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Effectiveness of the Barrier-and-Renovate Approach to Recovery of Warmwater Native Fishes in the Gila River Basin

By Robert W. Clarkson[1] and Paul C. Marsh[2]

Abstract

Segregating native from nonnative species is the primary tactic in recent efforts to conserve and recover imperiled warmwater native fishes in the Gila River Basin of Arizona, New Mexico, and Sonora. Isolation of the two types of species has been achieved primarily through barrier construction followed by chemical eradication of the nonnative fauna and repatriation of native fishes. A similar approach has assisted with conservation of federally listed trouts across the West, but application to lower elevation, arid-land streams can be more difficult because of the larger watersheds involved and related hydrological differences. These latter distinctions often include: (1) a need for more massive (and hence expensive) fish barriers, in part as protection against flood damage; (2) greater geomorphological impacts to the streambed from barrier emplacement; (3) consideration of upland stock tanks that may harbor nonnative fishes; and (4) diverse land ownership patterns that complicate right-of-entry and environmental compliance. Here we assess examples of barrier-and-renovate projects that have been applied to warmwater streams in the Gila River Basin. We conclude such projects represent the only viable solution currently available to conserve and recover native fishes, but these projects must be carefully selected and comprehensively implemented to achieve maximum conservation benefit with limited funding.

Introduction

Segregating native from nonnative species, or isolation management (Novinger and Rahel, 2003), is the primary tactic in recent efforts to conserve and recover imperiled warmwater native fishes in the Gila River Basin of Arizona, New Mexico, and Sonora. Establishment of nonnative fishes in waters of the American Southwest is now considered the primary cause of the deteriorating status of native fishes in the region and prevents their recovery (Minckley, 1991; Clarkson and others, 2005; Light and Marchetti, 2007; Minckley and Marsh, 2009; Stefferud and others, 2009). Segregation of the native and nonnative faunas has been achieved primarily through chemical eradication of nonnative fishes and repatriation of native fishes following barrier construction to preclude re-contamination of the upstream, treated reach. A similar approach has been incorporated into recovery planning for many federally listed trouts across the West, which has improved or minimally halted further deterioration of their conservation status (Young, 1995; Thompson and Rahel, 1998; Avenetti and others, 2006; Pritchard and Cowley, 2006; but see Hilderbrand and Kershner, 2000; Novinger and Rahel, 2003). However, application of the barrier-and-renovate approach to lower elevation, arid-land streams can be more difficult because of the larger watersheds involved and more complex hydrological and land-use differences.

The purpose of our paper is to describe the characteristics of warmwater streams in the Gila River Basin as they relate to fish barrier construction and chemical renovations, and to assess the successes and failures of barrier-and-renovate projects that have been applied toward native fish recovery in these stream types. We conclude with a discussion of potential future directions of recovery efforts for the warmwater native fauna in the region.

Methods

We have participated at various levels in the planning and implementation of most barrier-and-renovate projects for warmwater native fishes in the Gila River Basin during the past decade, and our experiences form the basis of this paper. Robert W. Clarkson leads a Bureau of Reclamation (Reclamation) program mandated by the U.S. Fish and Wildlife Service to construct fish barriers on a dozen streams to assist with recovery of federally listed warmwater native fishes in the

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basin. Clarkson and Paul C. Marsh developed criteria for the basic designs of the newly constructed fish barriers discussed below (with the exception of Arnett Creek), and both have reviewed and modified construction specifications. In addition, Clarkson co-authored and Marsh commented on environmental planning documents (National Environmental Policy Act and Endangered Species Act) for all aspects of the barrier-and-renovate projects (barrier construction, fish salvage, chemical renovation, native fish repatriation, post-project monitoring) and participated with much of the on-the-ground implementation of the projects.

Marsh also assisted with project planning and most aspects of project implementation, and his consulting company has been a primary contractor for post-project fish monitoring and reporting relative to the success of the barriers and species repatriations. This collective involvement provided us with documentation and first-hand experience with such projects from concept to conclusion. Locations of the various fish barrier projects discussed here are shown in figure 1.

