introduced fish

perspective

Predatory Fish Removal and Native Fish Recovery in the Colorado River Mainstem: What Have We Learned?

ABSTRACT

Mechanical predator removal programs have gained popularity in the United States and have benefited the recovery of several native trout and spring fish. These successes have been limited to headwater streams and small, isolated ponds or springs. Nevertheless, these same approaches are being applied to large river systems on the belief that any degree of predator removal will somehow benefit natives. This attitude is prevalent in the Colorado River mainstem where recovery and conservation programs are struggling to reverse the decline of four endangered fish species. Predator removal and prevention are major thrusts of that work but unfortunately, after 10 years and the removal of >1.5 million predators, we have yet to see a positive response from the native fish community. This leads to the obvious question: is mechanical removal or control in large (>100 cfs base flow) western streams technically or politically feasible? If not, recovery for some mainstem fishes may not be practical in the conventional sense, but require innovative management strategies to prevent their extirpation or possible extinction. This article examines (1) what has been attempted, (2) what has worked, and (3) what has not worked in the Colorado River mainstem and provides recommendations for future efforts in this critical management area.

Gordon A. Mueller

Mueller is a research fishery biologist, U.S. Geological Survey in Denver, Colorado. He can be contacted at Gordon_A_Mueller@usgs.gov.

Introduction

Native Fishes

The Colorado River is isolated by mountain ranges and deserts and represents one of the few major drainages in the world where ictalurids and centrarchids were not found in the native fauna. Historically, the mainstem fish community was composed of 10 freshwater species (Table 1). Today, 7 are federally listed as endangered, another is state listed, and one is of special concern. Of these, Colorado pikeminnow (*Ptychocheilus lucius*), bonytail (*Gila elegans*), and razorback sucker (*Xyrauchen texanus*) were widely distributed throughout the mainstem river and have been the subject of varying recovery and management activities for nearly 3 decades. The Colorado pikeminnow is the largest member of the cyprinid family in the Northern Hemisphere, reaching lengths of nearly 2 m while bonytail and razorback sucker reach less than half that length. All three are found only in the Colorado River Basin and have life spans exceeding 30 years (Minckley et al. 1989; Hawkins et al. 2004).

Table 1. Native fish historically common to the Colorado River mainstem.

Common name		Scientific name	Mainstem status
Minnows		**Cyprinids**	
Bonytail		*Gila elegans*	endangered–stocked
Roundtail chub		*Gila robusta*	state listed–declining
Humpback chub		*Gila cypha*	endangered–declining
Colorado pikeminnow		*Ptychocheilus lucius*	endangered–declining
Woundfin		*Plagopterus argentissimus*	endangered–absent
Speckled dace		*Rhinichthys osculus*	declining
Suckers		**Catostomids**	
Razorback sucker		*Xyrauchen texanus*	endangered–stocked
Flannelmouth sucker		*Catostomus latipinnis*	declining–stocked
Pupfish		**Cyprinodontids**	
Desert pupfish		*Cyprinodon macularius*	endangered–absent
Live-bearer		**Poeciliids**	
Sonoran topminnows	Gila	*Poeciliopsis occidentalis occidentalis*	endangered-absent
	Yoqui	*Poeciliopsis occidentalis sonoriensis*	endangered-absent

Fish Introductions

European settlement brought dramatic biological and physical change. Channel catfish (*Ictalurus punctatus*) and carp (*Cyprinus carpio*) were introduced in the late nineteenth century and by 1935 largemouth bass (*Micropterus salmoides*), bluegill (*Lepomis macrochirus*), and several other centrarchids were reported common while natives had become rare (Dill 1944). Construction of Hoover Dam in 1935 and other major water development projects greatly altered physical conditions which benefited these new arrivals. Spring run-off was captured by upstream storage reservoirs and used to augment naturally depleted summer flows to satisfy downstream agricultural demands. Basin water storage grew to exceed >5 times the river's annual flow and now floods large expanses (1,750 km^2) of the floodplain (Mueller and Marsh 2002). Those reservoirs and their tailwaters were stocked with recreational species and have become economically important recreational fisheries.

Stocking programs accelerated after World War II resulting in the

introduction of >80 fish species, the majority of which are aggressive predators (Mueller and Marsh 2002). Dill (1944) reported that native fish in the lower mainstem river had become rare by the mid-1930s, and attributed their loss to a combination of predation and habitat destruction. Their decline progressed upstream with the exception of a brief resurgence when mainstem reservoirs were initially filled. Numbers of razorback sucker and to a lesser extent bonytail rebounded when Lakes Mead, Roosevelt, and Mohave formed (Minckley 1983).

