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Nonnative Fish Control and Endangered Fish Recovery: Lessons from the Colorado River

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Nonnative Fish Control and Endangered Fish Recovery:

Lessons from the Colorado River

By Harold M. Tyus and James F. Saunders, III

ABSTRACT

Native freshwater fish populations are declining in North America and more than 100 fishes are federally listed as threatened or endangered. The Colorado River system in the southwestern United States has been especially affected. Most of its native fish populations are in decline, including four "big river" fishes, Colorado pikeminnow (*Ptychocheilus lucius*), humpback chub (*Gila cypha*), bonytail (*G. elegans*), and razorback sucker (*Xyrauchen texanus*), whose populations have declined so precipitously that they are endangered. Physical habitat alteration caused native fish declines, but nonnative fishes pose a more serious threat to native fishes than previously thought. Nonnative fish control measures needed in the upper Colorado River system, identified in part by a workshop of experts, include: (1) preventing movements of game fishes out of impoundments and curtailing future stockings, (2) reducing numbers of small, nonnative cyprinids in shoreline habitat used as rearing areas by young native fishes, and (3) increasing the harvest of channel catfish (*Ictalurus punctatus*) and common carp (*Cyprinus carpio*) in the mainstream. Large-scale implementation of these nonnative fish control measures has proven difficult. Recovery efforts have identified the need for developing nonnative fish control strategies and testing methodologies, but no solutions have emerged. A holistic approach, including ecosystem recovery plans, should be used in systems where more than one species share common problems, such as interactions with nonnative fishes. Nonnative fish interactions should be suspected as a potential cause of declining native fish populations.

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Introduction

At least 536 nonnative fishes (representing 75 families) have been introduced into freshwaters of the United States for some practical or aesthetic purpose (Fuller et al. 1999; Heidinger 1999; Li and Moyle 1999). However, almost all introductions have proven harmful to native communities (Taylor et al. 1984; Courtenay and Robins 1989). As nonnative fishes were introduced, many native fish populations declined, presumably due to adverse interactions that have affected 70% of fishes listed under provisions of the Endangered Species Act (ESA) of 1973 (Lassuy 1995; U.S. Fish and Wildlife Service [USFWS] 1998a). Of 30 fishes that became extinct in the United States during the 20th century, introduced fishes were implicated in 24 extinctions (80%), and introduced fishes were the only factor in two extinctions (Miller et al. 1989). Although adverse effects of nonnative fishes have been reported for many years, relatively little has been done to solve the nonnative fish problem (Courtenay 1995).

The Colorado River basin of the southwestern United States has been extensively changed by physical habitat alteration and also is among the top five river basins in the United States most affected by introduction of nonnative fishes (Fuller et al. 1999). Effects on the 51 freshwater fish taxa (species and subspecies) native to the Colorado River have been extreme: 2 are extinct, 22 are federally listed as endangered (16) or threatened (6), and 1 fish is a candidate for listing (USFWS 1997, 1998a). Many of the remaining are considered species at risk and protected by state agencies (Carlson and Muth 1989; Rahel et al. 1999). In addition, three estuarine species have been virtually extirpated from the once extensive and productive lower Colorado River delta.

The effects of nonnative fish introductions on stream fish communities have not been well documented, but the few studies that exist have reported serious declines of the native stream fishes (e.g., 77% of 31 cases; Ross 1991). The Colorado River basin arguably provides the most complete record for nonnative fish problems than any other large river system in the world, and can perhaps provide some valuable lessons for conservation of native fishes. We explore the role of nonnative species in

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Figure 1. Northern pike, introduced into the Yampa River of Colorado, rapidly spread downstream into critical habitat of endangered fishes.

the decline of four endangered Colorado River fishes of the native big-river fish community (Minckley et al. 1986), Colorado pikeminnow (*Ptychocheilus lucius*), humpback chub (*Gila cypha*), bonytail (*G. elegans*), and razorback sucker (*Xyrauchen texanus*). Fish control needs and options were considered, in part, by using information obtained from a fish control workshop sponsored by the Upper Colorado River Endangered Fish Recovery Program. Finally, we present strategies for controlling the most troublesome nonnative species in the upper Colorado River basin, and discuss some of the lessons learned from our evaluation of recovery efforts.

