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.

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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).

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

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

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).

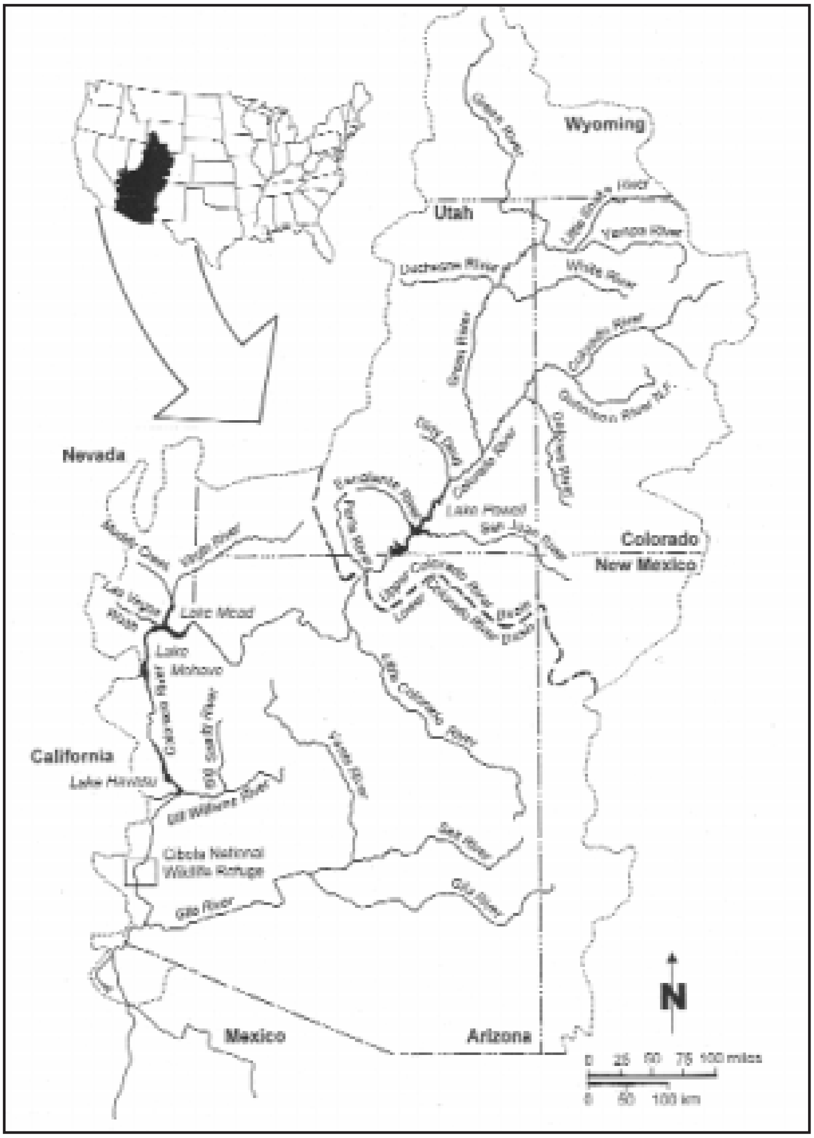
Colorado pikeminnow were extirpated from the lower basin by 1975 but small populations persist in the upper basin. Bonytail and razorback sucker have experienced recruitment failure for nearly 4 decades and attempts are being made to augment populations through stocking (USFWS 2002b,c). Wild bonytail 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

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.


ANITA MARTINEZ

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

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).

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Conflicts between Native Fish and Nonnative Sport Fish Management in the Southwestern United States

ABSTRACT

The ubiquitous presence of nonnative fishes, both sport and nongame, within waters of the southwestern United States is the foremost factor preventing immediate conservation and recovery of imperiled native fishes. We present evidence that the two fishery types cannot be co-managed in sympatry if natives are to persist. A dual responsibility of federal and state fish and wildlife agencies to manage both fishery types creates internal conflicts that typically are resolved in favor of nonnative sport fisheries, despite existence of the Endangered Species Act. We advocate designation of watersheds to be managed exclusively for one fishery type or the other, and implementation of an aggressive program to eliminate nonnatives in native-designated waters and protect against their reinvasion. To mitigate institutional conflicts, agency infrastructures should be segregated to promote independent management of native fisheries and introduced sport fisheries. This approach can fulfill mandates of both the Endangered Species Act and the 1996 Fish and Wildlife Service policy on recreational fishing.

