisting goal. We evaluated recovery of this subspecies in light of developing theory in conservation biology and with regard to recovery of other salmonids in the inland western United States. Four of the five criteria used to define populations that would count toward delisting appeared to underestimate the risk of extinction of those populations. Typically, recovery goals for numbers of greenback cutthroat trout populations were less stringent than those for other inland salmonids petitioned for listing or listed as threatened under the Endangered Species Act and were comparable to those for a federally endangered species. Before delisting is considered, we propose that historical populations be replicated in additional waters to protect genetic diversity and that existing populations be enlarged to reduce their vulnerability to demographic variation, to increase their access to refugia, and to permit reestablishment of mobile life histories. Existing stocks should also be evaluated to determine whether they represent distinct population segments.

APPENDIX B

DESERT FISHES COUNCIL PROCEEDINGS ABSTRACTS, 1984 – 2004

This compilation is the product of searching for information on barriers and renovations from presentations, abstracts, and papers given at the Desert Fishes Council Annual Meetings. We accessed the DFC website: http://www.desertfishes.org/meetings/dfc_meet_specific.html, downloaded individual annual symposia, and searched the entries for the following words or word fragments:

Barrier
Renov
Chemic
Roten
Antim
Trans
Restor
Remov
Prenfish
Fintrol
Noxfish
ocide
icide

The following pages provide only the sections of text that specifically relate to barriers, renovations, and translocations, within the geographic and context criteria described in the introduction of this report. We did not include sections that are 1) described stockings or transplants into artificially created refuges or 2) locations that do not have existing or proposed barriers or chemical renovations for non-native fish and that are known to contain numerous exotics (e.g., razorback sucker repatriation into mainstem Colorado and Verde Rivers). Nor did we include all status reports on natives that might be impacted by barriers and renovations, although we may have used this information to develop the barrier/renovation database (Tables 4 - 7). Abstracts are listed in chronological order, beginning with 1991 and ending with 2004. For each annual proceeding, abstracts are listed in alphabetical order, by first author.

Deletions within an abstract are typically noted by multiple periods, e.g., “ . . .”. We have added some clarification to abstracts; these comments are in brackets, e.g., {}.

Users can access the DFC’s main website, using the above URL, to upload the original council proceedings if they wish to locate these papers to obtain additional information, such as the author’s affiliation or to read the abstracts in their entirety.

1991 DFC ABSTRACTS

Stefferud, JA; Propst, DL; Burton, GL

USE OF ANTIMYCIN TO REMOVE RAINBOW TROUT FROM WHITE CREEK, NEW MEXICO

A major goal of recovery for the endangered Gila trout, *Oncorhynchus gilae*, is re-establishment of populations in streams within its native range. Six streams have been treated with the piscicide antimycin A to remove non-native rainbow trout*, O. mykiss*, and brown trout, *Salmo trutta*. Toxicant application and monitoring techniques have been refined with each treatment. White Creek, a tributary of West Fork Gila River, met criteria established by the Gila Trout Recovery Team for re-establishment of Gila trout but supported a population of rainbow trout. Data on the population of rainbow trout and the aquatic habitat were gathered in 1990, and used to develop the renovation plan for the stream. More than 10 km of stream above a 10-m high natural waterfall barrier were treated with antimycin A in June 1991. Post-treatment surveys are planned for summer 1992 to determine if the population of rainbow trout was removed. A second application of antimycin may be applied then. Methodologies used for survey and renovation are described.

Note: The abstract above included an entire paper with a very good detailed description of a renovation. Below are relevant excerpts from the paper:

The piscicide antimycin A in liquid form. . .has been used in six streams (Table 1) in the Gila National Forest. . .Ten treatments have been necessary to remove non-native trouts. All renovated streams have received Gila trout except White Creek. Little and Mogollon creeks supported populations of native speckled dace, *Rhinichthys osculus*, Little Creek contained native Sonora sucker, *Catostomus insignis*, and desert sucker, *Pantosteus clarki*. McKnight Creek had a population of native Rio Grande sucker, *Pantosteus plebius*, eliminated by treatment with rotenone in 1973 (Bickle, 1973). Only Little Creek retains a population of speckled dace.

Techniques used in selecting and treating a stream have been refined with each renovation and will continue to do so as we evaluate each project. Our purpose is to describe the application of antimycin A in White Creek and factors that have influenced the success of other treatments.

…A protocol has been developed for renovation project planning for recovery of Gila trout (USFWS, in prep.). Surveys are done to determine the structure of the existing population of trout, which is then used as a template to identify when the translocated Gila trout population can be considered "established." Differences in response to physical habitat by rainbow or brown trout, versus Gila trout, are considered before a determination of "establishment" is made.

The physical, chemical and biological properties of the habitat are surveyed and these data then employed to determine the potential of a stream to support Gila trout, and whether significant differences in the population structure between Gila trout and the non-native population can be expected. Habitat surveys are used to develop the renovation plan, and whether any structural changes are necessary.

. . . The upper 43 drip stations were calibrated to run for 3 h and to provide a dosage of 20 ug/L active ingredient of antimycin A. The lower 8 drip stations ran for 2 h at a concentration of 30 ug/L active ingredient. . .Backpack sprayers were used to treat small tributaries from above the uppermost drip stations to the spring sources.

. . . Post-treatment monitoring of White Creek will be done in 1992. Experience in other streams leads us to believe a second treatment, and perhaps a third, will be necessary to achieve complete removal of rainbow trout from the stream. To date, only Little Creek has been reclaimed with a single treatment.

. . . We have found that detailed planning is vital to success of a treatment. Knowledge of the physical, chemical and biological properties of the stream system to be treated is essential for solving myriad unanticipated complexities of an ordinary treatment. Stream surveys to determine the length of stream, its discharge and standing volume, location of springs, seeps and intermittent areas, annual thermal regime, species present (fall or spring spawners), community structure, location of a barrier to exclude non-native trout, access and location of camping areas must be done early so alternative treatment scenarios can be devised.

. . . We have gained most of our knowledge through experience, and while the efforts we expend in treatments may seem tedious, sometimes arbitrary and superficial, they are the result of episodes that occurred during previous treatments. We fully expect that our methods and equipment will continue to be refined with additional treatments, and that our efforts will become more streamlined as our base of knowledge expands.

1992 DFC ABSTRACTS

Heinrich, JE; Sjoberg, JC

STATUS OF NEVADA FISHES

. . .16. Moorman White River springfish, *Crenichthys baileyi thermophilus*. - This warm spring system has been invaded by largemouth bass from the Reservoir below, and fish numbers are extremely low. These bass will be removed and fish barriers improved so that this population can be protected. {Hot Creek Springs ?}

1993 DFC ABSTRACTS

Heinrich, JE; Sjoberg, JC

STATUS OF NEVADA FISHES

. . . 13. Moorman White River springfish, *Crenichthys baileyi thermophilis* - At the springfish sanctuary on Hot Creek, largemouth bass were removed in 1992, but have since re- invaded. Springfish numbers were very healthy after the bass removal, but will decline as the young invading bass begin to feed. NDOW has made plans to improve the fish barriers and remove the bass so that this population can again be protected. . .

Minckley, CO

REPORT OF THE U.S.F.W.S. PARKER FISHERY RESOURCE OFFICE

The following report presents activities of the Parker Fishery Resource Office, Parker, AZ., between 3 August 1992 to present. In most cases this office was in a support role providing assistance to the various organizations listed below.

Razorback Sucker (*Xyrauchen texanus*): During August 1992, the FRO assisted in the retrieval of razorback suckers from Yuma Cove on Lake Mohave. The recovered fish were placed in Davis Cove. During winter (November) the Parker FRO assisted with ongoing research being conducted on razorback suckers on Lake Mohave, actively netting the reservoir and again working Yuma Cove to remove fish from that facility. Subsequent to that effort, the FRO participated in rotenoning Yuma Cove to remove all fish.

Withers, D; Kanim, N; Stubbs, K; White, R

U. S. FISH AND WILDLIFE SERVICE, REGION 1, REPORT ON CONSERVATION ACTIONS UNDERTAKEN DURING 1993 FOR FEDERALLY LISTED AND CANDIDATE FISHES IN CALIFORNIA, NEVADA, AND OREGON

. . .The Service's Seattle National Fisheries Research Center has been conducting life history and habitat requirement research on the endangered White River spinedace. In 1991, the one remaining population of this species was estimated at less than 100 individuals. In June 1993, only 14 adults were observed during intensive snorkel surveys**.** Largemouth bass *Micropterus salmoides* predation restricts the remaining fish into relatively unsuitable habitat. The Service and the Nevada Department of Wildlife, who owns the spring containing the remnant population, have been working diligently to prevent the extinction of this species by installing bass barriers, removing bass, and improving habitat conditions. Although adult spinedace incidentally captured in 1993 exhibited spawning conditions, no recruitment has been documented. Due to the few numbers of fish remaining and the recent efforts to improve habitat conditions, the decision was made to leave the fish in their native ecosystem versus placing them in captivity. However, that decision will be revisited in the spring of 1994. . .