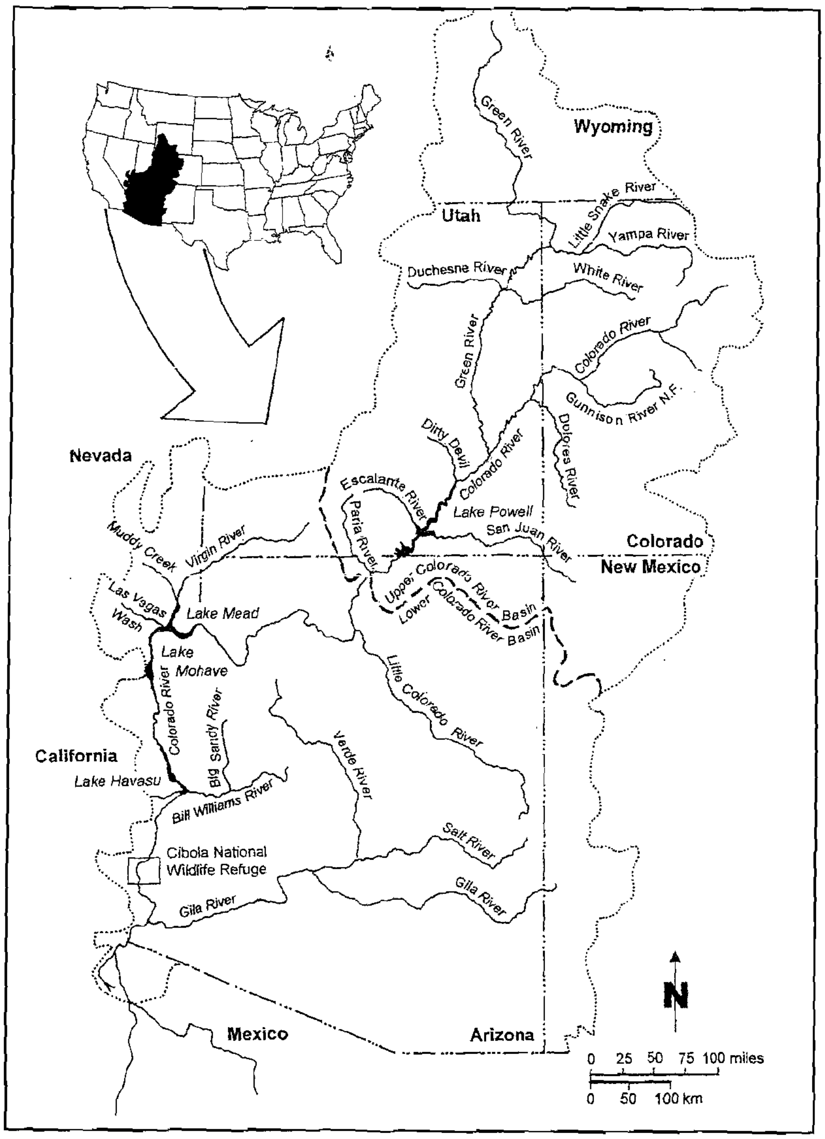
Colorado pikeminnow were extirpated from the lower basin by 1975 but small populations persist in the upper basin. Bonytail and razorback sucker have experienced recruitment failure for nearly 4 decades and attempts are being made to augment populations through stocking (USFWS 2002b,c). Wild bonytail are believed gone, the last one was captured from Lake Mohave during the late 1990s (Marsh 1997). Estimates of wild razorback sucker have dropped to <1,000 individuals—approximately 100 in the Green River, 300 in Lake Mead, and 500 in Lake Mohave (Holden et al. 1997; Bestgen et al. 2002; P. Marsh, ASU, pers. comm.). The significance of these losses has been reported by Miller (1961), Minckley and Deacon (1991), Fuller et al. (1999), and many other noted ichthyologists.

The decline of native communities is not unique to the Colorado River basin (Moyle et al. 1986; Lassuy 1995). Indeed, this trend has become a national crisis that helped trigger the passage of the Endangered Species Act in 1973. Under the act, species are provided federal protection, critical habitat is designated, and fish are sometimes stocked to reverse population declines. For example, the U.S. Fish and Wildlife Service (USFWS) stocked more than 12 million razorback sucker fry from 1981 to 1991 in an attempt to reestablish the species in Arizona and avoid federal listing (Johnson 1985). However, survival was extremely poor as less than 200 of these fish were ever captured (Minckley et al. 1991). Marsh and Brooks (1989) followed initial releases and found that razorback suckers were lost to resident catfish within a matter of hours. Predation by non-natives was finally recognized as a basin-wide problem by the early 1990s (Hawkins and Nesler 1991). Since then researchers have identified that the majority of introduced fish species, including their young and nonnative crayfish (Decapoda) and frogs (Salientia) contribute to predation losses (Tyus and Saunders 2000a; Carpenter 2000; Mueller et al. 2003).

Differing Native Fish Management Philosophies

Two resource philosophies evolved in the Colorado River basin during the late 1980s: the establishment of (1) the Upper Colorado River Basin Recovery Implementation Program in 1987 and (2) a conservation movement to actively manage two endangered species in the lower basin which began in 1989. The goal of the Recovery Program was to recover the four mainstem native fishes: the Colorado pikeminnow, humpback chub (*Gila cypha*), bonytail, and razorback sucker, the latter in an effort to prevent listing through habitat restoration. The program consisted of a consortium of resource agencies and water users and was developed on the premise that recovery could occur within 15 years in conjunction with continued water development (Wydoski and Hamill 1991). Recovery efforts were led by USFWS Region 6 and were limited to the upper basin where habitat alteration was believed less severe. Initially, recovery centered on habitat restoration, including the restoration of historic flow regimes which had been disrupted by reservoir storage (Valentine and

Figure 1. Map of the Colorado River basin, southwestern United States.



Archer 1882). Since 1990, emphasis has shifted toward restoring floodplain wetlands and predator removal and control (Lentsch et al. 1996a,b; Wydoski and Wick 1998). The challenges of predator control and recovery were presented by Tyus and Saunders (2000) in an earlier issue of *Fisheries* (25[9]:17-24).

While recovery efforts were focusing on the upper basin, the only wild bonytail (numbers unknown) and the majority of surviving razorback suckers (95%) were found in Lake Mohave, a reservoir downstream of Hoover Dam (Lanigan and Tyus 1989; Marsh et al. 2003). Minckley et al. (1991) reported the relic razorback sucker population was comprised of old individuals and predicted their demise by the end of the century. By this time, bonytail had become exceedingly rare. An ad hoc work group was formed to prevent that from happening. While area biologists felt recovery was neither technically nor politically feasible in the lower basin, it was believed that both populations could be augmented and maintained through periodic stocking and active management (Mueller 1995). Philosophically, these approaches proved as different as night and day; one program set out to recover the species within 15 years while another acknowledged that long-term management was needed simply to prevent their extinction. Biologically, they both proved difficult to implement.

Stocking Programs

Both razorback sucker and bonytail established impressive communities when several reservoirs filled in the lower basin (Minckley 1983). The razorback sucker population in Lake Mohave swelled to more than 100,000 fish while bonytail were believed less numerous. Aging studies suggested sucker recruitment occurred before predator populations fully established and ceased when they became abundant (McCarthy and Minckley 1987). The population's decline was extensively studied beginning in the early 1970s. Based on the species longevity, the population was predicted to die off near the turn of the century (Minckley et al. 1989; Marsh et al. in press).

Bonytail became extremely rare by the early 1980s. Efforts to secure brood stock were almost too late; the species was saved from extinction by the production from a maximum of five females (Minckley et al. 1989). Stocking of bonytail in Lake Mohave began in 1980 and since then, more than 200,000 small (<10 cm) bonytail have been stocked (Minckley and Thorson 2004). A similar stocking effort for razorback sucker began in 1989 using larger fish (Mueller 1995). The approach involved capturing wild larvae and rearing them to a size large enough to avoid predation. The goal was not only to augment the declining population, but to capture the population's genetic variability, which would have been impractical in hatchery production. Rearing space was in short supply and as an alternative to hatchery production, fish were reared in municipal ponds, isolated reservoir coves, and backwaters blocked by nets (Mueller 1995). The concept expanded to other reaches of the lower river (USFWS 1993; USFWS 1997).