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Introduction

Native freshwater ichthyofaunas of the southwestern United States have declined and their status continues to deteriorate; the entire fauna is imperiled (Miller 1961; Minckley and Deacon 1968; Fagan et al. in press). Losses are due to development of water supplies, physical habitat alteration that favors nonnative fishes, and introduction and establishment of nonnative fishes and other aquatic biota (Fradkin 1981; Minckley and Deacon 1991). Early declines were principally a result of habitat destruction and alteration. However, in the past few decades it has become apparent that presence of nonnative fishes precludes or negates benefits from habitat protection and restoration (Mueller 2005, this issue). Contamination by nonnative fishes now is the most consequential factor preventing sustenance and recovery of imperiled native fishes in the Southwest (Meffe 1985; Minckley 1991; Marsh and Pacey 2005), and perhaps globally (Cambray 2003). No amount of habitat restoration can successfully advance biological recovery unless preceded or accompanied by elimination of nonnatives (Marsh and Pacey 2005; Mueller 2005, this issue).

Most of the 50+ nonnative fishes established in the region were introduced as sport species, as forage for sport fish, or as bait (Fuller et al. 1999). Although the rate of introductions of novel, nonnative sport species has declined (Rinne and Janisch 1995; Dill and Cordone 1997), both federal and state agencies continue to actively stock, manage, and promote nonnative recreational fisheries. States derive monetary benefit from these programs via license sales and federal subsidies, and federal excise taxes help support the U.S. Fish and Wildlife Service's (USFWS) sport fish programs (e.g., Federal Aid in Sport Fish Restoration). Primary political support for state game and fish agencies comes from the hunting and recreational fishing public. Yet these same agencies are charged with protection and recovery of native fishes that are directly affected by introduced sport fish species.

We examine the conflicts that arise from the dual responsibilities of USFWS and state fish and game agencies to conserve and recover threatened and endangered native fishes and stock, and manage nonnative sport fisheries. Our experience is in the Southwest, but the issue is relevant to all states that promote nonnative sport fisheries. We define the scope of these management conflicts and show how they result in the neglect of nongame native fishes, an assertion supported by continuing declines of these species even since passage of the Endangered Species Act (ESA) and completion of recovery plans under that act. We present our thoughts as to how to minimize or isolate these conflicts through both institutional and on-the-ground changes in management.

The Problem with Nonnatives

Nonnative fish are now nearly everywhere in the region (Fuller et al. 1999), and where habitable perennial habitats remain, prevent stabilization and recovery of most imperiled native species (Moyle et al. 1986; Minckley 1991; Marsh and Pacey 2005). Effects of nonnative fishes on natives result from interactions among life histories, behaviors, and habitat use. The introduced fauna is comprised of mostly piscivores, while native species are mostly generalists (Pacey and Marsh 1998). Native fishes of the region are considered predator-naïve (Johnson et al. 1993; Johnson and Hines 1999), and lack behavioral mechanisms to cope with or avoid the array of predators introduced into their habitats. In the Colorado River basin, for example, native warmwater fishes co-evolved with only a single piscivore (Colorado pikeminnow *Ptychocheilus lucius*), while most introduced fishes evolved within drainages containing many predators (e.g., Mississippi River basin).

Introduced fishes typically are phylogenetically advanced taxa that possess sophisticated life history and behavioral traits that allow them to persist within intensely competitive, saturated communities (Minckley and Rinne 1991; Douglas et al. 1994). For example, most nonnative fishes afford some degree of active protection to their young via nest building or other behavioral traits, while native forms are mostly broadcast spawners with no parental care, and generally do not possess such sophistication of life history and behavior (Pacey and Marsh 1998).