1994 DFC ABSTRACTS

Minckley, CO

SUMMARY OF ARIZONA FISHERY RESOURCE OFFICE ACTIVITIES, 1994

The following is a summary of 1994 activities for the three Arizona Fishery Resource Offices. Additional activities for AESO and Fish Health are anticipated but had not been received prior to the development of this summary. They will be presented if received.

PINETOP OFFICE - During June, approximately five miles of Ord Creek, on the Fort Apache Indian Reservation were renovated to remove brook trout and to prepare the stream for introduction of pure Apache trout. This was conducted by the AZFRO staff, members of the White Mountain Apache Game and Fish Department, YCC members and volunteers. Additionally, the staff of the Pinetop Fish Health Center conducted disease surveys on the creek during the renovation. Currently, electroshocking surveys are assessing the success of the renovation.

This summer fish migration barriers were constructed on Big Bonito and Squaw Creek by the YCC crew and volunteers of the White Mountain Apache Tribe. Work was also started on a fish migration barrier on Flash Creek, and minor repairs were made to barriers on Paradise and Ord Creeks. . .

Propst, DL
NATIVE FISH RESEARCH AND MANAGEMENT IN NEW MEXICO DURING 1993 AND 1994

. . .During 1993-1994, White Creek was renovated and stocked with Gila trout, *Oncorhynchus gilae*, fertilized eggs were obtained from McKnight Creek for development of a brood stock to aid recovery efforts, Gila trout were re-established in Main Diamond Creek (type locality), several streams inventoried to assess suitability for renovation, eight populations monitored, and 150 individuals evacuated from Spruce Creek during a wildfire which threatened the population. Local opposition to several planned recovery activities forced postponement of needed actions. Status of Gila trout has improved since 1989, when proposed downlisting was postponed because natural events severely reduced two wild populations and eliminated another, to the point that downlisting may be soon recommended.

1995 DFC ABSTRACTS

Heinrich, JE; Sjoberg, JC
RECOVERY EFFORTS FOR THE WHITE RIVER SPINEDACE

The White River spinedace, *Lepidomeda albivallis*, is endemic to the White River Valley, the headwaters of the Pluvial White River. This spinedace historically occurred from mountain streams, such as Ellison Creek, to valley-floor meadows and springs such as Sunnyside Creek. In 1985, the White River spinedace was federally listed as Endangered primarily because surveys indicated that only two small spring systems contained this now rare fish. Follow-up studies in 1992 indicated that distribution was reduced to a single location and was further restricted to only 2 headwater pools.

Since habitats and numbers of spinedace were so restricted, a limited number of alternatives were available to fisheries managers to enhance recovery. Any recovery or research activities required little to no handling of remaining fish. Managers undertook a variety of activities to improve habitats and encourage recruitment. Habitats that once contained spinedace were rehabilitated in a number of ways including: native and nonnative fish removal, physical stream reconstruction, removal of man-made control structures, substrate modification, and vegetation control. In addition, other measures were completed to protect the remaining population of spinedace, including: fish barrier modification and construction, protective netting installed on the main springhead to prevent bird predation, and periodic dive surveys to monitor and remove downstream predators. To date, no indication of recruitment has occurred along this short section of North Flag Spring. At this time the entire population of White River spinedace may be as low as 25 individuals.

Kitcheyan, DC; Maughan, OE; Leon, SC; Landye, JJ; Major, RD
THE GROWTH AND SURVIVAL OF APACHE TROUT FOLLOWING STREAM REHABILITATION TO REMOVE BROWN TROUT

The historic distribution of the Apache trout *Oncorhynchus apache* includes the White Mountains on the Fort Apache Indian Reservation and the Apache-Sitgreaves National Forest. Physical modifications of habitat, interspecific competition with brown trout Salmo trutta and brook trout Salvelinus fontinalis and hybridization with rainbow trout *Oncorhynchus mykiss* have reduced historic distribution to a fraction of that area. Land management agencies on the reservation attempted to increase available habitat and decrease the potential for interspecific competition.

In 1994 Apache trout had nearly disappeared from the Big Bonito drainage of the Fort Apache Indian Reservation. On June 28, 1995 the last known pure stock of Apache trout in the Big Bonito drainage was located in the extreme upper reaches of Flash Creek. To restore Apache trout to the Big Bonito Drainage, Flash and Squaw creeks were renovated with antimycin to remove all brown trout. To ensure a complete kill, a bioassay was performed at 4-25 meter intervals with 3 to 5 fish placed in live wells. The purpose of bioassay was to determine if the concentration of antimycin used would kill all brown trout. Brown trout were also collected for viral and bacterial samples and to identify stomach contents and parasite loads.

Prior to renovation, benthos were collected with a surber sampler. They will continue to be collected following renovation to determine the rate of benthos recovery in these streams. Re-introduced Apache trout will be dispersed throughout the rehabilitated streams and population levels periodically estimated based on mark-recapture, catch per unit effort, or per unit area. Habitat use will be determined by capture and visual observation and measurements of physical characteristics including water depth, water velocity, substrate type, and cover. Habitat availability at the time of sampling will be estimated along transects in the capture area.

1996 DFC ABSTRACTS

Hobbes, AL

REGIONAL REPORT OF ACTIVITIES PERTAINING TO NATIVE FISH IN NEW MEXICO, 1996

. . .Activities for Gila trout, *Oncorhynchus gilae*, included status inventories of several populations, initiation of a population viability analysis study, and renovation of the Mogollon Creek drainage where wildfire had already eliminated a large number of fish in 1994 and 1995.. .

Minckley, CO

STATUS OF NATIVE FISHES IN THE LOWER COLORADO RIVER BASIN AND AN OVERVIEW OF FISH AND WILDLIFE ACTIVITIES IN REGION II, 1996

. . .Arizona Fishery Resource Office: Pinetop Office: Renovation of designated streams and partial reintroduction of Apache trout into those systems was accomplished. Habitat restoration of Bylas Spring (S2 Spring) on the San Carlos Apache Reservation and reintroduction of Gila topminnow was completed.

. . .San Carlos Substation: Participated in razorback sucker studies on Lake Mohave, was a major participant in the Bylas Spring renovation and assisted Pinetop with work on Apache trout (*Oncorhynchus apache*) and loach minnow (*Rhinichthys cobitis*).

1997 DFC ABSTRACTS

Clarkson, RW

ELECTRICAL AND PHYSICAL BARRIERS TO PREVENT UPSTREAM MOVEMENTS OF FISHES: RECLAMATION'S EXPERIENCE IN THE GILA RIVER BASIN, ARIZONA

As partial mitigation for impacts to native fishes from transport of Central Arizona Project water from the Colorado River to the Gila River Basin, Arizona and New Mexico, Reclamation has emplaced several electrical barriers and is attempting to construct several concrete drop barriers to prevent upstream movements of invading non-native fishes. What possibly could go wrong with electrical barriers has gone wrong, but tightened monitoring and back-up procedures have reduced barrier failure rates. Accumulating evidence suggests, however, that fishes are able to transgress electrical barriers during periods of flow recession. Without condemnation authority, and despite three years of trying, Reclamation has been unable to locate an acceptable site for a drop barrier on private property because of landowner concerns. We expect that sites on public land, although less geomorphically suitable, will receive less resistance from the pubic. The functional philosophy behind drop barriers, and some potential design concepts are discussed.

Fridell, R; Lentsch, LD; Jensen, MS

USE OF FISH BARRIERS IN RECOVERY PROGRAMS FOR ENDANGERED VIRGIN RIVER FISHES IN UTAH

Virgin River fishes have declined due to cumulative impacts including proliferation of non-native red shiner, de-watering from diversion projects, and alteration of natural flow, temperature and sediment regimes. A multiple agency cooperative effort has been established to formulate and implement a recovery program for the Virgin River Basin in Utah. A major goal of the recovery program is the eradication of non-native fish. A stepwise approach is being implemented on a reach by reach basis to eliminate competition between red shiners and native fish. Fish barriers are being used in concert with chemical treatment projects to eradicate red shiners from the Virgin River mainstem and tributaries. Currently, there are three existing barriers on the Virgin River mainstem, one under construction on Ft. Pierce Wash, and two planned on drains to the Washington Fields agricultural area. We will discuss the design, success, and current status of fish barriers associated with the red shiner eradication program.