Results and Discussion

Features of Low-Elevation Watersheds

The most obvious features of watersheds that distinguish low-elevation streams from high-elevation streams in the southwestern desert region are the larger watersheds involved and the increased frequency and magnitude of flood events. Lower parts of watersheds accumulate flood impacts from disparate subbasins upstream, resulting in highly variable and more-elevated hydrographs. Low-order, headwater reaches exhibit more stable flow regimes. Relative to streams in more mesic areas, design specifications for barriers across this continuum must accommodate variable flooding impacts that result from differences in drainage size, precipitation patterns, and other factors.

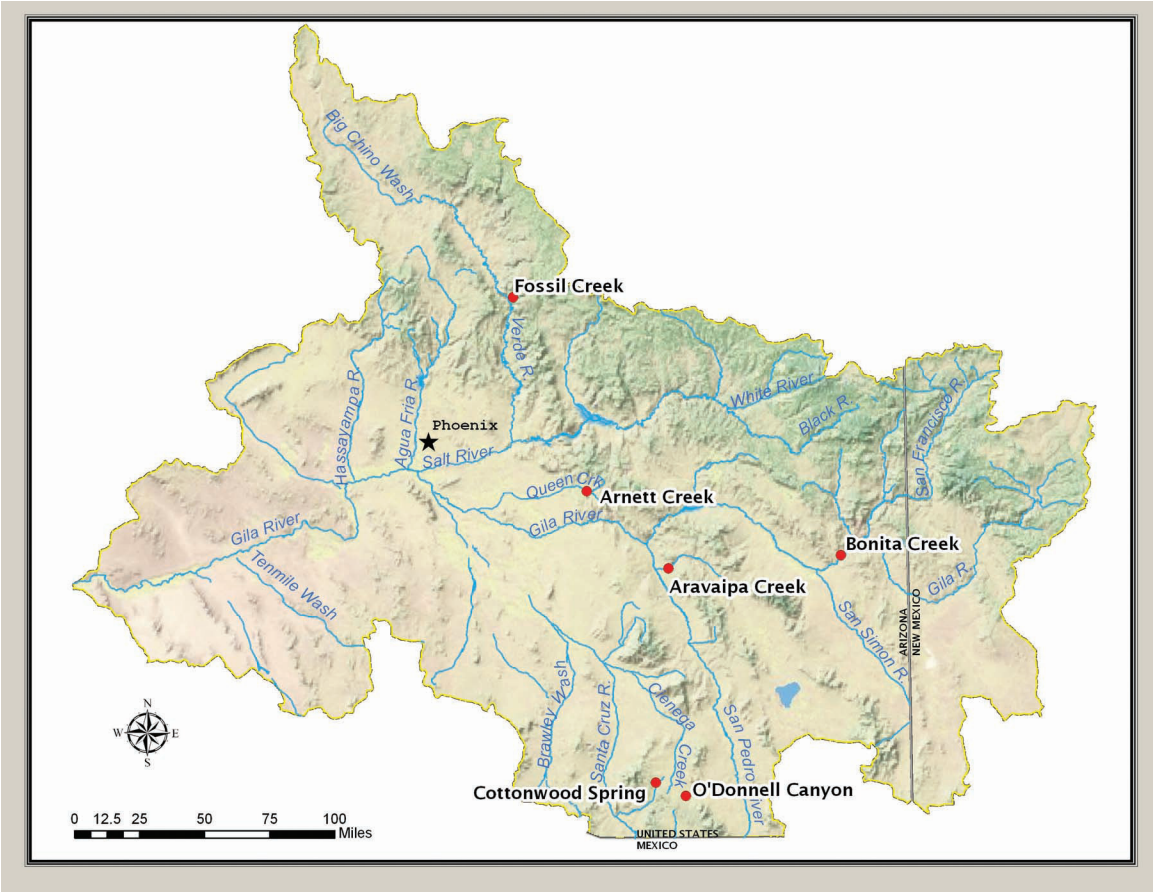

Figure 1. Boundaries of the Gila River Basin, Arizona and New Mexico (exclusive of Sonora), showing major streams and locations of fish barrier projects discussed in the text.

Unless tied into bedrock at all points across the stream channel, high-magnitude floods dictate that fish barrier designs accommodate increased scour effects to protect them from flood damage. Most barrier-and-renovate projects we describe below are of steel-reinforced concrete design and incorporated upstream and downstream keys (scour walls) to protect against natural bed scour, bridge pier-type scour, and scour induced by the structure. In one case, reinforced concrete piles were sunk up to 60 feet below grade to help protect the structure against sliding forces (fig. 2). In addition, riprap placement along the downstream key is a common design element in an attempt to prevent a scour hole from developing downstream from the structures (fig. 3). Prevention of scour holes also minimizes the attraction of recreationists to the site, which should reduce the potential for humans to move nonnatives above the barrier.