Introduction and effects of nonnative fishes

Native Colorado River fishes have been swamped by introduction of at least 100 nonnative fishes during the last century (Fuller et al. 1999). Nonnative fishes adapt well to altered habitats (e.g., reservoirs and their tailwaters) in the lower Colorado River basin (i.e., below Lee Ferry Arizona; Minckley 1982). Riverine habitat in the upper Colorado River basin has been less affected by habitat alteration, and thus supports most of the remaining big-river fish populations (Tyus et al. 1982; Carlson and Muth 1989). Main channels in the upper basin that supported only 13 native fishes (Tyus et al. 1982) have been invaded by over 60 fishes (Fuller et al. 1999), many of which are now self-sustaining.

Scientists have expressed concern for more than 50 years about potential problems of nonnative fish introductions on native Colorado River fishes. In about 1930, Dill (1944) first noted declining native fish populations coincident with increases in channel catfish (*Ictalurus punctatus*), largemouth bass (*Micropterus salmoides*) and other nonnative fishes, and suggested that introduced fishes were the cause. This pattern of declining native fish populations with increasing nonnative populations has become more pronounced and widespread (Miller 1961; Minckley 1982; Carlson and Muth 1989).

Federal, state, and local agencies have purposefully stocked vast regions of the United States with nonnative fishes, including waters of the upper Colorado River basin. The largest drainage areas in the upper basin include lands in the states of Colorado and Utah. Nonnative sportfish stocking in those states has been intense, and supports 99% and 96% of their recreational fisheries, respectively (Horak 1995). The state of Colorado also has stocked the greater diversity of fishes, and it ranks third in the number of nonnative fish introductions in the United States (106 species; Fuller et al. 1999). Recently however, after years of negotiation, all agencies have agreed to cease stocking nonnative fish, with the exception of trout, into waters of the upper Colorado River basin.

Although major stocking efforts in the waters of the upper Colorado River basin have been suspended, previous stocking efforts left a potent legacy. Nonnative sport fishes continue to proliferate by reproducing in river channels and invading from off-channel habitat. For example, smallmouth bass (*Micropterus dolomieu*) and northern pike (*Esox lucius*; Figure 1) reproduce annually in main river channels, resulting in a steady supply of young predators. Impoundments and other water bodies with seasonal or permanent connections to river channels provide crops of sunfishes, pike, catfish, and carp that subsequently invade riverine habitat.

In addition to intentionally introduced game fishes, one of the most troublesome groups of nonnative fishes are small, nongame fishes [e.g., red shiner (*Cyprinella lutrensis*) and fathead minnow (*Pimephales promelas*)] that were unintentionally introduced into the Colorado system via baitbuckets and as "hitch-hikers" accompanying stockings of other species. These small fishes are aggressive, abundant, and widely distributed, constituting over 90% of the standing crop of fishes in backwater habitat used as nursery areas by the listed fishes (McAda et al. 1994). As a result of all of the preceding introductions, the fauna of the mainstream river ecosystem is continually changing with ongoing "biological pollution" (McKnight 1993).

Not only has the decline of the big-river fishes been associated with fish introductions, but there is a large and growing body of evidence that reveals the mechanisms (Hawkins and Nesler 1991; Minckley et al. 1991; Lentsch et al. 1996). [Note: Much of the information is available only in report form. Unpublished reports cited here can be obtained from the U.S. Fish and Wildlife Service, Upper Colorado River Endangered Fish Recovery Program, Box 25486, Denver Federal Center, Denver, CO 80225]. Predation and competition from nonnative fishes are the most frequent mechanism cited, but they are not the only negative interactions. There are several accounts of the piscivorous Colorado pikeminnow "choking" on spines of channel catfish (McAda 1983; Pimental et al. 1985), and introgressive hybridization with nonnatives can pose a serious threat (reviewed by Ross 1997).

Competition between native and nonnative fishes is certain to occur to some degree (Taylor et al. 1984), but there is little quantitative information. Red shiner and fathead minnow are of great concern because of their

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aggressive nature. Both fishes compete for space with, and are more aggressive than young of native cyprinids, including Colorado pikeminnow (Karp and Tyus 1990). Diets of the red shiner and the fathead minnow overlap with young Colorado pikeminnow (Muth and Snyder 1995).