Propst, DL

NATIVE FISH RESEARCH AND MANAGEMENT IN NEW MEXICO DURING 1997

. . .Renovation of Mogollon Creek was completed during 1997 and about 1,000 Age-0 Gila trout were stocked into the stream. After three stockings, the Gila trout population in Main Diamond Creek (type locality) appears to be re-establishing. A cooperative agreement among natural resource agencies, New Mexico Trout, and Mesilla Valley Flyfishers to construct a waterfall barrier on Black Canyon was signed. This barrier will protect about 15 km of stream for Gila trout. . .

Smith, D

ELECTRIC FISH BARRIERS

Electric barriers are a valuable tool in the arsenal for controlling fish movement. Smith-Root has developed an effective design which is in use in at least 25 locations around the United States. Four of those are in Arizona and guard connections between the Central Arizona Project aqueduct and canals of other water projects to prevent movement of fish from the aqueduct into those canals and then on into the surface waters of the Gila River basin. Others are in use to control movement of anadromous fishes into rearing facilities and to prevent fish from becoming entrained in water intakes for various human facilities.

Effective operation and maintenance are important in the use of electric barriers. Standard operating procedures have been developed for each barrier, tailored to the specific situation and use. These procedures include regular inspections and repair, backup systems, and emergency procedures for notification and response if outages occur.

Stefferud, JA

FISH BARRIERS AS A MANAGEMENT TOOL: CONSERVATION OF SOUTHWESTERN TROUTS

The status and distribution of three trouts native to Arizona and New Mexico (Rio Grande cutthroat trout, *Oncorhynchus clarki virginalis*, Gila trout, *Oncorhynchus gilae*, and Apache trout, *Oncorhynchus apache*) has declined during the past century due to invasion by non-native trouts (brown trout, *Salmo trutta*, cutthroat trout, *Oncorhynchus clarki*, and rainbow trout, *Oncorhynchus mykiss*). Pure populations of native trout survived only where natural barriers prevented upstream invasion by non-native trouts, and where non-native trouts weren't stocked. Efforts by management agencies to prevent further spread of the non-native trouts into extant or reclaimed habitats of the native species usually require locating natural barriers or constructing new barriers to upstream migration. During the past few decades more than 25 barriers have been constructed to protect populations of the native trouts in southwestern streams.

Natural waterfall barriers provide the best protection for trout populations. They typically have substantial height, are in generally inaccessible locations, and are unlikely to be washed out during floods. Extended dry reaches that flow water only during exceptional runoff, and then into non-trout-bearing waters are also effective barriers. Of constructed barriers, most have been of rock-masonry or gabion basket construction to provide a waterfall two to three meters high. By necessity, most are in accessible areas and thus subject to anglers moving non-native trouts above them, and many have been damaged during runoff or became ineffective due to the changes they induced in stream channel morphology. Knowledge and consideration of the stream's hydrologic and geomorphologic characteristics is necessary for proper site selection, design, and construction of an effective barrier.

Use of fish barriers to isolate selected populations of native trout from invasion by other competing trouts is an effective tool for sustaining species, at least in the short-term. In the long-term, however, extra efforts may be required to ensure genetic integrity of those species. By necessity, early management efforts focused on sustaining these species through isolation in numerous small headwater populations where security was good, but where external events could have catastrophic consequences on habitat and populations. Use of protective barriers segregated the target species in an array of non-connected and fragmented habitats spread across the landscape, thus blocking potadromy and natural interchange of genetic material. Current management emphasis is moving towards protection of complete drainages with multiple tributaries in order to prevent localized extinction of ecologically-significant units by natural events. This will also allow for at least limited gene flow within the stream hierarchy, thus decreasing potential for local population divergence. In the arid southwest, the number of hydrologically-complex drainages available for conversion to native trout waters is limited by topography, climate, and human-induced factors. Monitoring and human intervention to ensure genetic integrity of the species will remain an important part of their conservation and management.

Stein, JR; Heinrich, JE; Sjoberg, JC; Martinez, C; Werdon, SJ; Byers, S; St. George, D

SOUTHERN NEVADA ECO-REGION REPORT

. . .Quarterly Pahranagat roundtail chub, *Gila robusta jordani*, counts were initiated on the River Ranch in November 1996. The initial results show a wide population flux at the survey site. The lowest count was 141 chub in

January 1997. The highest count was 811 chub in August 1997. The majority of the juvenile chub leave the system between November and December. The January survey showed adult chub sequestered to cold water inflow areas and below a barrier in the system.

. . .There are current negotiations for a formal agreement with the representatives of the River Ranch for a type of habitat conservation agreement. The agreement focuses on the removal of the barrier in the system, replacing it with another structure and creating off-site water for livestock.

. . .The remainder of Sunnyside Creek was chemically treated to remove largemouth bass. Two hundred bass were killed. The portion of Sunnyside Creek which was treated is found immediately below the currently occupied White River spinedace habitat at the Flag Springs complex.

The White River springfish found at Hot Creek, *Crenichthys baileyi thermophilis*, have responded to the largemouth bass removal efforts, and the population is estimated to be at least 50,000 fish. Four largemouth bass were removed below the dike barrier that was constructed in 1995. Springfish and juvenile bullfrogs were found during stomach content analysis.

. . .Muddy River 1997 surveys in the Warm Springs area indicate that roundtail chub, *Gila seminuda*, numbers are down substantially. This decrease can be attributed to the removal of a power diversion dam and the resulting encroachment of blue tilapia, *Tilapia aurea*, into upstream waters. Numbers of Moapa dace, *Moapa coriacea*, have also declined. The populations of Moapa White River springfish, *Crenichthys baileyi moapae*, are steady. Surveys in 1996 of the Moapa speckled dace, *Rhinichthys osculus moapae*, estimated 6,800 fish over their seven miles of distribution. Initial plans have been made for chemical eradication of the blue tilapia in the Muddy River. . .

1998 DFC ABSTRACTS

Propst, D; McCarthy, P; Brooks, J; Platania, S

NATIVE FISH RESEARCH AND MANAGEMENT IN NEW MEXICO DURING 1998

Research and management of native fishes in New Mexico during 1998 was focused on the Rio Grande, Pecos, Gila, Mimbres, and San Juan (reported in Upper Colorado basin summary) basins. In the Gila River drainage, the gabion waterfall barrier on Black Canyon was completed as a cooperative effort by the U. S. Forest Service, U. S. Fish and Wildlife Service, and New Mexico Department of Game and Fish, with volunteers from New Mexico Trout, Sierra Club, Mesilla Valley Flyfishers, and Gila Watch. Illegally stocked non-native trout (*Oncorhynchus mykiss*, *O. clarki virginalis*, and *Salmo trutta*) were found in Black Canyon above the waterfall barrier. Multiple electrofishing passes were required to remove non-native trouts and 15km of stream were stocked with Gila trout (*O. gilae*) in early November. Secretary of Interior, Bruce Babbitt, participated in the Black Canyon stocking effort. Autumn monitoring of fish communities at eight sites in the Gila-San Francisco drainage indicated a slight increase in abundance of native fishes (including *Meda fulgida* and *Tiaroga cobitis*) over that found in 1997. The Nature Conservancy's Gila River property was fenced to preclude livestock and ORV trespass. . .

Stefferud, JA; Young, KL; Clarkson, RW; Minckley, CO; Simms, JR; Sillas, A

LOWER COLORADO RIVER AREA REPORT

. . .ARIZONA GAME AND FISH DEPARTMENT (AGFD) NATIVE FISH ACTIVITIES

. . .4) Aravaipa Creek -- Low to moderate numbers of the nonnative red shiner, *Cyprinella lutrensis*, have been present in Aravaipa Creek since November 1997. Resultant activities include development of sampling protocol and intensive red shiner monitoring; establishing an upstream (temporary barrier); and supporting Bureau of Reclamation (BoR) in construction of a downstream permanent barrier.

BUREAU OF RECLAMATION PHOENIX AREA OFFICE NATIVE FISH ACTIVITIES

. . . 2. Maintained operation of electrical fish barriers on the Salt River Project (SRP) and Florence-Casa Grande (FCG) canals, and investigated emplacement of concrete drop barriers on Aravaipa Creek and San Pedro River, to prevent upstream invasions by nonnative fishes.