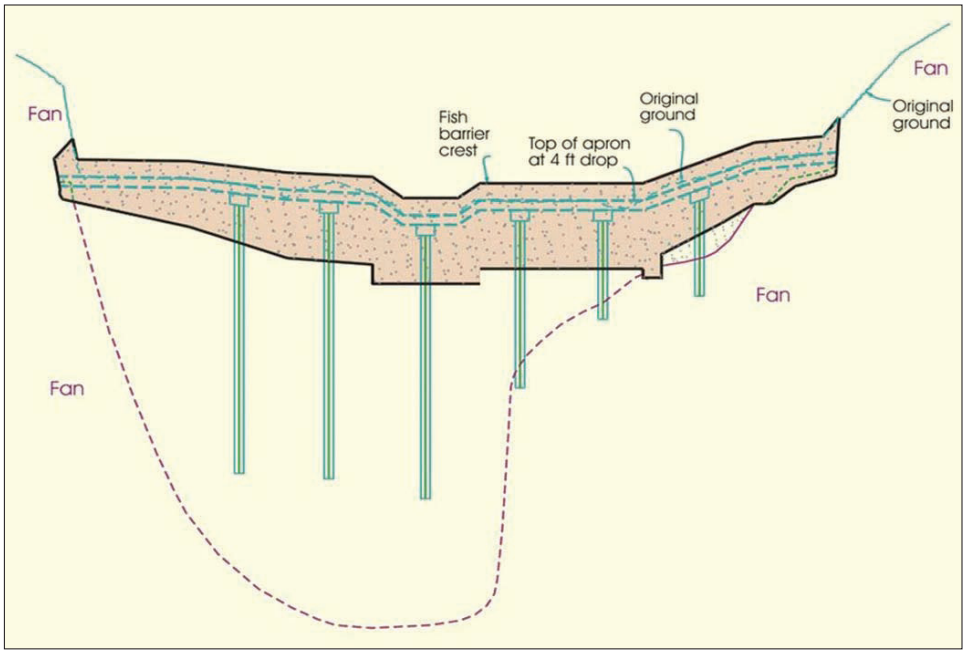

Figure 2. Plan view of the lower fish barrier on Aravaipa Creek, Pinal County, Arizona, showing the placement of concrete piles to stabilize the structure. "Fan" refers to fanglomerate, an accumulation of cemented coarse materials in an alluvial fan.

Although design engineers can protect barriers against most flood damage, emplacement of a hard structure within an alluvial stream channel has strong potential to alter channel geomorphology. In addition to alteration of channel slopes upstream from barriers as a result of aggradation, scour effects downstream from barriers have potential to remove sediment from stream terraces and the thalweg, despite emplacement of riprap armoring. If riprap materials are not of sufficient diameter and their placement does not extend below scour depth, scour during high-magnitude floods can erode underneath and sink or transport materials downstream. In addition, riprap must be emplaced with these considerations in mind across the width of the entire channel to prevent erosion from progressing from channel margins toward the thalweg. Prevention of these types of scour appears to be the most daunting challenge to fish barrier designs in low-elevation streams in the basin.

Figure 3. Riprap placement downstream from the apron of the Bonita Creek fish barrier, Graham County, Arizona.

Because of the aridity of lower elevations of the Gila River Basin, uncounted stock ponds have been constructed to facilitate better use of uplands by domestic livestock. Many of these artificial impoundments hold water year round, and they often harbor populations of nonnative fishes that have potential to contaminate downstream waters during spill events. Because fish barriers only prevent upstream invasion of nonnative fishes, stream restoration projects must also eliminate nonnative fishes from upstream sources to secure the drainage.

The larger drainage areas typically associated with low-elevation perennial streams in arid environments often mean that there is greater variability in land ownership. For example, application of piscicide to private property parcels that typically fall along stream corridors requires that each property owner must approve the project or the project cannot be completed successfully. Often, different Federal or State land managers have differing management priorities that can conflict with project goals. In general, as watershed size increases, so does project complexity and potential for controversy.