Evidence for nonnative fish predation on native Colorado River fishes includes visual observations and stomach content analyses. We have compiled a list of such predation (Table 1), which should leave no doubt that nonnative predation is a potentially powerful force. Especially affected is the razorback sucker, in which basinwide recruitment failure has been linked to predation by nonnative fishes (reviewed by Minckley et al. 1991; USFWS 1998b).

Predation on larval Colorado River fishes by some of the smaller introduced cyprinids has been suspected for some time, and several species have been recently implicated. The small, but highly territorial fathead minnow, has been shown to tear apart and consume sucker larvae even in the presence of other suitable prey (Dunsmoor 1996). Red shiner, an opportunistic feeder of larval fishes, also is suspected of causing declines of several native western fishes (Rinne 1991; Ruppert et al. 1993; USFWS 1995). Less is known about other small nonnative fishes, including redside shiner (*Balteatus richardsonius*) and sand shiner (*Notropis stramineus*), but both pose threats to Colorado River fishes through predation and competition (reviewed by Tyus and Saunders 1996).

Evidence for deleterious effects of nonnatives on Colorado River fishes is so compelling that 81% of regional fisheries experts are convinced that nonnative fishes have caused significant problems in the upper basin (Hawkins and Nesler 1991). The nonnative fish issue has been studied thoroughly and the conclusions are inescapable: introduced species have played, and continue to play, a significant role in the decline of the native big river fishes.

Developing solutions

No effective program exists for the control of nonnative fish populations in the Colorado River. However, recovery of the listed big-river fishes will require developing long-term programs for removing or reducing at least some nonnative fish populations. The Upper Colorado River Endangered Fish Recovery Program has been concerned with the nonnative fish problem since its 1987 inception (Wydoski and Hamill 1991). This program, which presently coordinates recovery efforts for the four endangered big-river fishes in the upper Colorado River above Lake Powell (Figure 2), has funded efforts to define the problem and to develop solutions (e.g., Lentsch et al. 1996). In November 1995, the program contracted us to convene a workshop of scientists and managers familiar with problems in the upper Colorado River basin, and to prepare a report and strategic plan for nonnative fish control (i.e., Tyus and Saunders 1996). We charged workshop participants with providing the following information: (1) which nonnatives pose serious threats, (2) which endangered species (and life stage) are the most affected, (3) what are the geographic areas where nonnatives cause problems for endangered species, and (4) what are the most promising techniques for controlling nonnative populations.

Table 1. Predation by nonnatives on native fishes of the Colorado River basin (after Tyus and Saunders 1996).

Native prey	Nonnative predator
razorback sucker	channel catfish
	common carp
	green sunfish
	sunfishes
	largemouth bass
	flathead catfish
Colorado pikeminnow	channel catfish
	green sunfish
	largemouth bass
	smallmouth bass
	black crappie
	bullheads
	northern pike
humpback chub	channel catfish
	bullheads
	brown trout
	rainbow trout

Workshop consensus was that predation is the most important mechanism whereby nonnatives affect endangered fishes, and that several species posed significant threats (Table 2). Razorback sucker and Colorado pikeminnow larvae were considered the most vulnerable species