Creation of Predator-Free Habitats

In conjunction with the stocking program, biologists discovered to their amazement that both species had successfully produced young in a 2-ha grow-out pond at Cibola National Wildlife Refuge. This represented the first time in 4 decades where both species produced young in a "natural community." Surveys conducted in 2001 revealed the pond contained hundreds, possibly thousands of naturally spawned bonytail and razorback suckers. Carrying capacity of fish >15 cm was estimated at 4,350 fish/ha or 635 kg/ha (Mueller et al. 2002).

A conservation plan was developed based on the concept of creating predator-free habitats where natives could sustain populations that resembled isolated oxbow communities that were historically common (Minckley et al. 2003; USFWS 2004). These communities were considered temporary and when compromised by predators, natives would be salvaged, and the pond renovated and restocked (Minckley et al. 2003). Communities would provide research opportunities and surplus fish to augment river stocks.

Predator Removal

Hawkins and Nesler's 1991 issue paper emphasized the need for nonnative fish control which was further endorsed by the Tyus and Saunders (1996.) and Lentsch et al. (1996a) reports examining potential strategies. A predator control workshop held by the Upper Colorado River Basin Recovery Implementation Program in 1996 concluded that broad-scale mechanical control was not feasible. Regardless, these projects not only continued but increased in number. Annual funding grew from US $326,000 in 1997 to more than $1.41 million by FY 2000 (USFWS 1988-2003). The program expanded to include preventative programs that included screening, renovation of floodplain fish communities to reduce the likelihood of escape, and the development of new stocking procedures for game fish (USFWS 1996). Projects occurred on the Colorado, Green, Yampa, Gunnison, and San Juan rivers. Another workshop was held in 2002 but unfortunately, conclusions were taken verbatim from individual studies and no attempt was made to assess the program's direction (USFWS 2002a).

Individual removal efforts for the Upper Colorado River Basin Recovery Implementation Program have been typically short-lived, lasting only two or three years and targeting specific species (i.e., northern pike *Esox lucius*, channel catfish) or family groups (i.e., centrarchids, cyprinids). Removal has relied solely on mechanical methods, primarily electrofishing, netting, and angling, and efforts have been based on available resources as opposed to a specific removal level. It is our impression that program administrators believed any level of predator removal was beneficial and would elicit a measurable response from native fishes. The most persistent removal program has taken place in the San Juan River where predator removal has continued for nearly a decade (Holden 2000). Funding for this program has grown to nearly a quarter of a million dollars a year.

Program Status

Stocking Augmentation

Stocking large individuals has helped reestablish or augment declining populations but population levels remain dangerously low. Based on capture rates, survival appears exceedingly poor. Prior to 1996, annual surveys averaged 5.7 bonytails/year of the 180,000 stocked up to that time. Since then an additional 25,000 larger (>25 cm) bonytail were stocked but recent returns (1997–2004) have declined to 1.2 bonytails/year (Minckley and Thorson 2004). Stocked bonytail have survived in the upper river but population estimates or survival rates have yet to be developed (T. Czapla, USFWS, pers. comm.). Poor survival of reservoir and riverine stocks have prompted recommendations to further increase stocking size to >30 cm (Badame and Hudson 2002; Minckley and Thorson 2004).

To date, 85,000 razorback suckers had been stocked into Lake Mohave. Initially, fish as small as 15 cm were released due to a shortage of rearing space. When repatriated razorback suckers started showing up on spawning areas it became evident survival was low (2–6%). In an effort to improve survival, the minimum stocking size has been gradually increased to 35 cm (Marsh et al. in press). Approximately 1,400 razorback suckers have been successfully repatriated back into Lake Mohave by 2002, a scant 2% of the 58,000 fish stocked at that time. The recent size increase will hopefully bolster survival; however, it is quite possible other mortality factors (e.g., dam passage, unknowns) are at play.

Stocking programs elsewhere have experienced similar problems. More than 30,000 large razorback suckers were stocked into Lake Havasu since the mid-1990s and population estimates range between 1,600 and 3,600 fish (5–12%). Biologists are currently attempting to quantify survival rates in the San Juan River and other major tributaries of the upper Colorado River.

Development of Refuge Communities

Substantial recruitment has been documented outside the mainstem for both bonytail and razorback sucker but in all cases, predators were either absent or extremely rare (Pacey and Marsh 1998). Based on the concept of creating predator-free habitats, the Bureau of Reclamation is building 240-ha of refuge communities (USFWS 1997). A 90-ha portion of Beal Lake (Lake Havasu National Wildlife Refuge, Arizona-California) was developed for native fish in 2000 along with a smaller 17-ha pond at Imperial National Wildlife Refuge. The ponds were dredged, chemically renovated, and stocked with more than 20,000 juvenile razorback suckers. Unfortunately, these large-scale attempts to duplicate the success at Cibola have thus far failed. Unreasonable expectations led to reinvasion of unwanted species and fish losses from avian predators (Brouder and Jann 2004). Attempts are now being redirected toward the establishment of smaller, more manageable habitats (Minckley et al. 2003).

JOHN WOODLING

Christina Kemp with a northern pike removed during a large predator removal effort on the Yampa River downstream of Maybell, Colorado.

Predator Removal and Control

To date, nearly $4.4 million has been spent in the upper basin (USFWS 1988-2003) to mechanically remove >1.5 million fish from open systems (Table 2). Most of these fish were small cyprinids and removal costs ranged from $2 to $86 per fish. Increasing pressure from angler groups, land owners, and state resource agencies have restricted or limited removal of some recreational species; this has increased logistics and program costs (Swanson 2001). Recreational species salvaged from removal programs cost 2.5 to 10 times more than hatchery-produced fish (Brooks et al. 2000) and are sometimes placed where they can re-invade treatment areas.

Removal efforts began in 1994 (McAda 1997; Brooks et al. 2000). At the time of this writing, nine removal projects have completed reports (Table 2). The question of whether removal actually benefited natives was addressed by seven of the nine independent investigators and six (86%) responded negatively (Table 2). The one positive response was based solely on the presence of natives (Modde 1997). Six (67%) recommended removal efforts be intensified or expanded. Six reported no significant change while three reported a decline in large non-native predators (McAda 1997; Brooks et al. 2000; Modde and Fuller 2002). Northern pike were substantially reduced because these fish originated as escapees from an upstream reservoir (McAda 1997).