Successes and Failures of Barrier-and-Renovate Projects

Table 1 summarizes results of representative case histories of barrier-and-renovate projects, each treated in detail below. Data are mostly from unpublished reports that are available from the respective agencies. We include dates of repatriations and numbers of individuals stocked to provide the reader an opportunity to independently assess the actions. Additional information on fish barrier specifications can be found at *http://www.usbr.gov/lc/phoenix/biology/azfish/dropbarriers.html*.

O'Donnell Canyon

One of the first stream restoration projects attempted for warmwater native fishes in the Gila River Basin was undertaken in 2001 at O'Donnell Canyon, a tributary to Babocomari River in the San Pedro River drainage (fig. 1). Historically an important locality for endangered Gila chub (*Gila intermedia*), the population was increasingly depleted over time because of infestation by invasive green sunfish (*Lepomis cyanellus*). The stream already was protected against upstream fish invasions by two small dams constructed in the 1950s, and so the project consisted primarily of chemical renovation of the stream above the dams using the piscicide antimycin-A. The renovation was successful in removing the sunfish population, and the small number of salvaged Gila chub and Sonora sucker (*Catostomus insignis*) were repatriated (table 1).

In this case, although repatriated Gila chub reproduced and population numbers expanded, natural dispersal to previously occupied reaches of the stream has not yet occurred (repatriation was only to the upper of two reaches). Augmentation of the population appears necessary, as well as human-assisted releases of fish (including Sonora sucker) to unoccupied areas. O'Donnell Canyon is one of the few remaining ciénegas (marshes) formerly common in the southern Gila River Basin (Hendrickson and Minckley, 1985) and is characterized by mostly deep, narrow pools connected by low base-flow channels. A major drought occurred in the region around the time of the renovation, and most surface flows between pools have since been intermittent. Perhaps this flow reduction explains the lack of dispersal of Gila chub downstream.

Historical collection records indicated native longfin dace (*Agosia chrysogaster*) and Gila topminnow (*Poeciliopsis occidentalis*) were present in O'Donnell Canyon, but neither had been detected for many years before the renovation. Remarkably, both appeared post-project, and both have since been observed throughout most of the creek upstream from the barriers. In 2008, two stock tanks in the drainage above the ciénega were found to harbor nonnative fishes, and one (mosquitofish [*Gambusia affinis*]) was found in the ciénega headwaters in 2009. These sources, and possibly the entire stream system, will have to be re-renovated to re-establish an intact native fish assemblage.

Both of the 1950s-era dams that have functioned as fish barriers are currently in danger of failure, and planning is underway to stabilize one or both or to construct an additional barrier further downstream that would protect additional subdrainages. The decision to build a new barrier hinges on whether renovations of the new subdrainages are politically feasible because of the considerable number of private property owners along one of the streams.

Fossil Creek

The 2004 Fossil Creek Native Fish Restoration Project has thus far been the most complex, comprehensive, and successful attempt at securing a stream for warmwater native fish recovery purposes in the basin (fig. 1). Nearly all of the 43 cubic-feet-per-second base flow of this stream had been diverted for hydropower purposes for the past century, and nonnatives had also invaded or been stocked, drastically suppressing the remnant native fish community (headwater chub [*Gila nigra*], roundtail chub [*Gila robusta*], longfin dace, speckled dace [*Rhinichthys osculus*], Sonora sucker, and desert sucker [*Pantosteus clarki*]). In a remarkable and historic occasion, the hydropower company, Arizona Public Service, agreed to return full flows to the channel and decommission the project in concert with native fish restoration efforts. First, a fish barrier was constructed across an existing bedrock outcrop (fig. 4; cost $275 thousand), followed by native fish salvage and chemical renovation of the stream (antimycin-A) and upland stock tanks (rotenone). Full flows were returned to the stream, and salvaged fishes were repatriated.

Figure 4. The fish barrier on Fossil Creek, Gila and Yavapai Counties, Arizona.

Table 1. Species assemblages before and after native fish restorations of selected warmwater streams in the Gila River Basin, Arizona and New Mexico. Data sources are provided in the first column following stream name. Indications of reproduction are based on presence of young-of-year captured during routine post-project monitoring. Asterisks denote nonnative species. In most cases, augmentations of repatriations are ongoing.