One result of these differences is that native fishes typically fail to recruit young in the presence of nonnatives (Marsh and Minckley 1989; Pacey and Marsh 1998; Dudley and Matter 2000). Predation on natives by introduced forms during early life stages is the most likely mechanism resulting in failure of natives, but other avenues also contribute (Tyus and Saunders 2000). Nonnative fishes such as green sunfish (*Lepomis cyanellus*), western mosquitofish (*Gambusia affinis*), and red shiner (*Cyprinella lutrensis*) are ubiquitous even in shallow, nearshore habitats used as nursery areas by larval native fishes, where they consume or harass natives into decline or extirpation (Meffe 1985; Ruppert et al. 1993; Osmundson 2003).

In addition, nonnatives may be released from much of their co-evolved parasite and disease load due to over-dispersion of parasite communities and small founding populations of introduced fishes (Torchin et al. 2001; Stockwell and Leberg 2002). At the same time, novel introduced parasites and diseases that are not co-evolved may differentially affect native fishes (Stockwell and Leberg 2002).

Only in rare instances have natives persisted among introduced forms over a long history, and by long we mean only several decades (Stefferud and Stefferud 1995; Bryan et al. 2000). However, these situations are largely unstudied, and proposed mechanisms that might allow coexistence are speculative. Disturbance, especially flash flooding that is common to the Southwest, has been suggested as a mechanism that in some cases may allow persistence of native fishes when they are sympatric with introduced species (Johns 1963; Minckley and Sommerfeld 1979; Minckley and Meffe 1987). However, the near-ubiquity of nonnative fishes across the region ensures that the impacts of predation, competition, or parasitism are ever-present factors limiting successful completion of native fish life cycles. The fact is, where nonnatives become established, natives invariably wane or disappear. Given the present state of knowledge, our conclusion is that native and nonnative fishes must be segregated if the former are to survive.

Intra-Agency Conflicts

The dual management responsibility of federal and state fish and wildlife agencies for both threatened and endangered native fishes and nonnative sport fisheries has existed since before the 1973 enactment of the ESA. However, before the 1970s little conflict was apparent because neither state nor federal agencies invested much thought or effort in nongame native fish, and information on native fish declines alarmed only a few specialists (Minckley and Deacon 1991). At least one state characterized itself as "insensitive to native fish management" (Rinne and Janisch 1995:403).

Increased ESA listings of southwestern native fishes combined with poor recovery success highlighted the conflict between nonnative sport and native fish management (Cain 1993). Pressure to conduct ESA Section 7 consultation on federal and federally-funded state nonnative fish stocking programs increased awareness of the conflict,

GARY STEVENS

Fish barriers such as this one on Fossil Creek, Arizona, are needed to protect upstream native fish populations from contamination by nonnative species.

and within USFWS there were disagreements over allocation of federal fish hatchery resources between sport and native fishes (GAO 2000); neither resulted in resolution. The USFWS was directly confronted with the conflict in 1995 when an Executive Order directed federal agencies to "improve the quality, function, sustainable productivity, and distribution of U.S. aquatic resources for increased recreational fishing opportunities" (Federal Register 60:30769).

Working cooperatively with the Sport Fishing and Boating Partnership Council, an advisory panel to the Secretary of Interior, the USFWS and National Marine Fisheries Service formulated a policy to implement the Executive Order (Lassuy et al. 1999). Public comment on the draft policy expressed concern that elevating considerations for sport fisheries would dilute conservation efforts for threatened or endangered fishes. The 1996 final policy entitled "Conserving Species Listed or Proposed for Listing under the Endangered Species Act while Providing and Enhancing Recreational Fisheries" (Federal Register 61:27978) acknowledged the conflict between recovery of listed fishes and promotion of recreational fisheries, but lacked substantive guidance as to how to ameliorate or eliminate the problem. The policy's primary focus was to resolve conflicts through increased public education and increased involvement in native fish recovery programs for federal agencies, state and tribal governments, conservation organizations, and recreational fisheries stakeholders. Emphasis was placed on "eliminating unnecessary recovery based restrictions affecting recreational fisheries." The policy did not direct cessation of nonnative fish stocking into waters with federally-listed or proposed native fishes, but instead called for evaluation of potential impacts of such stockings based on biological information and socioeconomic objectives including recreational fisheries. However, it appears the policy has been generally ignored by management agencies in the Southwest.