BUREAU OF LAND MANAGEMENT (BLM) NATIVE FISH ACTIVITIES

. . .4. Aravaipa Creek appears to have established populations of red shiner, yellow bullhead, *Ameiurus natalis*, and green sunfish, *Lepomis cyanellus*. The native fish community is at risk of being over-run by nonnatives. As a result BLM has begun coordinating with other agencies to address the issue.

Stein, JR.; Heinrich, JE.; Hobbs, BM.; St. George, D

SOUTHERN NEVADA ECO-REGION REPORT

. . .In the Muddy River system, just as in 1997, 1998 surveys in the Warm Springs area found very few Virgin chub, *Gila seminuda*. Numbers of Moapa dace, *Moapa coriacea*, and Moapa White River springfish, *Crenichthys baileyi moapae*, appear to still be satisfactory considering the high numbers of blue tilapia that have invaded the system. The Apcar tributary, a past stronghold for Moapa dace, was scheduled for rotenone treatment in May 1998, but high numbers of spawning adults moving up the tributary delayed the treatment until October 1998. A barrier was placed on a portion of the Apcar reach which prevents the further upstream movement of the tilapia.

1999 DFC ABSTRACTS

Brooks, JE; Propst, DL

A NEW OBSTACLE TO RECOVERY OF GILA TROUT: UNAUTHORIZED STOCKING OF NON-NATIVE SALMONIDS

The Gila trout, *Oncorhynchus gilae*, is a rare salmonid restricted to headwaters of the Gila River basin of southwestern New Mexico and classified as endangered under the Endangered Species Act, as amended, and as threatened by the State of New Mexico. Formerly, this species was widespread in streams of the upper Gila River and further west in the Verde River drainage of Arizona. In the past, stocking of non-native rainbow, cutthroat, and brown trouts contributed to the elimination of many populations through hybridization and competitive and predative interactions. Concomitantly, suppression of wildfire within forested areas of the watershed during the last 100 years created high fuel-loading situations resulting in catastrophic fire impacts that rendered affected streams uninhabitable by fishes. Recovery efforts for Gila trout since the early 1970s have centered around removal of non-native salmonids from selected streams above natural or manmade physical barriers and restocking with Gila trout. Gila trout was proposed for downlisting from endangered to threatened in 1987; the proposal was withdrawn in 1989 after catastrophic fire eliminated two relict populations. Since that time, public opposition to recovery efforts has increased and slowed stream renovations through implementation of the National Environmental Policy Act. The use of antimycin, a piscicide, has been the focal point of public opposition and recent recovery actions have attempted to use fishless streams that do not require removal of nonnative salmonids. Black Canyon, tributary to the East Fork Gila River, formerly supported populations of rainbow and brown trouts. Stream habitat degradation related to historic grazing practices and wildfire in 1995 and 1996 eliminated these non-natives, as confirmed by stream surveys during 1996 and 1997. A gabion barrier was constructed on Black Canyon during June 1998, with the planned stocking of Gila trout to occur in October 1998. Final stream surveys during late June 1998 to confirm absence of non-native salmonids resulted in the collection of four brown trout, 70-74 mm TL, and one rainbow trout, 225 mm TL. Subsequent extensive efforts sampled the entire upper Black Canyon drainage to ascertain the extent of non-native salmonid distribution and abundance and to attempt complete mechanical removal. A total electrofishing effort of 4531.2 minutes resulted in the collection of 376 non-native trout for a combined catch per unit effort of 0.08 fish per minute. We collected 345 young-of year or Age I brown trout, 24 adult rainbow trout, and 7 adult cutthroat trout. The absence of adult brown trout and young-of-year or juvenile rainbow and cutthroat trouts, the absence of non-native trout during 1996-1997 sampling, and scale analysis of captured brown trout support our contentions of unauthorized introductions of non-native salmonids in 1998. Elsewhere, a population in Mogollon Creek was established after stream renovation and restocking with hatchery-reared Gila trout. Subsequent genetic analyses indicated that rainbow trout had been introduced into the upper portion of this stream on two separate occasions, providing additional evidence for unauthorized stockings. Illegal stocking of non-native salmonids presents a serious challenge to conservation efforts for Gila trout. Although improved public relations may help, increased law enforcement efforts and presence are necessary to diminish the threat to extant populations of Gila trout.

Coleman, SM; Minckley, WL

MANAGEMENT OF YAQUI CHUB AND LONGFIN DACE IN WEST TURKEY CREEK, ARIZONA

A habitat conservation plan (HCP) was formalized in 1998 for endangered Yaqui chub, *Gila purpurea*, and a unique form of longfin dace, *Agosia chrysogaster*, in West Turkey Creek, AZ. Major threats to Yaqui chub survival came from non-native fishes, mostly fathead minnow, which appeared to eliminate chub recruitment within a year. The system was renovated in 1999. Native fishes were removed, retained, then repatriated successfully, as judged by reproduction a few weeks after reintroduction. Details of the HCP process and problems encountered with renovations are presented. Among the latter were a lack of recognition of habitat heterogeneity which resulted in failure of two renovations, mistakes in sorting native from non-native fishes held for restocking, and uncontrollable climatic factors (monsoonal rains of unusual severity).

Stein, JR; Heinrich, JE; Hobbs, BM; Sjoberg, JC
NATIVE FISH AND AMPHIBIAN MANAGEMENT IN SOUTHERN NEVADA

. . .In the Muddy River system, Moapa dace, *Moapa coriacea*, continue to show declines due to the invasion of blue tilapia. Management has focused on eradication of these exotics from portions of the system. The Apcar tributary was successfully treated with rotenone in December 1998. With assistance from The Nature Conservancy, 99 Moapa dace have been repatriated into the tributary. A temporary barrier placed at the site has functioned properly, and with funding from the Bureau of Reclamation, a more permanent structure will be constructed. There has also been considerable concern for the population of Virgin chub, *Gila seminuda*, found in the Muddy River. The population declined dramatically, suspected to be also caused from the tilapia invasion. Currently, ponds at a coal-fired generating plant operated by Nevada Power are being evaluated as a potential refugium {Reid/Gardner}. . .

2000 DFC ABSTRACTS

Brooks, J; Propst, D; Dudley, R; Hoagstrom, C; Monzingo, J; Platania, S; Smith, J
NATIVE FISH RESEARCH AND MANAGEMENT IN NEW MEXICO DURING 2000

. . .Activities in the Gila River Basin centered around conservation efforts for Gila trout, *Oncorhynchus gilae*, and monitoring of spikedace, *Meda fulgida*, and loach minnow, *Tiaroga* [=*Rhinichthys*] *cobitis*, populations. Gila trout activities included the successful renovation of White Creek to remove hybrid trout for restocking during October 2000, introduction of hatchery-reared Gila trout into lower Little Creek, transplantation and spawning of Gila trout from Whiskey Creek for introductions into upper Little Creek, transplantation and spawning of wild Gila trout from Spruce Creek for introduction into Dude Creek (Arizona), monitoring and stocking of Black Canyon, and documentation of successful spawning of Gila trout in Mogollon and South Diamond creeks.

Phelps, J; Wald, M; Unmack, PJ
WINTER REPRODUCTION OF INTRODUCED POECILIIDS IN WARM SPRINGS

Numerous poeciliid fishes have been introduced into warm springs in the western United States, a novel environment due to their constant warm temperatures. This provides an ideal situation for testing of hypotheses relating to factors influencing reproduction, e.g., changes in photoperiod versus seasonal temperature variation. Unfortunately, these introductions have also resulted in declines of native species, and the only real option for controlling exotics is removal, usually achieved via ichthyocide application. Removal is more likely to succeed when populations are at their lowest level and/or non-reproductive, since young can inhabit the extreme shallow margins and avoid poisoning. We sampled multiple populations of exotic poeciliids: *Gambusia affinis*, *Poecilia mexicana*, *P. latipinnis*, and *P. reticulata*, autumn through spring, to test if reproduction was occurring based on the presence of developing embryos. Principal sites included springs in Ash Meadows, and Rogers Spring (Lake Mead), both in Nevada, and Watson Wash, Arizona. Single samples were obtained from an additional seven springs. In all species, winter reproductive output was lower than in spring and varied among localities at the same time of year. All guppy populations were reproductive through winter, while the remaining species had some populations which were non-reproductive, and others reproducing only at relatively low levels. These results demonstrate considerable variation, even between geographically proximate springs with similar habitat parameters. If eradication efforts were to be attempted and one were concerned about juvenile survival, January would be the most appropriate time to treat a spring. Reproductive potential would be lowest and marginal habitats coldest (at least at night), hence more likely avoided by juvenile poeciliids.