Channel catfish, on the other hand, do reproduce in the river and present a different dilemma. Biologists have successfully reduced the abundance of large channel catfish in the San Juan River (Davis 2003); however, juveniles have become more plentiful, suggesting distribution has simply shifted toward smaller fish. Razorback suckers are being lost when they are only a few days old; this implies they are being lost to small or intermediate, not large, predators (Begon et al. 1996). If so, a shift toward more numerous smaller predators could actually worsen predation pressure for early life stages.

Typically, predator removal programs target the adults of one or two species (Temple et al. 1998; Weidel et al. 2002; Todd et al. 2003). However, the problem is so widespread in the Colorado basin that a minimum of six species are being targeted (USFWS 2002a). Recent studies suggest this number is conservative, as predation is occurring from a much broader host of species and life stages than currently acknowledged (Beyers et al. 1994; Ruppert et al. 1993; Mueller and Carpenter, 2004).

Programs that have measured removal rates and survival are rare. One example occurred in the lower basin where they attempted to mechanically suppress, not eliminate, the predator community to a level where stocked razorback sucker fry would survive. It was assumed predation could be mechanically suppressed in a 1.3 ha backwater that was isolated by barrier net (Mueller and Burke in press). After an intense 5-day effort, 1,900 fish (1,460 fish/ha, 181 kg/ha), mostly largemouth bass, bluegill, and carp (*Cyprinis carpio*) were removed by netting and electrofishing. The backwater was then stocked with 10,000 7-cm razorback suckers. Predator removal continued on a monthly basis using large meshed nets and after 1 year, it was estimated that only nine (0.09%) razorback suckers had survived from the initial stocking. A subsequent rotenone effort 3 years later suggested that nearly 58% of the initial predator biomass was probably removed, based on the assumption the community had recovered (Mueller and Burke in press). The effort was humbling and clearly illustrated the problem faced in larger or less confined habitats.

Discussion

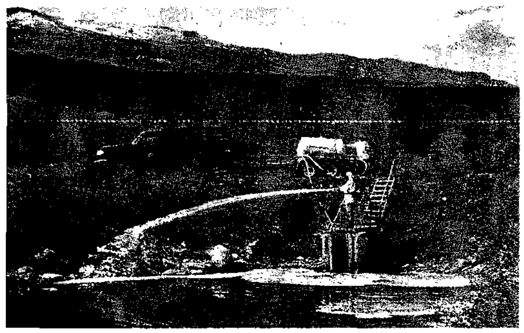
Status of the Natives

We are facing a crisis on the Colorado River. Mainstem native fishes continue to decline in spite of nearly 3 decades of preventative programs. Efforts to prevent the listing of the razorback sucker failed and the species was federally listed as endangered in 1991 (56 FR 54957). In the mainstem,

Table 2. Summary of non-native removal projects conducted on the upper Colorado River in terms of their year(s), location, treatment area, targeted species, method of removal, author's perception of whether natives responded, recommendation to continue treatment, and report citation.

Year	River	Area	Target	Method	Natives+	Continue?	Reference
1994–96	Green*	67 ha	all nonnative species	drain	yes	yes	Modde 1997
1994–98	San Juan	280 km	channel catfish	electrofish	no	yes	Brooks et al. 2000
1995–96	Gunnison	16 km	northern pike	electrofish, fyke nets, trammel nets	not addressed	yes	McAda 1997
1997–98	Green	48 km	Centrarchids, channel catfish	electrofish, fyke nets, trammel nets	no	yes	Jackson and Badame 2002
1998–99	Yampa	57 km	channel catfish	angling, electrofish, fyke nets	not addressed	yes	Modde and Fuller 2002
1998–00	Colorado	28 km	all nonnative species	seining	no	no	Trammel et al. 2002
1998–00	Colorado*	9 ha	all nonnative species	electrofish, trammel nets	no	no	Burdick 2002
1999–01	San Juan	280 km	channel catfish	electrofish	no	yes	Davis 2003
1999–01	Colorado	29 km	Centrarchids	electrofish	no	no	Osmundson 2003

*oxbow



ANITA MARTINEZ

Jon Romatzke and Desiree Powell (Colorado Division of Wildlife) apply rotenone to remove predatory fish from a floodplain pond near Rulison, Colorado.

natural recruitment is absent for both the bonytail and razorback sucker and current monitoring suggests populations of Colorado pikeminnow and humpback chub populations are also declining (K. Bestgen, Colorado State University, pers. comm.). Today, 7 of the 10 mainstem native species are federally listed as endangered, one is state listed, and another is of special concern. The entire native component comprises <2% of the basin's mainstem fish fauna (Minckley 1979; Bundy and Bestgen 2001). The Colorado River has the dubious distinction of being one of the largest rivers in the world with a totally displaced fish community.

The impact of nonnative introductions has become a problem of national concern (Moyle et al. 1986; Minckley and Deacon 1991; Fuller et al. 1999). Lassuy (1995) reported that of 69 fish species listed under the Endangered Species Act, introduced species were cited as a factor in 70% of the cases. Minckley and Deacon (1991) predicted: "Native fishes of the American West will not remain on earth without active management, and I argue forcefully that control of nonnative, warm water species is the single most important requirement for achieving that goal." However, it is one thing to recognize the problem and another to do something about it. Minckley and Deacon (1991) questioned whether we had the resources not to mention the political fortitude to deal with the problem. Unfortunately, this still remains to be seen more than a decade later.

The initial end of the 15-year Upper Basin Recovery Plan has passed without celebration or review. Institutional momentum has pushed for a 10-year continuance but major changes in recovery strategies may not be an option. Brower et al. (2001) reviewed the Upper Basin Recovery Program and suggested the fishes' fate may have become secondary to the recovery process itself. It seems to me that politically, consensus may have become more important than recovery. For example, the Multi-Species Conservation Plan in the lower basin was just finalized after 8 years of debate (SAIC/Jones and Stokes 2004). These programs are popular because the process insures the continued use of water while providing funds necessary to maintain environmental programs. Unfortunately, the process then becomes self-perpetuating, while relic populations are lost. Lassuy (1995) quotes Soule's (1986) warning; "dithering and endangering are often linked." Lassuy went on to say "let us not dither any longer." Once these wild populations are gone, they become increasingly difficult to recover, let alone reintroduce. For example, the Colorado pikeminnow disappeared from the lower mainstem nearly 3 decades ago. Its reintroduction to the lower river continues to be blocked by incidental take concerns by the state of California (California Fish and Game Code 5515).