The USFWS has little dedicated funding for implementing coordinated recovery programs and only a small proportion of that amount is allocated to nongame fishes (GAO 2002; USFWS 2003). State funding ratios are similar (Gabelhouse 2005). Moreover, most of those monies are spent on high "public appeal" species and those approaching recovery (GAO 1988). Piecemeal conservation is sometimes achieved when federal actions are mitigated through Section 7 ESA consultations. In addition, USFWS delegates much of its recovery authority and a portion of its funding to the states through Section 6 of the ESA, and in fact has begun executing formal memoranda of agreement (MOA) with states to further increase their role in implementing ESA (e.g., USFWS and AZGFD 2002).

In concept, this relationship should foster recovery efforts for listed species. In reality, because states have no mandated authorities to implement the ESA except as delegated by (and largely funded by) the USFWS, and because most southwestern states do not have provisions for citizen lawsuits in behalf of wildlife, they are seemingly immune to legal pressures from groups that seek more proactive recovery efforts. The dilution of federal authority and accountability through such MOAs may actually weaken recovery efforts for listed fishes, not strengthen them.

Whether one agrees or disagrees with these assertions, the fact remains that regional native fish faunas continue to decline (Minckley and Rinne 1991; Fagan et al. 2002), and recovery actions that have been undertaken or proposed for threatened or endangered fish have been ineffective, or worse, neglected and avoided. It is inarguable that not enough is being done to stem continuing losses. We believe this is mostly due to internecine conflicts between nonnative sport and native fishery interests, and we have observed that these conflicts are usually resolved in favor of the sport fishery.

The only exceptions seem to be where threatened or endangered fishes happen also to be sport species (e.g., trouts), or where habitat conservation plans have been established that provide ambiguous assurances to development and sport fishing interests. Southwestern states have implemented programs for endemic trouts that included removal of established nonnative trout fisheries (Rinne and Turner 1991; Propst et al. 1992; Young and Harig 2001). In many cases, nonnatives have been removed from entire watersheds and replaced with indigenous trouts, usually protected against recontamination by natural or artificial barriers. These are highly commendable programs that need to be mimicked with nongame native species, but similar programs for such species are conspicuously rare.

Recommendations to Minimize the Conflict

In most cases, we know what is needed to begin the recovery process for southwestern native fishes, which simply is to segregate natives and nonnatives. The techniques to do so for the most part are technically and economically feasible. Significant recovery of many southwestern native fishes can be accomplished with reasonable compromise by sport fishing interests. Once waters are designated for exclusive management of one fishery type or the other, full devotion of resources to both will better enable accomplishment of management goals. We argue that by recovering threatened and endangered fishes now, long-term costs for conservation, sport-fishing interests, and the nation and its people will be greatly lessened.

Biological Conflicts

The exemplary success to date with recovery programs for native trouts in the Southwest has been completely reliant upon the premise that native trouts cannot persist in the presence of nonnative, especially congeneric, trouts. Rinne and Janisch (1995) described use of segregated management to allow for recovery of native trouts while maintaining sportfishing opportunities for nonnative trouts. It is routine in high elevation, cold water streams to identify native trout recovery reaches, erect physical barriers to prevent contamination by nonnatives, chemically or otherwise remove nonnatives above the barriers, and repatriate native trouts (Finlayson et al. 2005). The same can be done for many native warmwater species.

Warmwater fish communities of most major southwestern rivers are predominated by nonnative species and native kinds are severely depleted or gone (Tyus et al. 1982; Minckley 1991; Mueller and Marsh 2002). We do not at this time see a practical approach to completely reclaiming these systems for native fish recovery (Dawson and Kolar 2003), and expect the nonnative fishes and the minor recreational use they support will continue. However, this does not minimize the value of major rivers to native fish recovery, for example, where active programs are in place to enhance imperiled species and reduce the abundance of nonnatives, and thereby reduce their impacts (Tyus and Saunders 2000), or where off-channel habitats can be constructed and managed exclusively for natives (Minckley et al. 2003).