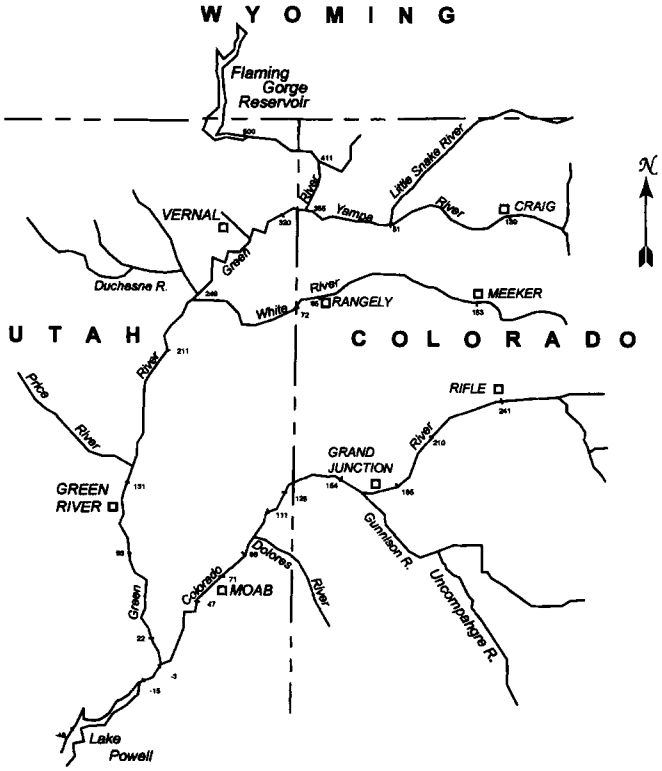

Figure 2. Geographic area covered by the upper Colorado River Endangered Fish Recovery Program (numbers are kilometers above and below the confluence of the Colorado and Green rivers).

Table 2. Nonnative predators in the UCR basin. Primary sources of recruitment are indicated for each predator, and the life history stage most susceptible to that predator is given. Susceptibility is determined by predator feeding habits and the chance of finding that predator in the same habitat.

	Proximate source			Life history stage of prey		
Nonnative Species	River	Pond	Reservoir	Juvenile	Larvae	Eggs*
channel catfish	+			+	+	+
common carp	+				+	+
northern pike	+		+	+		
fathead minnow	+					
sand shiner	+				+	
red shiner	+				+	
redside shiner	+				+	
green sunfish	+	+		+	+	
largemouth bass		+	+	+		
smallmouth bass		+		+	+	
white crappie		+		+		
black crappie		+		+	+	
walleye	+		+	+		
bluegill		+			+	
white sucker	+					+
mosquitofish		+			+	
striped bass			+	+		
plains topminnow		+			+	
trout	+			+		

* - including sac fry

and life stages affected by nonnative predation, and this pattern is probably similar for the humpback chub, although there is little documentation.

Control

Development of control strategies was facilitated by placing nonnative predators (i.e., small cyprinids and carp, centrarchids, channel catfish, and northern pike) into groups that reflected their source and the habitats where they affect endangered fishes. This facilitated evaluation of the potential efficacy of chemical, mechanical, and other control measures.

Small nonnative cyprinids (fathead minnow, red shiner, sand shiner, redside shiner) are ubiquitous and reproduce in shoreline habitat. Chemical control measures (e.g., poisons) would not be feasible because native fishes occupy the same or adjacent habitat. Mechanical control (e.g., active and passive netting) is feasible from a technical standpoint, but total removal is presumed impossible. Small cyprinids are chiefly a threat to native fish larvae, and control measures would target nursery habitat used by endangered fishes. Intensive use of seines in nursery habitat (Figure 3) could remove a large proportion of small cyprinids before the endangered fish spawn each year, thus possibly removing an impediment to recruitment. Native fishes (such as juvenile suckers, chubs, and pikeminnow) are large enough to be identified and released. Seining also would remove some other nonnative predators (e.g., centrarchids or small channel catfish).

The use of high water discharge also has been suggested as a control option for small nonnative cyprinids (McAda and Kaeding 1991; Muth and Nesler 1993) based on observations of some nonnatives being displaced by flood flows in constrained channels (Minckley and Meffe 1987). However, red shiner populations in the Colorado River system have rebounded within a few years following depression by high flow events (McAda et al. 1994). Unfortunately, high flows can adversely affect native fishes by increasing mortality and/or reducing growth rates (i.e., Tyus and Haines 1991). Lack of selectivity and the need for frequent high flow events diminishes the attractiveness of flow manipulation as a mechanism for controlling the abundance of nonnative fishes, even in regulated portions of the river system. In addition, manipulating dam operations to increase flooding could violate provisions of the ESA if it increased the "take" (e.g., mortality or reduced growth) of a listed species.