Predator Control

Predator control is undoubtedly the key to natural recruitment, but how and where to accomplish this continues to be debated. Some species show a remarkable persistence in spite of preventative efforts. Our past experience has shown that:

- Past attempts to benefit mainstem communities or establish large refuge populations have generally failed due to nonnative fish (USFWS 2002a).
- Studies have shown that recolonization by unwanted species is typically rapid (Martinez 2004; Davis 2003; USFWS 2002a; Brouder and Jann 2004);
- Successful stream renovation has been limited to headwaters and relied exclusively on the use of physical barriers and multiple chemical applications (Rinne and Turner 1991);
- Thus far, successful removal efforts have been limited to non-native species with limited reproduction and large individuals that were more susceptible to capture (McAda 1997); and
- Significant bonytail and razorback sucker recruitment has been limited to small (<3 ha) ponds where predators were absent (Mueller 1995; Pacey and Marsh 1998) or in larger ponds that were drained and resident predator populations were completely removed (Modde 1997; Mueller et al. 2002).

Is Mechanical Predator Control Even Feasible?

The above five statements beckon the question: "Is mainstem nonnative fish control even feasible?" We can remove unwanted fish but we have yet to do it on a scale and duration that triggers positive responses from native fish communities. In a previous *Fisheries* article, Beamesderfer (2000) proposed a simple decision making model that contained three basic questions.

- The first: "Is predation significant?"
- The second is: "Is predator removal affectable?"
- The last question is: "Would the public accept it?"

There is no doubt predation is impacting and in some cases preventing native fish recruitment. Beamesderfer's second question remains unanswered, partly due to a common misconception that any predator reduction somehow benefits natives. As a result, removal levels have seldom been measured or systematically increased to a level that triggers a native response. Predators continue to be removed but we fail to address the real question: what level of treatment is necessary to facilitate native recruitment? Until that is known, it is impossible to determine if mechanical removal is a practical solution.

Renovation has been successful especially for small isolated habitats or headwaters where physical barriers can be installed. Seldom is the opportunity taken to test the effect of partial suppression, which would provide valuable insight for communities where total eradication is not possible or desirable. Can native communities exist if predator numbers are artificially suppressed and to what level? Such thresholds are typically the foundation of larger control programs (Wiley and Wydoski 1993; Hankin and Richards 2000; Ward 2002). Unfortunately, the information needed to determine removal levels is difficult and often conducted in stages of increased intensity which takes considerable planning, effort, time, and coordination. Most importantly, it should be conducted on a scale that permits experimental integrity and measurable results.

The continued decline of native communities suggests that either predator removal is simply not feasible or we have not approached the problem aggressively enough. For example, the 58% (181 kg/ha) treatment of Davis Cove only resulted in the survival of 0.09% of the razorback sucker stocked (Mueller and Burke in press). This rate would likely have been even lower if fish smaller than 7 cm had been stocked. Predation experiments compared larval razorback sucker (44,000/ha) survival among three different sunfish densities (14, 71, 354/ha; Pacey and Marsh 1998). High density trials mimicked sunfish densities found in Davis Cove; after 4 months all suckers were lost, even though fish were provided supplemental feed. Suckers did survive when predator numbers were reduced by >80% (Pacey and Marsh 1998).

Other studies suggest that even a higher removal level may be necessary in natural settings. Weidel et al. (2002) reported a positive response by prey species when smallmouth bass (*Micropterus dolomieui*) were reduced by >90% and other studies suggest even greater reductions might be necessary (Lydeard and Belk 1993; Dudley and Matter 2000). Based on available information, it appears reductions >80% may be required to facilitate some measurable response in recruitment.

Charting a Future Course

A great deal of time and funding has been expended that has done little or nothing to reverse the native species decline. We have to slow and hopefully reverse that trend. In charting a future course, as Beamesderfer (2000) pointed out, we must determine what actually works and what the public will accept. We have been poking the beast half-heartedly for more than a decade and have yet to seen any reaction. If we're to maintain public support we have to be more realistic, disciplined, and creative in implementing what works rather than what does not work.

Boersma et al. (2001) recently reviewed the effectiveness of recovery plans and found the most successful had seized opportunities for adaptive management, promoted effective recovery planning while improving the species' status, and clearly linked recovery criteria to the species' biology. Their analysis showed that multi-species or broad ecological approaches were less effective than single-species plans, which suggests we need to capitalize on what has worked at Cibola High Levee Pond with bonytail and razorback suckers.

The solution may well be an integrated approach that examines ways of benefiting specific species both in and out of the mainstem. Additional predator/prey research is critically needed to determine what level of predator removal and suppression is necessary in the mainstem. While riverine stocks are being rebuilt, small refuge communities could provide researchers and managers opportunities to quantify and interpret predator/prey interactions. For example, predators could be introduced and monitored to determine at what point they restricted native recruitment. At that point, predator removal could be tested to measure their effectiveness and determine the treatment level necessary to resume natural recruitment. It would allow managers to test the practicality of removal techniques on a manageable, measurable, and economic scale.

Forcing recovery in altered habitats choked with predators or developing refuge communities to meet either acreage commitments or down-listing criteria has distracted us from realizing any biological progress. I'm not suggesting we give up on recovery in the river. However, we need to embrace recovery and conservation features that directly benefit the species while advancing our knowledge beyond things that do not work. Small, manageable habitats would improve the species' status and provide opportunities to study natural recruitment in a setting where complex research issues (predator/prey) can be effectively tested. It would also provide opportunities to actively manage these species, which hopefully will lead to the knowledge required for their eventual recovery (Williams 1991; Rinne and Turner 1991; Magoulick and Kobza 2003).

The basin desperately needs an open and frank review of what has and has not worked in predator removal programs worldwide. I recommend the U.S. Fish and Wildlife Service convene a panel of outside experts to help develop strategies to best combat predation within the basin. The debate needs to include not only listed, but all native fish species. In the mean time, I would suggest recovery and conservation programs consider the following actions:

1. Prioritize and design future removal and control activities based on the likelihood of reducing and maintaining the densities of unwanted communities by >80%.
2. Construct small (<2 ha) or drainable oxbow or refuge communities for the dual purpose of conservation and predator/prey research (Minckley et al. 2003). Increases in size should be based on prior biological success rather than institutional mandates.
3. Measure program success based on parameters directly linked to species biology and community response (e.g., stocking goals based on survival rather than hatchery production, habitat alterations based on community response rather than acreage developed).
4. Lastly, develop a conceptual model that links relevant ecosystem and biological components that could be used to identify, plan, and measure future removal actions (Bestgen et al. 1997).