Ruiz, LR; Gatewood, T; Novy, JR; Young, K; Ward, J
RECOVERY STATUS OF THE APACHE TROUT, *ONCORHYNCHUS APACHE*

Listed as endangered in 1973 and downlisted in 1974 to threatened, the Apache trout, *Oncorhynchus apache*, is one of three trouts native to the southwestern United States. Historically, the trout was distributed throughout the headwaters and tributaries of the Salt and Little Colorado rivers and extant populations are now protected by natural barriers in headwater reaches of streams that originate in the White Mountains of Arizona. The U.S. Fish and Wildlife Service, U.S. Forest Service, Arizona Game and Fish Department, and the White Mountain Apache Tribe cooperatively lead the recovery efforts of the Apache trout, including the following activities: 1) surveys and inventories of Apache trout in historical habitats; 2) analytical techniques that allow for verification of genetic purity; 3) construction of artificial barriers to prevent upstream migration of nonnative salmonids, thus impeding potential hybridization with rainbow trout, *O. mykiss*, and cutthroat trout, *O. clarkii*, and competition with and predation by brown trout, *Salmo trutta*, and brook trout, *Salvelinus fontinalis*; 4) renovation to remove hybridized and non-native salmonids from historical habitats; 5) replication of pure Apache trout populations into renovated habitats; 6) hatchery propagation of Apache trout; and, 7) education and outreach programs.

Schleusner, C
RENOVATION AND HABITAT RESTORATION FOR GILA TOPMINNOW, *POECILIOPSIS O. OCCIDENTALIS*, IN THE BYLAS SPRINGS COMPLEX

Bylas Springs is a complex of three springs located in the floodplain of the Gila River, approximately one mile north of Bylas, AZ, on the San Carlos Apache Indian Reservation. Springs S1, S2 and S3 were found to contain natural populations of Gila topminnow in 1968. Flooding in 1980 connected the springs with the Gila River and allowed the invasion of western mosquitofish, *Gambusia affinis*, into S1 and S3. Habitat alterations reduced the surface flow in S2, resulting in the loss of that population of Gila topminnow. Subsequent renovations and barrier construction failed to permanently remove mosquitofish from the springs, and by 1996 only a few Gila topminnow persisted in a small pool in S1. From 1996-2000 the U.S. Fish & Wildlife Service Arizona Fisheries Resources Office (AZFRO) planned and executed the successful renovations of S1, S2 and S3. The renovations included barrier construction, riparian rehabilitation and reintroduction of Gila topminnow into the springs. Cooperators included AZFRO, Arizona Ecological Services, San Bernardino National Wildlife Refuge, the San Carlos Apache Tribe, Arizona State University, Arizona Game and Fish Department, San Carlos Environmental Protection Agency, and the Monsanto Company.

Stefferud, J; Bettaso, R; Minckley, C; Stefferud, S; Clarkson, R; Tibbitts, T; Myers, T; Rinne, J
LOWER COLORADO RIVER AREA REPORT

Researchers and managers concerned with native fisheries in the Lower Colorado River Basin in Arizona (including the Little Colorado, Virgin, Bill Williams, and Gila rivers) were contacted to provide brief summaries of their activities on native fishes during the past year. Following is a summary of their responses.

Apache trout, *Oncorhynchus gilae apache*. Arizona Fisheries Resources Office (AZFRO)-Pinetop: Sections of two streams were renovated on the Fort Apache Indian Reservation for Apache trout. Population surveys are underway for all Apache trout populations. Repairs to the gabion barriers on Paradise and Ord creeks were conducted.

. . .Gila chub, *Gila intermedia*. AZGFD, NFS-Coronado: Sabino Canyon, northeast of Tucson, was renovated to remove nonnative green sunfish, *Lepomis cyanellus*, and western mosquitofish, *Gambusia affinis*. {Renovation was in 1999}. Gila chub are present higher in the drainage and have begun to naturally recolonize the renovated waters. NFS-Coronado: Plans are ongoing to modify into barriers two bridges downstream of the main barrier to discourage upstream reinvasion of the nonnative fishes.

. . .Gila topminnow [Sonoran topminnow], *Poeciliopsis occidentalis*. AZFRO-San Carlos: In spring 2000, began work on the renovation of the third and final spring in the Bylas Springs complex, S1. Following barrier modifications and removal of introduced riparian vegetation, the spring was successfully renovated with the cooperation of the San Carlos Apache Tribe, AZGFD, Bureau of Indian Affairs, Environmental Protection Agency, and AZESO. Gila topminnow from the original S1 stock are scheduled to be released into S1 in the fall of 2000. Springs S2 and S3 were successfully renovated and restocked in 1996 and 1998, respectively. BLM: In September, Gila topminnow were stocked into Lousy Canyon in the Agua Fria drainage. This stream is already the site of a restoration stocking of Gila chub. This is the first new Gila topminnow population started in the wild since 1993. AZGFD: Fifteen localities were monitored for presence of natural Gila topminnow populations. Only ten of the locations continue to support topminnow: Bylas Spring, Middle (or "MZ") Spring, Salt Creek, Redrock Canyon below Cott Tank, Sonoita Creek below Patagonia Lake Dam, Monkey Spring, Fresno Canyon, Cottonwood Spring, Santa Cruz River (at Chavez Siding and Santa Gertrudis roads), and a tributary to Sonoita Creek east of Fresno Canyon. No topminnow were collected from Sheehy Spring, Santa Cruz River above the Mexican border, Sonoita Creek through the The Nature Conservancy Preserve, and most notably, none were collected from Redrock Canyon at the Falls or from Sharp Spring. Nine monitoring events were conducted at localities supporting reintroduced Gila topminnow populations. Kayler Spring failed to produce Gila topminnow for the second time in eight years. Two captive populations of Gila topminnow and desert pupfish were also surveyed. The Hassayampa River Preserve no longer supports Gila topminnow or desert pupfish, but Acacia Elementary School does support a small topminnow population.

. . .General. . . BR-Phoenix: A $2.7M contract to construct fish barriers on Aravaipa Creek has been awarded and construction should be completed before Christmas. Plans for similar fish barriers on San Pedro and Santa Cruz rivers are progressing. A comprehensive statistical power analysis of Reclamation's long-term monitoring program to detect non-native fish invasions was recently completed, and monitoring protocol are being adjusted accordingly. The fourth annual transfer of $500K to USFWS for native fish conservation and non-native fish eradication projects was finalized. BR-Phoenix has been involved with funding of several native fish research projects, and has undertaken engineering analyses of various other fish barrier and artificial stream construction projects.

Stefferud, SE; Marsh, PC; Clarkson, RW

MANAGING NONNATIVE AQUATIC SPECIES IMPACTS: IMPLEMENTATION OF THE 1994 CENTRAL ARIZONA PROJECT BIOLOGICAL OPINION

In 1994, a biological opinion was issued by the U.S. Fish and Wildlife Service (USFWS) finding that the Central Arizona Project (CAP) has the potential to introduce and spread nonnative aquatic species in the Gila River basin in Arizona, and thus jeopardize the continued existence of the federally-listed spikedace, *Meda fulgida*, loach minnow, *Tiaroga* [*Rhinichthys*] *cobitis*, Gila topminnow, *Poeciliopsis occidentalis*, and razorback sucker, *Xyrauchen texanus*. To remove jeopardy, the Bureau of Reclamation was charged with a five-part program, including constructing physical barriers on Aravaipa Creek and San Pedro River, monitoring, information and education, providing funding for management against aquatic nonnatives, and providing funding for other recovery actions for the four listed fishes. Unfortunately, opinion implementation has met many roadblocks, including political lobbying to block funding and lawsuits seeking to overturn the opinion. However, the battle for acceptance that a problem with CAP and nonnatives exists, and that resources must be brought to bear on it, is winding down and we are moving forward in the on-the-ground battle to reduce nonnative/native conflicts to a level allowing survival, and hopefully recovery, of Gila basin native fishes. The "umbrella" approach taken by the 1994 opinion attempts to deal with the nonnative issue on a basin-wide basis, although physical barriers are focused at the bottom of the important native fish habitats. This approach is now being extended into the Santa Cruz subbasin, and USFWS and Arizona Department of Game and Fish are considering whether a similar "umbrella" approach is appropriate for dealing with effects to native fishes from sport fish stockings. There are a number of controversial aspects of the CAP "umbrella" approach. The underlying analysis is "big picture", where the potential for nonnatives to move throughout systems is assessed on a multi-decade basis, with consideration of future changes in weather patterns and human water and land uses. Some believe this is too speculative, resulting in overly negative conclusions. Reliance on a "last-ditch" stand at barriers just below native fish habitats rather than removing problem nonnatives near their point of incursion, is considered risky by some. Difficulty in detecting rare species during monitoring is a drawback in early identification of new incursions of nonnatives or increases in abundance. The emphasis on controlling threats from nonnative fishes may be short-sighted in light of recent aquatic invertebrate, disease, and plant invasions. And, use of mitigation concepts where recovery actions are substituted for removal of threats is controversial, although in keeping with trends in the FWS. The success of the CAP approach cannot be judged this early in implementation; but, whether or not it works overall, substantial numbers of recovery actions are underway that would not have happened without the 1994 opinion. Many of those are discussed in a separate presentation.