Stream/data source	Pre-restoration			Post-restoration			
	Species assemblage[a]	Date of barrier construction	Date of renovation	Date(s) of repatriation	Numbers repatriated	Species assemblage	Reproduction
Aravaipa Creek[b]	Desert sucker	2001	Not applicable	Not applicable	Not applicable	Desert sucker	Yes
Reinthal, P., University of Arizona, unpub. data, 2009	Sonora sucker					Sonora sucker	Yes
	Roundtail chub					Roundtail chub	Yes
	Speckled dace					Speckled dace	Yes
	Longfin dace					Longfin dace	Yes
	Loach minnow					Loach minnow	Yes
	Spikedace					Spikedace	Yes
	Green sunfish*					Green sunfish*	Yes
	Yellow bullhead*					Yellow bullhead*	Yes
	Red shiner*					Red shiner*	Yes
Arnett Creek	Green sunfish*	1997	1997	1999	13	Desert sucker	No
Robinson, A.T., unpub. report, 2008	Mosquitofish*			1999	1	Sonora sucker	-
				1999	23	Longfin dace	No
				2007	100	Longfin dace	Yes
Bonita Creek	Desert sucker	2008	2008	2008	1	Desert sucker	-
Robinson and others, unpub. report, 2009	Sonora sucker			2008	201	Sonora sucker	Undetermined
	Gila chub			2008	230	Gila chub	Undetermined
	Speckled dace			2008	25	Speckled dace	Undetermined
	Longfin dace			2008	107	Longfin dace	Undetermined
	Green sunfish*			2008	678	Loach minnow	Undetermined
	Smallmouth bass*			2008	448	Spikedace	Undetermined
	Fathead minnow*			2008	147	Desert pupfish	Undetermined
	Common carp*			2008	975	Gila topminnow	Undetermined
	Yellow bullhead*			-	0	Mosquitofish*	Undetermined
	Black bullhead*						
	Channel catfish*						
	Flathead catfish*						
	Mosquitofish*						
Cottonwood Spring[b]	Gila topminnow	2003	Not applicable	Not applicable	Not applicable	Gila topminnow	Yes
Stefferud, S. (retired), U.S. Fish and Wildlife Service, oral comm., 2009	Desert sucker					Desert sucker	Yes
	Longfin dace					Longfin dace	Yes
Fossil Creek	Desert sucker	2004	2004	2004	354	Desert sucker	Yes
Weedman and others, unpub. report, 2005	Sonora sucker			2004	204	Sonora sucker	Yes
	Roundtail chub			2004	250	Chub spp.	Yes
Marsh and others, unpub. report, 2009	Headwater chub			2004	906	Speckled dace	Yes
	Speckled dace			2004, 2007	318	Longfin dace	Undetermined
Robinson, A.T., unpub. report, 2009	Longfin dace			2007–2008	2128	Loach minnow	Undetermined
	Green sunfish*			2007–2008	725	Spikedace	Undetermined
	Smallmouth bass*			2007–2008	5000	Gila topminnow	Yes
	Yellow bullhead*			2007–2008	579	Razorback sucker	No
O'Donnell Canyon[c]	Sonora sucker	1950s	2001	2001	~30	Sonora sucker	Yes
Blasius, H., Bureau of Land Management, oral comm., 2009	Gila chub			2001	~20	Gila chub	Yes
	Gila topminnow			-	0	Gila topminnow	Yes
	Longfin dace			-	0	Longfin dace	Yes
	Green sunfish*						

[a] Does not necessarily reflect the historical (pre-settlement) assemblage of native species.

[b] Barrier construction only; project intended to prevent invasions of new nonnatives.

[c] Renovation and repatriations upstream of pre-existing fish barriers.

Native fishes reproduced (table 1) and have recolonized most of the stream. Five additional federally listed species (Gila topminnow, desert pupfish [*Cyprinodon macularius*], loach minnow [*Tiaroga cobitis*], spikedace [*Meda fulgida*], and razorback sucker [*Xyrauchen texanus*]) were also released to the stream in 2008, but it is too early to determine if they have persisted and established self-reproducing populations. Monitoring has found that two stock tanks were stocked with nonnatives and both were successfully re-renovated. No nonnatives have reinvaded the stream to date (table 1), and only relatively minor barrier maintenance has yet been required.