Most centrarchids (e.g., smallmouth bass, largemouth bass, white crappie *Poxomis annularis*, black crappie *P. nigromaculatus*, bluegill *Lepomis macrochirus*) reproduce mainly in ponds or reservoirs in the upper Colorado River basin, and can prey on almost any stage of the listed species. Control of centrarchids, with exception of the green sunfish (*L. cyanellus*), involves preventing entrance into the river by structural controls. Chemical control measures would be appropriate where there is no risk to the listed fishes, but may not be politically acceptable due to pollution, health risks, and sportfishing interests. Structures

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designed to withstand flooding within an acceptable flood recurrence interval (e.g., 50 years) could provide nonnative controls while preserving sportfishing interests. Once the supply of centrarchids is curtailed, their numbers in the river could be expected to dwindle, and mechanical measures, such as netting in shoreline habitat would expedite their removal.

Green sunfish are widely distributed in shoreline habitats, but reproduce in deeper and more isolated backwaters (Tyus, pers. observ.). These areas should be especially targeted.

Finding effective control measures for nonnative fishes adapted to the main channel (e.g., channel catfish; Figure 4) poses an especially difficult challenge. Chemical measures cannot be used because it would harm sympatric endangered species. Mechanical removal would be prohibitively expensive. Eddy and other main channel habitats preferred by the catfish are very difficult to sample and the entire river would need to be targeted indefinitely. However, one possibility that emerged from the workshop is use of intensive fishing to remove larger predators. In general, channel catfish in the Upper Colorado River basin are not fully piscivorous until they attain a length of about 420 mm (Tyus and Nikirk 1990). Larger catfish are very vulnerable to fishing pressure and angling has virtually eliminated the larger individuals in some locations (e.g., Wyoming; Gerhardt and Hubert 1991). Commercial fishing for channel catfish in the Missouri (Hesse 1994) and Mississippi rivers (Pitlo 1997) has been so effective that fishing had to be closed or size restrictions imposed to allow the fisheries to recover. However, reduction in fish size, or even collapse of the "fishery" would be a desirable outcome in the Colorado River. Because the preferred commercial method of catfishing is baited hoopnets (Hesse and Mestl 1989), catch rates of native fishes would presumably be very low and any endangered fish captured would likely be alive for return to the river. Other nonnative predators, like pike or carp, also can be caught in the nets and could be removed from the system.

Unfortunately, there is no intensive warmwater fishery in the Upper Colorado River basin, and it is doubtful if sufficient fishing pressure can be generated to significantly reduce catfish stocks. A commercial fishery would avoid the high costs of intensive fishing that would be incurred by agencies, but state fish and game agencies have expressed reluctance to allow establishment of commercial fishing due to potential regulatory and sociopolitical problems. In addition, there are no established local markets for channel catfish or carp. Nevertheless, markets in the midwestern United States are sufficiently well-developed that a trial program might entice entrepreneurs into the Upper Colorado River basin, especially if suitable incentives were offered (L. Hesse, River Ecosystems, Crofton, NB, pers. comm.). If successful, economic benefits derived from a commercial program could be used to aid recovery efforts. A pilot program, established in a reach where the existing channel catfish population could be fished commercially and monitored accurately, is needed to explore benefits and costs of this novel control measure.

Figure 3. Alongshore habitats, such as this large backwater, are preferred habitat of small cyprinids and utilized as rearing areas by young of endangered fishes.

Control of northern pike may be relatively easy, provided that steps are taken to prevent escape from reservoirs. Some of the fish are reproducing in coolwater pond areas where they congregate for spawning in late winter. Mechanical removal with seines or stationary nets could provide a very efficient control technique when the individuals are concentrated in a relatively confined habitat, such as low-lying reaches of the Yampa River above Craig, Colorado (John Hawkins, Colorado State University, pers. comm.).

Control of common carp (*Cyprinus carpio*) is made difficult by their ability to invade many different habitats. Almost every conceivable control measure has been applied to carp at one time or another, but mechanical methods are the most widely used (Panek 1987; Wiley and Wydoski 1999). We propose mechanical removal of carp from major source areas, such as the Browns Park National Wildlife Refuge (NWR). Adult carp have ready access to ideal spawning habitat when the NWR is flooded, and their progeny populate the river reaches. If it proves practical to block access to the NWR, reproduction could be reduced and resident carp could be poisoned. If access cannot be blocked completely, harvesting could reduce

Figure 4. Channel catfish are now common in many rocky habitats in the mainstream rivers of the Colorado River basin.

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recruitment. In addition, there also may be potential for commercial harvesting with hoop and block nets.