Populations of introduced species already occupy reservoirs and the few natural lakes in the region, and these habitats support substantial recreational fisheries. It is impractical, by any measure, to eliminate these fishes from these lentic habitats. We envision these systems will continue into the foreseeable future to harbor nonnative fish assemblages and support sport fisheries, and mostly will not be amenable to management in behalf of native fishes (but see Mueller 1995 for a notable exception).

Medium and small warmwater streams and stream systems, however, represent valuable native fish habitat but are of little value as recreational fisheries. In addition to native species that persist, many of these streams are occupied only by smaller-bodied, nonnative centrarchids, ictalurids, and cyprinids and not the large individuals typically sought by sport fishers. In addition, they often are remote and difficult to access, and some are isolated from other waters by typically dry reaches or in some instances by natural or other barriers. Finally, because of their relatively small size and seasonal low flows, many of these systems appear amenable to removal or substantial reduction of nonnative fishes. We envision these places as potential candidates for recovery of most imperiled native species. These streams provide opportunities where the biological conflicts can be resolved and where the institutional conflicts can be minimized.

Most stream dwelling native fishes of the American Southwest were historically widespread in distribution, and local populations were interconnected through time, affording opportunity for individuals to move freely among streams. While the historical condition will not again exist in the foreseeable future, a recovery strategy that incorporates the concept of connectedness is critical to long-term conservation of these fishes. The geographic scope of this strategy needs to include interconnected drainage networks of tens to hundreds of kilometers of live streams embedded in watersheds of hundreds to thousands of square kilometers. It is not enough to segregate the natives within short, isolated reaches because such populations cannot exchange genetic material with their conspecifics, unless by active human management, and thus can suffer undesirable effects of inbreeding, genetic bottlenecking, or extirpation that often are associated with small populations (Ballou et al. 1995). Connectedness is also important in avoiding demographic and environmental events that can eliminate small, fragmented populations (Propst et al. 1992; Meffe and Carroll 1994). Specific criteria for size and hydrological complexity of watersheds to support desired abundance of populations and other demographic variables can be defined, and moni-

Medium and small warmwater streams and stream systems represent valuable native fish habitat but are of little value as recreational fisheries.


GARY STEVENS

tored for attainment (Hilderbrand and Kershner 2000; Young and Harig 2001).

The management strategy is simple. First, state fish and wildlife agencies, together with USFWS and other federal land management agencies, identify which waters and watersheds will be devoted to exclusive management for native fishes, and which will be devoted to nonnative sport fishing. Then, beginning in the low order streams, barriers are installed, any native species are salvaged, nonnatives are chemically removed, and natives are repatriated or introduced from appropriate stocks. Barriers then are emplaced in higher order streams and upstream reaches are reclaimed. Through this process, native fish populations are interconnected once again, and exchange of individuals is possible. The number of tributaries treated and the order of the stream on which the downstream-most barrier is located would be determined on a case-by-case basis, as would the species or species assemblage to be restored to each interconnected stream system. Ideally, each imperiled native fish population would be replicated into one or more such restored and protected systems. Finally, simple and inexpensive monitoring protocols to detect nonnative reinvasion of reclaimed reaches must be established to ensure long-term accomplishment of the program's goals.

In sum, management agencies need to designate watersheds or sub-watersheds for exclusive establishment of either native fisheries or nonnative sport fisheries. There is just no other way to retain both fishery types. This will entail some compromise by sportfishing interests and a shift in paradigm amongst management agency personnel. However, native fishes in the region have for too long been compromised by the continuing development of nonnative sport fisheries, and parity for native species needs to be established. Recreational fishing should be closed on waters designated for native fishes, or regulations promulgated to reduce potential for transfers of undesired species, which is proportional to angler use (Ludwig and Leitch 1996).