Acknowledgements

Thanks to John Rinne, Chuck McAda, David Hamilton, Jeanette Carpenter, and the anonymous reviewers for their comments and suggestions. I also thank Anita Martinez and Lori Martin for providing photographs.

References

Badame, P. V., and **J. M. Hudson.** 2002. Reintroduction and monitoring of hatchery-reared bonytail in the Colorado and Green rivers: 1996-2001. Publication 03-13, Utah Division of Wildlife Resources, Salt Lake City, UT.

Beamesderfer, R. 2000. Managing fish predators and competitors: deciding when intervention is effective and appropriate. Fisheries 25(6):18-23.

Begon, M., J. L. Harper, and **C. R. Townsend.** 1996. Ecology: individuals, populations, and communities. 3rd edition. Blackwell Science Ltd., London.

Bestgen, K. R., D. W. Beyers, G. B. Haines, and **J. A. Rice.** 1997. Recruitment models for Colorado squawfish: tools for evaluating relative importance of natural and managed processes. Contribution 95, Larval Fish Laboratory, Colorado State University, Fort Collins.

Bestgen, K. R., G. B. Haines, R. Brunson, T. Chart, M. Trammell, R. T. Muth, G. Birchell, K. Chrisopherson, and **J. M. Bundy.** 2002. Status of wild razorback sucker in the Green River basin, Utah and Colorado, determined from basin wide monitoring and other sampling programs. Contribution 126, Colorado State University Larval Fish Laboratory, Fort Collins.

Beyers, D. W., R. T. Muth, and **M. S. Farmer.** 1994. Experimental evidence of competition between larvae of Colorado squawfish and fathead minnow. Contribution 72, Larval Fish Laboratory, Colorado State University, Fort Collins.

Boersma, P. D., P. Kareiva, W. F. Fagan, J. A. Clark, and **J. M. Hoekstra.** 2001. How good are endangered species recovery plans? BioScience 51:643-649.

Brooks, J. E., M. J. Buntjer, and **J. R. Smith.** 2000. Non-native species interactions: management implications to aid in recovery of the Colorado pikeminnow *Ptychocheilus lucius* and razorback sucker *Xyrauchen texanus* in the San Juan River, CO-NM-UT. San Juan River Basin Recovery Implementation Program, U.S. Fish and Wildlife Service, Albuquerque, New Mexico.

Brouder, M. J. and **D. B. Jann.** 2004. Management of native fish protected habitats on Imperial and Havasu National Wildlife Refuges, 2002-2004. USFWS-AZFRO-PA-04-016, U.S. Fish and Wildlife Service, Pinetop, Arizona.

Brower, A., C. Reedy, and **J. Yelin-Kefer.** 2001. Consensus versus conservation in the Upper Colorado River Basin Recovery Implementation Program. Conservation Biology 15:1001-1007.

Bundy, J. M., and **K. R. Bestgen.** 2001. Evaluation of the Interagency Standard Monitoring Program Sampling Technique in backwaters of the Colorado River in the Grand Valley, Colorado Contribution 119, Larval Fish Laboratory, Colorado State University, Fort Collins.

Burdick, B. D. 2002. Evaluating the use of sloped gravel-pit ponds by listed and non-listed native fishes and removal of non-native fishes from sloped gravel-pit ponds in the upper Colorado River near Grand Junction, Colorado. Recovery Program Report Project C-6-G, Colorado River Fishery Project, U.S. Fish and Wildlife Service, Grand Junction, Colorado.

Carpenter, J. 2000. Effects of introduced crayfish on selected native fishes of Arizona. Ph.D. dissertation, University of Arizona, Tucson.

Davis, J. E. 2003. Non-native species monitoring and control, San Juan River 1999-2001. Progress report for the San Juan River Recovery Implementation Program. U.S. Fish and Wildlife Service, Albuquerque, New Mexico.

Dill, W. A. 1944. The fishery of the lower Colorado River: California Fish and Game. 30:109-211.

Dudley, R. K., and **W. J. Matter.** 2000. Effects of small green sunfish (*Lepomis cyanellus*) on recruitment of Gila chub (*Gila intermedia*) in Sabino Creek, Arizona. Southwestern Naturalist 45:24-29

Fuller, P. L., L. G. Nico, and **J. D. Williams.** 1999. Nonindigenous fishes introduced into inland waters of the United States. American Fisheries Society Special Publication 27, Bethesda, Maryland.

Hankin, D. G., and **J. Richards.** 2000. The northern pikeminnow management program. An independent review of program justification, performance, and cost-effectiveness. Submitted to Northwest Power Planning Council, Portland, Oregon.

Hawkins, J. A., and **T. P. Nesler.** 1991. Non-native fishes of the Upper Colorado River Basin: an issue paper. Larval Fish Laboratory, Colorado State University, Fort Collins.

Hawkins, L. A., H. M. Tyus, W. L. Minckley, and D. L. Schultz. 2004. Comparison of four techniques for aging adult Colorado pikeminnow, *Ptychocheilus lucius*. Southwestern Naturalist 49:203-208.

Holden, P. B. 2000. Program evaluation report for the 7-year research period (1991-1997). San Juan River Basin Recovery Implementation Program, U.S. Fish and Wildlife Service, Albuquerque, New Mexico.

Holden, P. B., P. D. Abate, and J. B. Ruppert. 1997. Razorback sucker studies on Lake Mead, Nevada 1996-1997 Annual Report, PR-578-1. Bio/West Inc., Logan, Utah.

Jackson, J. A., and P. V. Badame. 2002. Centrarchid and channel catfish control in the middle and lower Green River; 1997 and 1998. Upper Colorado River Endangered Fish Recovery Program Project 59, Utah Division of Wildlife Resources, Moab.

Johnson, J. E. 1985. Reintroducing the natives: razorback sucker. Proceedings of the Desert Fishes Council 13(1981):73-79.

Lanigan, S. H., and H. M. Tyus. 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.

Lassuy, D. R. 1995. Introduced species as a factor in extinction and endangerment of native fish species. American Fisheries Society Symposium 15:391-396.

Lentsch, L. D., R. T. Muth, P. D. Thompson, B. G. Hoskins, and T. A. Crowl. 1996a. Options for selective control of non-native fishes in the Upper Colorado River Basin. Publication 96-14. Utah Division of Wildlife Resources, Salt Lake City.