Stein, JR; Heinrich, JE; Sjoberg, JF; Hobbs, BM; St. George, D

NATIVE FISH AND AMPHIBIAN MANAGEMENT IN SOUTHERN NEVADA

. . .During a survey in March-April 2000 at the Muddy River, 940 Moapa dace, *Moapa coriacea*, were counted. This is similar to numbers in the reaches surveyed in 1999. Muddy Spring, the main stem of the Muddy River, and Plummer Springs were not surveyed. The management focus on the Muddy River has been the eradication of blue tilapia. Rotenone treatments have been successful at the Apcar tributary and the refuge springs. A permanent barrier was constructed in July 2000 to prevent upstream movement of tilapia into these treated segments. Virgin chub, *Gila seminuda*, Moapa speckled dace, *Rhinichthys osculus moapae*, and Moapa White River springfish, *Crenichthys baileyi moapae*, have also been negatively impacted by the tilapia. . .

2001 DFC ABSTRACTS

Blasius, HB

CHEMICAL REMOVAL OF GREEN SUNFISH, *LEPOMIS CYANELLUS*, FROM SABINO CREEK, ARIZONA

In Sabino Creek, near Tucson, the nonnative green sunfish threatened the continued existence of the Gila chub, *Gila intermedia,* population. Gila chub and green sunfish co-occurred in about 1.5 miles of downstream reaches. Studies found Gila chub densities to be 90% lower in downstream reaches where green sunfish occurred compared to upstream reaches where the latter was absent. Additionally, Gila chubs of less than 4.0 cm total length were absent in areas where green sunfish occurred. Green sunfish is currently prevented from moving upstream by a large rock barrier (Bridge 9). However, green sunfish has successfully moved over similar barriers downstream from that bridge either during high flows and/or from translocation by humans. To prevent green sunfish from moving above Bridge 9 and potentially extirpating one of the few remaining populations of Gila chub, the Arizona Game and Fish Department and the Coronado National Forest chemically treated Sabino Creek in the summer of 1999 to remove green sunfish. The renovation resulted in 100% removal, and Gila chub is now successfully recolonizing lower Sabino Creek.

Cook, AE; Martinez, CT; Clemmer, G; Goochild, S; Heinrich, JE; Scoppettone, GG; Sevon, M; St George, D

NEVADA AREA REPORT

Overview of desert fishes and amphibian research and management in Nevada:

. . .Muddy River: Moapa dace, *Moapa coriacea*, numbers remain depressed below 1,000 individuals because of impacts from blue tilapia, *Oreochromis aurea*. Virgin chub, *Gila seminuda*, populations also remain low but stable over the past three years, with most occurring in the middle reach of the Muddy River. Chub population demographics also have remained the same, with signs of successful recruitment. The U.S.Geological Survey-Biological Resources Division (USGS-BRD) Reno Field Station is studying interactions between Muddy River native fishes and the nonnative tilapia to determine the best method to control or manage this invasive species. Moapa White River springfish, *Crenichthys baileyi moapae*, was re-introduced into Cardy-Lamb Spring after tilapia were successfully eradicated using rotenone. Tilapia removal efforts are ongoing.

Golden, ME; Holden, PB; Heinrich, J

EFFECT OF MECHANICAL REMOVAL OF NONNATIVE RED SHINER, *CYPRINELLA LUTRENSIS*, ON REESTABLISHMENT OF ENDANGERED WOUNDFIN, *PLAGOPTERUS ARGENTISSIMUS*, IN THE VIRGIN RIVER, NEVADA AND ARIZONA

Red shiner, *Cyprinella lutrensis*, invaded the Virgin River in Arizona and Utah in the mid-1980s at the same time that the endangered woundfin, *Plagopterus argentissimus*, declined dramatically. This prompted the recovery strategy for woundfin to shift from that of habitat improvement to one of red shiner removal using toxicants followed by stocking of hatchery-reared woundfin. Poisoning of sections of the Virgin River in Utah was initiated in 1988, and, although numerous attempts to poison red shiner have occurred since then, they remain common in the Utah portion of the river. Lack of success with the primary recovery actions have lead some researchers to conclude that we may need to learn to live with red shiner in the Virgin River, since we may not be able to eradicate it.

Attempts to stock yearling woundfin into the Nevada portion of the river had occurred annually since 1994 without red shiner removal, but stocked fish did not survive more than a few months. Our study focused on evaluating the success of mechanically removing red shiner using seines from a 4.5-mile study section of the Virgin River on the Arizona-Nevada border. In addition, we evaluated success of stocking hatchery-reared woundfin into the study section. Other objectives included evaluating the stocking of different ages of woundfin, and determining timing and likely mode of negative interaction between red shiner and woundfin. General protocol was to remove as many red shiner as possible over a three-day period, followed by stocking of woundfin. Initial stocking in May 1999 was of yearling woundfin (approximately 1,700 fish), but two additional stockings in October 1999 (approximately 9,500 fish) and October 2000 (approximately 4,500) were of young-of-the-year (YOY) woundfin. Stocked fish were reared at Dexter National Fish Hatchery, New Mexico. Monitoring of stocked fish occurred at least monthly by seining the entire study section. Red shiner were continually removed during monitoring.

After the May 1999 removal, catch rates for red shiner remained about 10 fish/seine-haul for most of the summer of 1999, but stocked woundfin nearly disappeared by August. Red shiner abundance rose in late summer as YOY came into the catch. Another three-day removal in October 1999 reduced red shiner catch rate from about 30 to 15/seine-haul. Following the removal, 9,500 YOY woundfin were stocked. Catch rates of red shiner during the fall, winter, and spring of 1999-2000 remained low, typically less than 10/seine-haul. Woundfin catch rates consistently remained about 1/seine-haul. Another red shiner removal occurred in early June 2000, with the objective of removing them prior to woundfin spawning. But during that sampling, YOY woundfin were captured. A population estimate showed that about 600 of the stocked woundfin had survived in the study section, and more importantly, they had reproduced in late April or early May, 2000.

Monitoring during the summer of 2000 showed red shiner numbers had increased dramatically, to about 90/seinehaul. Woundfin numbers, from the October 1999 stocked fish and their progeny, declined during that period. Red shiner removal and subsequent stocking of YOY woundfin occurred again in October 2000, but red shiner abundance was only reduced from about 90 to about 80/seine-haul. Red shiner numbers did decline to about 20/seine-haul in December 2000, and remained low during the winter of 2000-2001. Woundfin catch rates from the October 2000 stocking remained about 0.5 to 1.0/seine-haul during the same winter. However, woundfin numbers declined dramatically in late May, and red shiner numbers skyrocketed again over the summer of 2001.

A comparison of flows in the study section during the summers of 1999, 2000, and 2001 indicated that all three were low-flow years, but 1999 had more spike-flow events due to rain storms, whereas 2000 and 2001 had lower flows with few spike events. We suspect that low, consistent flows during summer 2000 allowed the low number of red shiners to reproduce and achieve very high recruitment, whereas the more variable flows of 1999 did not allow for such. Spring runoff was low and early again in 2001, leaving the river low and clear by late May.

Our study is ongoing, but results to date show that during some years red shiner numbers can be reduced and maintained at low levels through mechanical removal. However, low but consistent summer flows allow red shiner recruitment to rapidly rebuild the population. The decline in red shiner catch rate during the winter of 2000-2001 suggests that cold winter temperatures naturally reduce red shiner numbers in the Virgin River. The study also shows that hatchery-reared YOY woundfin survive better than yearling woundfin, even in the presence of high numbers of red shiner, and that stocked woundfin will reproduce in the Virgin River. The interaction between red shiner and woundfin is less clear. Woundfin numbers declined during summer 2000 when red shiner numbers increased, but woundfin are known to have poor recruitment during low-flow years. Additionally, woundfin showed fairly good survival during winter/spring 2000-2001 in the presence of large numbers of red shiners. Therefore, the decline may have been caused by flow conditions, or a combination of flow and interactions with red shiner. Results to date suggest that woundfin can survive with red shiner, and reproduce, but that flow conditions may be the most important factor to long-term survival.