Institutional Conflicts

Resolving the biological conflicts is largely a technical matter. Resolving the institutional conflicts, however, is a political and social matter. A first step is a strong policy statement in support of nongame native fishes. Such a statement must come first from the states, because only they have a broad mandate and authority to manage the aquatic resources within their respective borders. The statement should make it clear that the standing of native species has been elevated to a position at least comparable to that of introduced sport fishes. The ESA already sets a basic federal policy mandating precedence of listed fishes over conflicting uses of federal land and money, but policy needs to be articulated specifically for the native/nonnative sport fish conflict. This is a small but necessary first step. It must be more than just congenial rhetoric—effective leadership, resource allocation, and actions must back it up.

Next, we recommend dedicated funding for nongame fish conservation and recovery programs that at a minimum is comparable to the funds allocated to sport fishes. This funding should come with specific direction that funds are to be spent on projects that directly benefit target species. Currently, many dollars potentially available to native fishes are expended on projects that may be highly visible and productive in some ways, but do not result in measurable improvement in species' status. We have observed that too much money and effort goes into infrastructure, marketing, planning, monitoring, studies, and peripheral activities, and too little toward on-the-ground actions that directly benefit native fishes. These sentiments are echoed throughout several special issues of journals that specifically evaluated implementation of the ESA (e.g., Conservation Biology 15[5], Ecological Applications 12[3]).

Potential sources of native fish conservation dollars include existing Section 6 ESA funds from USFWS, state heritage funds, tax check-offs, state wildlife grants, internal budgets, and other programs. We realize that existing funds may not be adequate to meet existing and new needs, so novel sources must be identified and developed. Congress and state legislatures need to allocate additional dollars to implement substantive conservation activities. Ultimate sources of these monies could include a federal tax check-off, an excise tax associated with nonconsumptive uses and products, and, because of the negative impacts of sportfishing on native species, a portion of the federal excise tax on sportfishing-related goods.

Finally, and perhaps most importantly, we recommend autonomy for nongame programs at both the state and federal levels. Agencies develop distinctive cultures, become entrenched in traditional ways, and often are unreceptive to innovation (Alvarez 1993; Hirt 1994). Given the deeply-rooted tradition of sportfishing promotion and the resulting political, social, and economic conflicts within the existing infrastructures of state and federal fish management agencies, it is unlikely that these conflicts can be resolved easily to the benefit of native fishes within existing institutional frameworks. It already is clear that native and nonnative fishes are incompatible and cannot be managed together in the same habitats, and we believe a parallel situation exists within the management agencies. States have native fish programs and USFWS has an Office of Endangered Species that promote a perception that native fishes are afforded independent attention. However, the fact remains that decisions are made at higher administrative levels by individuals who are subject to political and economic pressures that usually favor sport fishes.

Conclusions

Sportfishing has a long tradition in this country, but it is merely recreational pursuit, albeit an economically important one. To our knowledge, there are no major state or federal laws that require maintenance of sport fisheries. In contrast, imperiled fishes are protected under ESA, which legally reflects the wishes of the people of the United States. ESA was passed with overwhelming support from Congress, and has been the subject of repeated assaults. Yet, it remains with continued strong support from the people. Unfortunately, implementation of the ESA in the southwestern United States has not resulted in measurable improvements in the status of most listed fishes chiefly because agencies have been in denial regarding the overwhelming impact of nonnative species on native species (Minckley and Rinne1991; Fagan et al. 2002).

We applaud those efforts by state and federal agencies to conserve and recover native imperiled fishes. There are success stories in the 30-plus years since passage of the ESA, and more to come in the future. Nonetheless, most listed fishes in the region have diminished in extent of range from the time of their listing, and many other non-listed species are in decline and may qualify for federal listing, but have not yet been afforded that protection.

Changes must occur if native southwestern fishes are to persist. Status quo is simply not good enough. We believe, in fact, that maintenance of status quo for many of these species will result in a downward spiral to extinction. We recommend elimination of biological conflicts between native nongame fishes and nonnative sport species by implementing segregated management—watersheds dedicated to one kind or the other. We further recommend ameliorating institutional conflicts by reorganizing agency infrastructures to ensure autonomy of native fish programs and personnel, and dedicated funding for nongame fish programs.