Bonita Creek

In 2008, a 160-foot wide reinforced-concrete fish barrier was constructed on Bonita Creek (cost $2.01 million), a tributary to Gila River in eastern Arizona (figs. 1 and 5), and a contaminated portion of the stream was chemically renovated with rotenone (CFT Legumide). Salvaged native fishes (Gila chub, speckled dace, longfin dace, Sonora sucker, desert sucker) plus four federally listed taxa native to the area but not known to be from the stream (spikedace, loach minnow, Gila topminnow, desert pupfish) were repatriated in furtherance of the species' recovery goals. Newly added species will be augmented in spring 2009 to increase founding population size and enhance genetic variability. Future monitoring will determine success of this restoration attempt. This project required a compromise that provided water rights to a municipal water user that allowed the project to proceed.

Other Streams

Other situations exist in the basin where fish barriers have been constructed to protect either intact native assemblages from potential nonnative fish contamination in the future or where contaminated streams yet hold valuable native fish communities worth protecting against contamination by additional invasive species. In the case of Aravaipa Creek, tributary to San Pedro River (figs. 1 and 6) and one of Arizona's most valued native fish communities (seven extant species), two barriers were built in 2001 (total cost $3.1 million) to protect against invasion by species such as red shiner (*Cyprinella lutrensis*) and in the hope that extant nonnative species (primarily green sunfish and yellow bullhead [*Ameiurus natalis*]) could be washed from the system during flood events and prevented from reinvading. Unfortunately red shiner accessed the stream before the barriers could be completed, and a 50-year flood event that occurred after construction failed to remove any unwanted species.

Aravaipa Creek was the first barrier project completed under Reclamation's barrier construction program in the basin, and this project consisted of paired barriers. The rationale was that if nonnative fishes passed the lower barrier, they could be removed from between the barriers before they could invade further upstream. Private landowners opposed the project. As a result, the barriers were constructed downstream on a parcel that was too small, and design miscalculations resulted in the upper barrier being buried by aggradation behind the lower barrier. The paired barrier concept has since been abandoned primarily because of cost:benefit concerns; construction of single barriers on twice as many streams in theory could achieve greater conservation benefit for native fishes.

Figure 5. The fish barrier on Bonita Creek, Graham County, Arizona.

Figure 6. The lower fish barrier on Aravaipa Creek, Pinal County, Arizona.

Channel degradation downstream from the lower Aravaipa Creek barrier also has been significant (fig. 7), but the lower barrier has been successful in preventing invasion by Northern crayfish (*Orconectes virilis*) and possibly other species, and natives continue to vastly outnumber nonnatives upstream. Should natives begin to decline significantly relative to nonnatives, the stream could become a candidate for chemical renovation, but the size of the watershed and the significant number of private properties along the stream would make such a renovation a challenge.

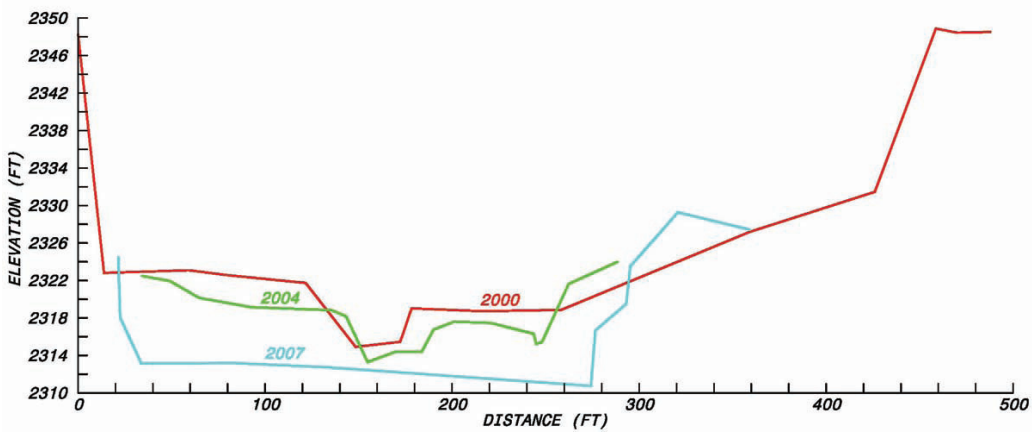

Figure 7. Surveyed cross sections of the stream channel on Aravaipa Creek immediately downstream from the lower fish barrier, showing channel configurations immediately pre-construction (2000), 3 years post-construction (2004), and 1 year following passage of an estimated 50-year flood event (2007).