Lentsch, L. D., T. A. Crowl, P. Nelson, and T. Modde. 1996b. Levee removal strategic plan. Publication 96-6. Utah Division of Wildlife Resources, Salt Lake City.

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

Magoulick, D. D., and R. M. Kobza. 2003. The role of refugia for fishes during drought: a review and synthesis. Freshwater Biology. 48:1186-1198.

Marsh, P. C. 1997. Age estimation from otoliths of bonytail chub *Gila elegans* from Lake Mohave, Arizona and Nevada. Order 22340-5-0033 to U.S. Fish and Wildlife Service, 24 February 1997, Parker Fishery Resources Office, Parker, Arizona.

Marsh, P. C., and J. E. Brooks. 1989. Predation by ictalurid catfishes as a deterrent to re-establishment of hatchery-reared razorback suckers. The Southwestern Naturalist 34(2):188-195.

Marsh, P. C., C. A. Pacey, and B. R. Kesner. 2003. Decline of wild razorback sucker in Lake Mohave, Colorado River, Arizona, and Nevada. Transactions of the American Fisheries Society 132: 1251-1256.

Marsh, P. C., B. R. Kesner, and C. A. Pacey. In press. Repatriation as a management strategy to conserve razorback sucker in Lake Mohave, AZ. North American Journal of Fisheries Management.

Martinez, A. M. 2004. An evaluation of nonnative fishes control treatments in ponds along the Colorado and Gunnison rivers. Recovery Program Project 18/19. Prepared for Upper Colorado River Endangered Fish Recovery Program. Colorado Division of Wildlife, Grand Junction.

McAda, C. W. 1997. Mechanical removal of northern pike from the Gunnison River, 1995-1996. Colorado River Recovery Implementation Program, Project 58. U.S. Fish and Wildlife Service, Grand Junction, Colorado.

McCarthy, M.S., and W.L. Minckley. 1987. Age estimation for razorback sucker from Lake Mohave, Arizona, and Nevada. Journal of Arizona-Nevada Academy of Sciences. 21:87-97.

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.

Minckley, C. O. and M. Thorson. 2004. Bonytail broodstock collection report, Lake Mohave AZ-NV, 2004. USFWS-AZFRO-PA-04-0017. U.S. Fish and Wildlife Service, Parker, Arizona.

Minckley, W. L. 1979. Aquatic habitats and fishes of the Lower Colorado River. Submitted to the Bureau of Reclamation, Contract No. 14-06-300-2529. Arizona State University, Tempe.

Minckley, W. L. 1983. Status of the razorback sucker, *Xyrauchen texanus* (Abbott), in the lower Colorado River basin. The Southwestern Naturalist 28:165-187.

_____. 1999. Aquatic habitats and fishes of the lower Colorado River, Southwestern United States. Contract 14-06-300-2529. Arizona State University submitted to Bureau of Reclamation, Boulder City, Nevada.

Minckley, W. L., B. G. Buth, and R. L. Mayden. 1989. Origin of brood stock and allozyme variation in hatchery-reared variation in hatchery-reared bonytail, endangered North American cyprinid fish. Transactions of the American Fisheries Society 118:131-137.

Minckley, W. L., and J. E. Deacon (editors). 1991. Battle against extinction, native fish management in the American West. The University of Arizona Press, Tucson.

Minckley, W. L., P. C. Marsh, J. E. Brooks, J. E. Johnson, and B. L. Jensen. 1991. Management toward recovery of the razorback sucker. Pages 303-378 *in* Minckley and Deacon, eds. Battle against extinction: native fish management in the American West. University of Arizona Press, Tucson.

Minckley, W. L., P. C. Marsh, J. E. Deacon, T. E. Dowling, P. W. Hedrich, W. J. Matthews, and G. Mueller. 2003. A conservation plan for native fishes of the lower Colorado River. BioScience 53:219-234.

Modde, T. 1997. Fish use of Old Charley Wash: an assessment of floodplain wetland importance to razorback sucker management and recovery. Recovery Program Project CAP-6. U.S. Fish and Wildlife Service, Vernal, Utah.

Modde, T., and M. Fuller. 2002. Feasibility of channel catfish reduction in the lower Yampa River. Upper Colorado River Basin Recovery Implementation Program Project 88. Colorado River Fish Project, Vernal, Utah.

Moyle, P. B., H. W. Li, and B. A. Barton. 1986. The Frankenstein effort: impacts of introduced fishes on native fishes in North America. Pages 415-426 *in* R. H. Stroud, ed. Fish culture in fisheries management. American Fisheries Society, Bethesda, MD.

Mueller, G. 1995. A program for maintaining the razorback sucker in Lake Mohave. American Fisheries Society Symposium 15:127-135.

Mueller, G. A., and P. C. Marsh. 2002. Lost, a desert river and its native fishes: A historical perspective of the lower Colorado River. USGS/BRD/ITR—2002—0010. U.S. Geological Survey, Denver, Colorado.

Mueller, G. A. and J. Carpenter. 2005. Cibola High Level Pond Annual Report 2004. Open-Fish Report 2005-1075, U.S. Geological Survey Denver Colorado.

Mueller, G., J. Carpenter, and C. Minckley. 2002. Cibola High Levee Pond: draft annual report for FY-2002. U.S. Geological Survey, Denver, Colorado. Available at www.fort.usgs.gov/products/publications/11000/11000-A.pdf.

Mueller, G., J. Carpenter, P. C. Marsh, and C. Minckley. 2003. Cibola High Levee Pond: draft annual report for FY-2003. U.S. Geological Survey, Denver, Colorado.

Mueller, G., and T. Burke. 2005. Survival of young razorback sucker (*Xyrauchen texanus*) in relation to stocking rates (fish/ha) and in the presence and absence of predator communities in Lake Mohave, Arizona-Nevada. Pages 155-163 *in* C. L. Springer and S. Leon, eds. Proceedings of two symposia. Restoring native fish to the lower Colorado River: Interactions of native and non-native fishes. 13-14 July 1999, Las Vegas, Nevada. Restoring natural function within a modified riverine environment: the lower

Colorado River. 8-9 July 1998. U.S. Fish and Wildlife Service, Southwestern Region, Albuquerque, New Mexico.

Osmundson, D. B. 2003. Removal of non-native centrarchids from Upper Colorado River Backwaters, 1999-2001: Summary of results. Recovery Implementation Program Project 89. Colorado River Fishery Project, U.S. Fish and Wildlife Service, Grand Junction, Colorado.