Stefferud, J; Bettaso, R; Voeltz, J; Gurtin, S; Blasius, H; Stefferud, S; Marsh, P; Sjoberg, J

LOWER COLORADO RIVER AREA REPORT

. . .A revised BO on the Central Arizona (water) Project shifted emphasis from general recovery and nonnative control to a more focused approach on barriers, renovation, and repatriation. Barriers at six locations were added to mitigation procedures. Feasibility investigations for barriers on Fossil and Granite creeks and East Fork White River, synthesis of existing geomorphologic and hydrologic information for Aravaipa Creek, acquisition of renovation chemicals, and other procedures were accomplished, and more are underway.

. . .Plans for decommissioning the Childs-Irving Project on Fossil Creek continue, with full-flows scheduled to return to the creek in 2004. In a stunning reversal of position, Arizona Game and Fish Department declined to support needed renovation efforts for native fishes. Federal agencies continue planning barrier construction and removal of nonnative species prior to return of flows. Two barriers were constructed in Aravaipa Creek. Mark-recapture investigations, non-native fish removal, and larval surveys were completed for woundfin, *Plagopterus argentissimus*, in the Virgin River, and a total of 5,100 woundfin were released. Red shiner contributed to the low numbers of woundfin. Virgin chub, *Gila seminuda*, numbers are down from previous years. Juvenile blue tilapia, *Oreochromis aurea*, were collected below Bunkerville diversion. . . .Apache trout, *O. g. apache*, from federal and state hatcheries were stocked into streams in the White Mountains. Renovations occurred at Pistol Butte, Wohlenburg Draw, and Flash Creek. Genetic analysis is ongoing.

2002 DFC ABSTRACTS

Blasius, HB

CHEMICAL REMOVAL OF GREEN SUNFISH, *LEPOMIS CYANELLUS,* FROM O'DONNELL CREEK, ARIZONA

Canelo Hills Cienega Preserve is owned and managed by the Arizona Chapter of The Nature Conservancy (TNC) and is located along O'Donnell Creek, a small grassland stream that originates in Canelo Hills. It is a tributary of the Babocomari River, which flows into the San Pedro River near Fairbank, Arizona.

O'Donnell creek supports three species of native fishes: Sonora sucker, *Catostomus insignis*, longfin dace, *Agosia chrysogaster*, and Gila chub, *Gila intermedia*, as well as Chiricahua leopard frog, *Rana chiricahuensis,* and Huachuca springsnail, *Pyrgulopsis thompsoni*.

In 1990, the nonnative green sunfish, *Lepomis cyanellus*, was first observed in O'Donnell Creek. Detrimental impacts from its illegal introduction were soon evident as numbers increased: numbers of Sonora sucker and Gila chub decreased, and longfin dace was extirpated.

To prevent extirpation of Sonora sucker and Gila chub, the Arizona Game and Fish Department, Coronado National Forest Service, and Arizona Chapter of The Nature Conservancy chemically treated O'Donnell Creek in summer 2002 to remove green sunfish.

Prior to treatment, efforts attempted to remove Gila chub and Sonora sucker. Approximately 104 Sonora sucker and 126 Gila chub were captured and held temporarily in outdoor exhibition ponds located at International Wildlife Museum.

Approximately 1¾ miles of perennial stream and 2½ acres of cienega were treated with liquid and sand Antimycin-A, applied over a three-day period. Liquid Antimycin-A was applied by backpack and handheld sprayers to all habitat types. Sand Antimycin-A was applied by hand and concentrated in cienega and deep-water habitats.

The renovation resulted in 100% removal of green sunfish. Gila chub and Sonora sucker have been returned to O'Donnell Creek.

Cook, AE; Martinez, CT; Sjoberg, JS; Goodchild, SC; Scoppettone, GG; Clemmer, G; Heinrich, JE; French, J

NEVADA 2002 AREA REPORT

. . .Muddy River Blue tilapia, *Oreochromis aureus*, in the Muddy River system continue to have a negative effect on native fishes. All chemical treatments of tributaries in the headwaters have been successful in tilapia eradication. Moapa dace, *Moapa coriacea*, numbers have responded accordingly, with 1085 counted in intra-agency dive counts completed in February 2002, 150 more than in year 2001 surveys.

Robinson, AT

HOW EFFECTIVE ARE CONSTRUCTED BARRIERS AT PROTECTING APACHE TROUT?

Barriers have been constructed on many White Mountain streams in Arizona to protect Apache trout, *Oncorhynchus apache*, from nonnative salmonids. These barriers can fail to serve their purpose if fishes are able to move through, around, or over the barrier due to poor design, decay of materials, and washout, or if anglers move fishes upstream of the barrier. In addition, barriers may hinder Apache trout movements and metapopulation dynamics. On each of seven streams, we marked nonnative trouts downstream of a barrier, then sampled both below and above it to detect their movements. We also marked Apache trout upstream of the barrier to detect downstream passage below it. In two years of study, we detected movement of only one marked nonnative trout upstream past a barrier, but several unmarked nonnative trouts have been found upstream from barriers on four streams. During autumn 2001, the distribution of length classes of Apache trout in two streams tended to be skewed towards smaller fish below barriers and bigger fish above them. This may indicate that young fish are dispersing downstream below barriers, and if so, could indicate a net loss of a dispersing genotype from the protected areas upstream.

Sjöberg, JC; Hobbs, B; Nielsen, B

IMPACTS ON A POPULATION OF WHITE RIVER SPINEDACE, *LEPIDOMEDA ALBIVALLIS*, FROM PREDATION BY DOUBLE-CRESTED CORMORANT, *PHALACROCORAX AURITUS*

. . . The White River spinedace, *Lepidomeda albivallis*, is restricted to a single spring outflow system, Flag Springs, in upper White River, Nye County, Nevada. Following removal of largemouth bass, *Micropterus salmoides*, from the spring outflow and other management actions, this sole population of White River spinedace had attained an estimated population of 1,573 individuals by 1999.

Stefferud, S; Stefferud, J; Clarkson, R; Heinrick, J; Slaughter, J; Bettaso, R; Whitney, M; Parmenter, S

LOWER COLORADO RIVER AREA REPORT

. . .It was a big year for Gila chub, *Gila intermedia*. The species was proposed for listing as endangered with critical habitat on 9 August 2002. O'Donnell Creek, a tributary of the Babocomari River in southern Arizona, was successfully renovated with antimycin in June 2002 to remove green sunfish, *Lepomis cyanellus*. Gila chub and desert sucker, *Pantosteus clarkii*, were restocked in August. Sabino Canyon, a Gila chub habitat, successfully renovated by removal of green sunfish in 1999, reached critically low water levels in lower canyon pools in July 2002. Gila chub were salvaged and held at the Forest Service Ranger Station. A September 2002 survey of Turkey Creek, in the Babocomari River basin, failed to find Gila chub (not seen there since 1991), but other surveys confirmed its continued existence at Williamson Valley Wash in the upper Verde River basin and found new locations in two Verde River mid-basin tributaries

…For Apache trout, *Oncorhynchus apache*, a renovation project to remove nonnative trouts was conducted in October 2002 in Snake Creek in the Apache-Sitgreaves National Forest.

. . .Beal Lake, along the lower Colorado, was treated with rotenone in December 2001 to remove a variety of nonnative fishes. It was restocked with 10,000 razorback sucker in April 2002. Western mosquitofish, *Gambusia affinis*, were recently discovered to have either survived the treatment or reinvaded from nearby waters. Another 40 acres, at the Imperial Duck Ponds, was renovated in October 2002. Restocking of razorback sucker has yet to occur, but 5,000 individuals are planned.

2003 DFC ABSTRACTS

Clarkson, RW

W. L. MINCKLEY AND THE ARAVAIPA CREEK FISH BARRIERS: HISTORY AND LEGACY

W. L. Minckley adopted the study of Aravaipa Creek and its native fish assemblage as one of his first research interests upon arriving to Arizona in 1963, and over the course of the next 35+ years of study there, he developed one of the longest continuous fish databases in the southwestern USA. During the mid-1980s, Minckley realized that threats of nonnative fish invasions into Aravaipa Creek were increasing, and recommended to the U.S. Fish and Wildlife Service and others that emplacement of a low-head fish barrier(s) on the lower creek was warranted. He and the Desert Fishes Recovery Team struggled through the late 1980s to implement his fish barrier vision, but it wasn't until an early-1990s' Section 7 Endangered Species Act consultation on the Central Arizona Project produced the means to fund construction. The Bureau of Reclamation worked closely with Minckley and others over nearly the next full decade to define the design and function of the structures, which were finally built in April 2001, shortly before his death. Minckley never saw the completed barriers, and he disagreed with aspects of their final design. However, his basic concept of paired structures capable of withstanding 100-year floods was realized. A plaque dedicating the barriers in Minckley's name was installed on the lower barrier following his death, acknowledging his enormous contributions to native fish conservation in Aravaipa Creek and throughout the American Southwest. This history and the complexities of design and construction of the barriers are illustrated and reviewed here in detail.