A fish barrier constructed downstream from Cottonwood Spring on Sonoita Creek in the Santa Cruz River subbasin (figs. 1 and 8; cost $115 thousand) protects a population of endangered Gila topminnow and a couple of other unlisted native species (table 1). Only the reach downstream from the barrier is contaminated by nonnatives. The purpose of this barrier, to prevent an important native fish population from nonnative invasion, has thus far been successful. A willing private landowner in this instance greatly facilitated the implementation of the project.

The Native Fish Restoration Project on Arnett Creek, tributary to Queen Creek in the lower Salt River drainage (figs. 1 and 9), is an example of what can go wrong with a barrier-and-renovate project. The stream historically harbored at least three native fishes (Gila chub, longfin dace, desert sucker), but green sunfish and mosquitofish had invaded and decimated the native fishes. A poorly designed rock gabion fish barrier was constructed and later nearly destroyed by flood. The barrier was rebuilt and reinforced with concrete. The stream was successfully chemically renovated to remove all fishes. Following stocking of very small numbers of two unlisted fishes (table 1), the stream desiccated in 2002 and remained fishless until longfin dace was repatriated in 2007. Plans to stock the stream with additional listed species have not yet been implemented because of various concerns, including drought and habitat changes, that have occurred since the barrier construction. We remain optimistic that Arnett Creek can eventually contribute to recovery of native fishes.

Figure 8. The fish barrier on Sonoita Creek, Santa Cruz County, Arizona, downstream from Cottonwood Spring.

Figure 9. The reconstructed fish barrier on Arnett Creek, Pinal County, Arizona.

Implications for Management

We acknowledge that artificial barriers fragment populations already partitioned by groundwater pumping, diversions, dams, and occupation of mainstem habitats by nonnative fishes. Such fragmentation depletes population genetic variability, and populations may become less adaptable to change and more susceptible to extirpation. However, the continued declining trend of native fishes in the region, including losses of populations in mainstem and tributary habitats, dictates that protection of remaining populations is a higher priority than meeting longer term evolutionary needs. Human intervention will be necessary to ensure that genetic variability of populations above barriers is maintained until adjacent stream reaches can be cleansed of nonnatives. Once a drainage network is protected, upstream barriers could then be breached to once again restore natural connectivity among populations. At present, sociopolitical circumstances prevent decontamination of nonnative fishes from larger drainage networks that also support nonnative sport fisheries (Clarkson and others, 2005).

Recently implemented barrier-and-renovate projects have demonstrated the viability of the approach in conserving native fishes in arid region streams typified by the Gila River Basin. However, success is contingent upon several important factors. First, streams must be carefully selected to ensure they meet physical, biological, and sociopolitical criteria necessary for successful barrier installation, renovation, and restoration of native communities. All aspects must be comprehensively performed, as failure of any ensures failure of the whole project. Comprehensive performance of a restoration means that all potential sources of contamination—from upstream, downstream, or by human transport—are identified and eliminated or minimized. Barrier construction and stream renovations are costly endeavors, and each demands detailed planning, substantial time, and a large workforce to successfully complete. The politics of federally listed species repatriations also must be carefully worked through to complete a project. The end result can be a substantial enhancement of the conservation status of native fish communities.

We stress that the only viable direction for recovery of native fishes in the region is segregation of native from nonnative fishes, and that in the Gila River Basin the barrier-and-renovate strategy appears to be the only currently available option that can effectively achieve such segregation. Potential alternatives, such as application of taxon-specific piscicides to remove target species without the need for complete assemblage renovation or genetic bioengineering that has similar potential to remove targeted populations while leaving others intact, have been identified but their implementation is far in the future. Both of these options likely would yet require use of fish barriers to maintain segregation. Although the handful of barrier-and-renovate projects described here appears to be mostly successful in establishing and preserving viable native fish communities in lower elevations of the Gila River Basin, dozens of additional streams must be dedicated toward these efforts, and tens of millions of dollars for barrier constructions and renovations will be required if biologically significant conservation of native species is to occur. Virtually all viable streams that could be devoted for native fish use without significant impact to existing sport fisheries already have been identified, and restoration projects are complete or in planning stages. Any further commitment to native fish conservation thus will require compromise on the behalf of sport fish and other interests. Without such compromise, we cannot envision a future where Gila River Basin native fishes are recovered and Endangered Species Act (Public Law 93–205) protections are eliminated.

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