Pacey, C. A., and **P. C. Marsh.** 1998. Resources used by native and non-native fishes of the lower Colorado River: literature review, summary, and assessment of relative roles of biotic and abiotic factors in management of imperiled indigenous ichthyofauna. Submitted to BOR, Boulder City, Nevada, Agreement 7-MT-30-R0012 by Arizona State University, Tempe.

Rinne, J. N., and **P. R. Turner.** 1991. Reclamation and alteration as management techniques, and a review of methodology in stream renovation. Pages 219-246 *in* Minckley and Deacon, eds. Battle against extinction: native fish management in the American West. The University of Arizona Press, Tucson.

Ruppert, J. B., R. T. Muth, and **T. P. Nesler.** 1993. Predation on fish larvae by adult red shiner, Yampa and Green rivers, Colorado. The Southwestern Naturalist 38:397-399.

Ryden, D. W. 1997. Five-year augmentation plan for razorback sucker in the San Juan River. USFWS, Colorado River Fishery Project, Grand Junction, Colorado.

SAIC/Jones and **Stokes.** 2004. Lower Colorado River Multi-Species Conservation Program. Volume II: Habitat Conservation Plan. Final Report. Dec17. (J&S 00450.00) Sacramento, California.

Soulé, M. E. 1986. Conservation biology: the science of scarcity and diversity. Sinauer Associates, Sunderland, Massachusetts.

Swanson, J. 2001. Resident shocked about fish tales (newspaper article). Craig Daily Press, 15 May 2001, Craig, Colorado.

Temple, R., K. Daily, T. Sharader and **B. Hooton.** 1998. Predation issues: introduced fishes. Oregon Department of Fish and Wildlife. Available at: www.dfw.state.or.us/odfwhtml/research&reports/predatorplans/fishactplan.html.

Todd, M. K., J. L. Arnold, P. E. Bigelow, B. D. Ertel, and **D. L. Mahony.** 2003. Yellowstone fisheries and aquatic sciences, annual report 2002. YCR-NR-2003-02, National Park Service, Yellowstone National Park, Wyoming.

Trammel, M., R. Valdez, H. Johnstone, and **L. Jonas.** 2002. Non-native fish control in backwater habitats in the Colorado River. Final Report, Recovery Implementation Program Project 87b. SWCA, Inc. Environmental Consultants, Flagstaff, Arizona.

Tyus, H.M., and **J. F. Saunders.** 1996. Nonnative fishes in the upper Colorado River basin and a strategic plan for their control. Final Report of University of Colorado Center for Limnology to Upper Colorado River Endangered Fish Recovery Program, Denver, Colorado.

Tyus, H. M., and **J. F. Saunders, III.** 2000a. Nonnative fishes in the upper Colorado River basin and a strategic plan for their control. Final Report to the U.S. Fish and Wildlife Service. (Contract 14-48-0006-95-923). Center for Limnology, University of Colorado, Boulder.

Tyus, H. M., and **J. F. Saunders, III.** 2000b. Nonnative fish control and endangered fish recovery: lessons from the Colorado River. Fisheries 25(9):17-24.

USFWS (U.S. Fish and **Wildlife Service).** 1988-2003. Fiscal year work plan. Recovery Implementation Program for endangered fish species in the Upper Colorado River Basin. USFWS Region 6, Denver, Colorado.

_____. 1993. Biological opinion on the proposed action of the Lake Havasu Fisheries Improvement Partnership Program. USFWS Region 2, Albuquerque, New Mexico.

_____. 1996. Procedures for stocking nonnative fish species in the Upper Colorado River Basin. Colorado Division of Wildlife, Utah Division of Wildlife Resources, Wyoming Game and Fish Department, and USFWS, Denver, Colorado.

_____. 1997. Biological and conference opinion on lower Colorado River operation and maintenance, Lake Mead to Southerly International Boundary. USFWS Region 2, Albuquerque, New Mexico.

_____. 2002a. Non-native fish control workshop: summary, conclusions, and recommendations. Proceeding of the September 2002 meeting. Upper Colorado River Endangered Fish Recovery Program, Lakewood, Colorado.

_____. 2002b. Bonytail (*Gila elegans*) Recovery goals: amendment and supplement to the Bonytail Chub Recovery Plan. USFWS, Mountain-Prairie Region 6, Denver, Colorado.

_____. 2002c. Razorback sucker (*Xyrauchen texanus*) recovery goals: amendment and supplement to the Razorback Sucker Recovery Plan. USFWS, Mountain-Prairie Region 6, Denver, CO.

_____. 2004. Draft management plan for the big-river fishes of the lower Colorado River basin: amendment and supplement to the bonytail, humpback chub, Colorado pikeminnow, and razorback sucker recovery plans. USFWS, Albuquerque, New Mexico.

Valentine, J. J. and **D. L. Archer.** 1982. Colorado River Fishery Project, Part I. Summary Report. Contract 9-07-40-L-1016. U.S. Fish and Wildlife Service, Salt Lake City, Utah.

Ward. D. L. 2002. Predator control program (24 October 2002 draft). Submitted to the Northwestern Power Planning Council. Oregon Department of Fish and Wildlife, Portland.

Weidel, B. C., D. C. Josephson, and **C. E. Kraft.** 2002. Fish community response to removal of introduced smallmouth bass in an oligotrophic Adirondack lake. Department of Natural Resources, Cornell University, Ithaca, N.Y. Available at: www.dnr.cornell.edu/facstf/kraft/publications/weidel_et_al_CJFAS.pdf.

Wiley, R. W., and **R. S. Wydoski.** 1993. Management of undesired species of fish. Pages 335-354 *in* C. C. Kohler and W. H. Hubert, eds. Inland fisheries management in North America. American Fisheries Society, Bethesda, Maryland.

Williams, J. E. 1991. Preserves and refuges for native western fishes: history and management. Pages 171-190 *in*, W. L. Minckley and J. E. Deacon, eds. Battle against extinction: native fish management in the American West. The University of Arizona Press, Tucson.

Wydoski, R. S., and **J. Hamill.** 1991. Evolution of a cooperative recovery program for endangered fishes in the upper Colorado River basin. Pages 123-135 *in* W.L. Minckley and J. E. Deacon, eds. Battle against extinction: native fish management in the American West. University of Arizona Press, Tucson.

Wydoski, R. S., and **E. J. Wick.** 1998. Ecological value of floodplain habitats to razorback suckers in the upper Colorado River basin. Upper Colorado River Basin Recovery Program. U.S. Fish and Wildlife Service, Denver, Colorado.