Coleman, SM

NON-NATIVE INVASION: FATHEAD MINNOW INTRODUCTION AND SPREAD IN WEST TURKEY CREEK, ARIZONA

West Turkey Creek is an ephemeral stream on the west slope of the Chiricahua Mountains in southeastern Arizona. The upper 2/3 of West Turkey Creek is encompassed by the El Coronado Ranch (1,900 acres private land/13,300 acres leased Forest Service allotments). Two species of native Rio Yaqui system fishes can be found in West Turkey Creek, the federally endangered Yaqui chub, *Gila purpurea*, and the Río Yaqui form of longfin dace, *Agosia* sp. Dr. W. L. Minckley ("Minck") had always been concerned with Río Yaqui fishes, so when the opportunity arose in 1996 to advise the owners of El Coronado Ranch in both Arizona and Mexico, he took it. Fathead minnow, *Pimephales promelas*, was first discovered by Arizona State University personnel in late fall 1997 in two locations: Forest Service land above El Coronado Ranch, and in one ranch pond. Within a year, fathead minnow had spread throughout West Turkey Creek and into seven ranch ponds via diversion systems on the El Coronado Ranch. Summer surveys showed fathead minnow outnumbered native fishes 100:1. No young-of-the-year Yaqui chub or longfin dace were captured during the surveys. The ability of fathead minnow to outcompete Yaqui chub and dominate the system both impressed and alarmed Minck. This led him to initiate and gather support for a complete renovation of West Turkey Creek.

Stefferud, SE; Barrett, P; Clarkson, RW; Marsh, PC; Milosovich, J; Propst, DL; Sponholtz, PJ

LOWER COLORADO RIVER AREA REPORT, NOVEMBER 2002 TO NOVEMBER 2003

Much activity occurred for fishes in the lower Colorado River basin this year, although there was little change in the declining status of native species. . . For Gila trout, *Oncorhynchus gilae*, the West Fork Gila River was renovated, fish were evacuated from Mogollon Creek due to fire threat, and a revised recovery plan was signed. For Apache trout, *Oncorhynchus gilae apache*, renovations occurred in Lee Valley, and Snake and Bear Wallow Creeks, but others are on hold pending EA reanalysis due to stakeholder concerns. Barrier repair occurred in Lee Valley, and Snake, Fish, and Centerfire Creeks.. . . Gila topminnow, *Poeciliopsis occidentalis*, was discovered to persist in O'Donnell Creek in the San Pedro River drainage. It was stocked there in 1974, then later thought to be extirpated, but apparently survived in the shallow marsh at the upstream end of the creek. Recent sightings were confirmed in October 2003. . . Speckled dace, *Rhinichthys osculus*, was stocked into Martinez Canyon, a tributary of the middle Gila River. Fire seriously affected Gila chub, *Gila intermedia*, habitats in the Santa Catalina Mountains above

Tucson, postponing plans for restocking Gila chub in newly renovated Romero Canyon, and requiring salvage of fish from Sabino Canyon.. . . Mexican stoneroller, *Campostoma ornatum*, was moved upstream in Rucker Canyon in the Chiricahua Mountains.

2004 DFC ABSTRACTS

Heinrich, J; Tripoli, V

A VIRGIN RIVER CHUB REFUGE AT THE REID GARDNER POWER GENERATION FACILITY IN MOAPA, NEVADA

The Muddy River population of *Gila seminuda*, the Virgin River chub, has shown drastic declines in the wild since the invasion of the exotic blue tilapia into the system in the early 1990's. More recent concern for this reduction resulted in a cooperative effort to develop a secure refuge population of chub in three raw water storage ponds located at the Reid Gardner Power Generating Station in Moapa, Nevada, operated by the Nevada Power Company. . .The 3 ponds used for this project are impressive, confining 5.37 million cubic feet of Muddy River water and are currently undergoing chemical treatments to remove the established blue tilapia. The ponds should provide an excellent backup population of chub while the construction of barriers and follow-up chemical treatments proceed downstream to remove tilapia from the Muddy River as well.

Hilwig, K; Bettaso, R; Knowles, G; Richards, M; Rinne, J

COLORADO RIVER BASIN AREA CONSERVATION STRATEGIES REPORT

Native fish conservation efforts in the Lower Colorado River Basin continue to be productive and successful in protecting native fish and their habitats, in spite of expected difficulties. . .A multi-agency group consisting of members from The Nature Conservancy, Bureau of Land Management (BLM), Forest Service (USFS), USFWS, State Lands Department, and AGFD are working cooperatively to translocate spikedace (*Meda fulgida*) and loach minnow (*Tiaroga cobitis*) to Hot Springs and Cherry Springs canyons on the Muleshoe Ecosystem Preserve. In addition, Gila topminnow (*Poeciliopsis occidentalis*), desert pupfish (*Cyprinodon macularius*) and several other native fishes are targeted for placement in appropriate habitats. The key to success for moving forward with habitat restoration and restocking of spinedace (*Lepidomeda vittata*) into the East Clear Creek drainage is cooperation between USFWS, The Flagstaff Arboretum, Coconino National Forest (CNF), AGFD, and private landowners and ranchers. Native fish recovery in the West Fork of Oak Creek, including Gila trout (*Oncorhynchus gilae*) is moving forward through the cooperative efforts of Northern Arizona Flycasters, Federation of Flyfishers, Bureau of Reclamation (BR), CNF, USFWS, and AGFD. Down listing and delisting efforts for Gila and Apache trout (*Oncorhynchus apache*) are also driven by similar cooperative programs. Native fish salvage, including Gila topminnow, longfin dace (*Agosia chrysogaster*), speckled dace (*Rhinichthys osculus*) and Gila chub (*Gila intermedia*) and stream renovation projects for Cave Creek are in the planning stages with cooperation from ASU, BR, Tonto National Forest, USFWS, Desert Foothills Land Trust, and Spur Cross Conservation Area.

Ward, D; Schultz, A.

SPECIES-SPECIFIC PISCICIDES: DREAM OR REALITY?

Attempts to remove unwanted nonnative fishes from areas with native fish are common but success is limited because very few tools are available for managing invasive fish populations. Only four chemicals are currently registered as piscicides, two of which are toxins specific to lampreys and the others are not selective for specific species. The first step in development of a species-specific piscicide is to perform toxicity screening on candidate chemicals. We recently discovered one such chemical that has the ability to selectively kill problematic nonnative fishes without harming three of Arizona's native fish species. In repeated laboratory tests this synthetic salicylanilide was found to kill nonnative fathead minnow *Pimephales promelas*, red shiner *Cyprinella lutrensis*, yellow bullhead *Ameiurus natalis*, and smallmouth bass *Micropterus dolomieui* without harming native longfin dace *Agosia chrysogaster*, Gila chub *Gila intermedia*, or Gila topminnow *Poeciliopsis occidentalis*. The apparent species-specific selectivity of this chemical and its similarity to currently licensed lampricides makes it a good candidate for further evaluation as a fish toxin. Testing, and licensing of new piscicides is very costly, but not pursuing new tools for managing invasive fishes may be even more costly if current trends are not reversed and native fishes continue to decline.

Watts, HE; Brooks, JE; Myers, M; Propst, DL; Remshardt, WJ; Davenport, SR; Dudley, RK; Platania, SP

NATIVE FISH RESEARCH AND MANAGEMENT IN THE UPPER/MIDDLE RIO GRANDE BASIN DURING 2004

Status of Rio Grande cutthroat trout

. . . Meanwhile, the New Mexico Game Commission moved in August 2004 to disallow piscicide application for non-native trout removal by the NM Department of Game and Fish, lead authority on RGCT conservation, in New Mexico. Proponents of this ruling requested that non-native trout, the greatest threat to RGCT conservation, be removed from streams by alternative methods, such as electro-fishing. This will pose a challenge to restoration projects proposed for RGCT because data have shown piscicide applications to be more effective than electro-fishing in complete removal of non-native species.