Discussion

There is compelling evidence that the decline of the native Colorado River fish fauna and lack of successful recovery is due in large part to adverse interactions with nonnative fishes. In the upper Colorado River basin (and presumably elsewhere) nonnative fishes pose a more serious threat to the native fish fauna than previously thought. An important lesson for fish recovery is that nonnative fishes should be given full consideration whenever there is any indication that they are a contributing factor in the decline of imperiled fishes.

Physical habitat alteration has been attributed to the decline of 91 to 94% of imperiled species in the United States, and nonnative fish interactions may have affected 53 to 70% (Lassuy 1995; Wilcove et al. 1998). Physical habitat alteration has been important in causing *declines* of native fishes. However, adverse nonnative fish interactions appear to be just as important, in causing *extinctions* of native fishes (Miller et al. 1989; Ross 1997), and fish extinctions due to nonnative fishes are not always preceded by habitat alteration (Lassuy 1995). In the Colorado River, fishery management practice has been to introduce hardy nonnative fishes into the altered physical habitats. Many of these introduced fishes were "preadapted" to the changed habitat (Minckley 1982) and flourished, affecting native fishes by predation, competition, and hybridization. Nonnative fish interactions may now be the major cause for extinction in this physically altered system.

The need for reducing impacts of nonnative fish introductions in the Colorado River basin has not drawn much support and the problem has been deferred to other options, such as provision of instream flows and improving physical habitat. A general reluctance by fish management agencies to recognize nonnative fishes as a problem is not surprising, because of traditional sportfish management practices (e.g., Everhart and Youngs 1981). In addition, the same agencies responsible for reducing nonnative populations are the ones that introduced the nonnatives in the first place.

Happily, more attention is being focused on the nonnative fish problem, and in the last few years an emphasis has been placed on evaluating the magnitude of the problem and seeking solutions. However, elimination or even reduction of nonnative fishes will not be an easy task. At present, we do not know how to initiate effective basinwide fish control programs or how to reduce or eliminate populations of nonnative fishes without adverse effects to the native fishes. Tactical problems, such as the need to develop and test methodologies for reducing or eliminating each troublesome species, are further compounded by a general lack of strategy: the very concept of "control" has yet to be defined in meaningful recovery terms. Even if the threat of nonnative fishes can be temporarily reduced, long-term control measures will need to be developed and implemented.

In general, recovery of endangered species is a formidable task, in part because it is an emerging field of science. The challenging nature of recovering endangered fishes has been clearly illustrated by the results of ESA implementation: no listed fish has been sufficiently recovered that it has been delisted. In over 20 years of recovery effort in the Colorado River basin, more fish have been incrementally listed and in the process, one fish (bonytail) has been extirpated from nature. It can be argued that lack of a more holistic approach is one of the foremost problems. It is generally agreed that declines of the endangered big-river fishes are due to many of the same problems. However, no multispecies or ecosystem recovery plan has been developed to address common problems although the ESA provides a clear mandate for an ecosystem approach. Instead there has been a tendency to address each species separately, and thus recovery priorities are presumably different than if all species were considered together. It is assumed that there would be greater support for recovery of several endangered species in a geographic area than for one species alone.

So little attention has been given to reducing the adverse effect of introductions on the native species in the Colorado River, or elsewhere for that matter (Lassuy 1995), that the riverine environment has been in a continual state of change due to addition and proliferation of new fishes at various locations. We believe that successful recovery of the endangered big-river fishes cannot be accomplished without some nonnative fish control, including: (1) the prevention of additional introductions, (2) preventing escapement of nonnatives fishes from off-channel areas to the river system, and (3) reduction or elimination of populations of introduced nonnative fishes that have become established in the riverine environment. Unfortunately, all of these measures are unpalatable due to sociopolitical reasons, and difficult to implement due to a lack of effective control methodologies.

At a minimum, future recovery actions should include intensive efforts to produce predator-free zones, with highest priorities placed on reducing the number of small cyprinids in endangered fish nursery areas and reducing the sizes and numbers of channel catfish in mainstream rivers. We applaud recent recovery implementation efforts in the Colorado River basin in identifying the need for developing control strategies, but little progress has been made in effectively implementing a nonnative fish control program. Even less progress has been accomplished elsewhere. We hope this effort will stimulate others to action.

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