In the words of the late W. L. Minckley, a renowned advocate and conservator of southwestern native fishes, "Native fishes of the American West will not remain on earth without active management, and control of nonnative, warmwater species is the single most important requirement for achieving that goal" (Minckley 1991:145). We believe our approach of segregated fisheries will accomplish this management with the least impact to existing sport fisheries, and is a realistic and practical approach to fulfilling mandates of the ESA and the 1996 USFWS policy on recreational fishing.

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guest director's line
column

Forest Service Rise to the Future Awards Reception Spotlights Hutton Program

Chief Bosworth presents Jennifer Robinson with her Hutton Award.

Jan Lubeck

Lubeck is AFS development coordinator and Hutton Program administrator. She can be reached at jlubeck@fisheries.org.

Forest Service employee, AFS member, and Hutton mentor Ken Roby and his Hutton scholar, Jennifer Robinson, were honored by the Society and the USDA Forest Service at the annual Forest Service Rise to the Future Awards Reception in Washington, DC, on 21 June 2005. The special Hutton Awards were presented by Forest Service Chief Dale Bosworth, with remarks by AFS Executive Director Gus Rassam and AFS Past President Ira Adelman.

A special committee selected Roby and Robinson to be recognized for their outstanding participation in the 2004 Hutton Junior Fisheries Biology Program and as representatives of the other 15 Forest Service mentors and their students who also successfully completed last summer's program.

The Hutton Program is the AFS mentoring program for high school students that matches them with fisheries professionals for a summer-long, hands-on experience in fisheries science.

During the 2004 Hutton Program, Robinson worked as part of a 4–6 person crew, responsible for collecting information on fisheries and other aquatic habitats, as well as assisting in population estimates of Chinook salmon in two anadromous streams. She learned numerous inventory and monitoring protocols, including the Forest Service R5 Stream Monitoring Protocol, the Lassen National Forest's stream inventory protocol, and the fish passage protocol (Fish Xing) developed by Forest Service cooperators, as well as standard protocols for macroinvertebrate sampling, amphibian surveys, and fish population estimates.

Ken Roby is a fisheries biologist at the Almanor Ranger District of the Lassen National Forest in Chester, California, and has mentored three Hutton students over the past four years. According to Roby, "Jen is intelligent, dependable, and punctual and got along well with me and other crew members. She was able to adapt to the sometimes physically taxing requirements of the job, approached all tasks enthusiastically, and never complained about long hours, hot weather, mosquitoes, snakes, or the like."

Robinson is enrolled at Shasta College for the 2005–2006 school year. Her current plans are to transfer to Humboldt State University and complete a degree in fisheries biology.

In his final report, Roby said of the Hutton Program, "I continue to be impressed with the objective of the program (increasing participation in the field by providing exposure to the profession) and its implementation (quality of materials provided, quality of support by staff to mentors and students). I think it is a great program."

AFS congratulates these award winners along with all the participants in the 2004 Hutton Junior Fisheries Biology Program.

Additional information on the Hutton Program can be found at www.fisheries.org.

Chief Bosworth presents Ken Roby with his Hutton Award as AFS Past President Ira Adelman shows approval.

economic growth **forum**

Environmental, Economic and Social Aspects of Animal Protein Production and the Opportunities for Aquaculture

Christine M. Moffitt

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Agricultural production for food and fiber has enormous effects on the aquatic environment. As human populations increase and occupy more urban environments, the energy demands of agricultural development increase because of additional transportation costs and increased development of prime agriculture land for other uses. According to Pimentel et al. (2004), world agriculture consumes approximately 70% of the freshwater withdrawn each year, and irrigated lands produce 40% of the world's food. In the American Fisheries Society, through our natural resource policy process, we have identified and developed policy analysis and policy statements addressing various agriculture impacts such as non-point source pollution, sedimentation, cumulative effects of habitat modification, altered stream flows, and riparian management, but we have not taken a holistic view to address the tradeoffs of our complex agricultural system within the agricultural economy and infrastructure. In this article I introduce a framework for comparing a few of the environmental, economic, and social aspects of animal protein production in land-based versus aquatic-based protein production, and suggest that AFS members should help provide more science-based analysis of the sustainability of aquaculture for animal protein production for human populations.

Utilization of fish for food is linked to many ancient and contemporary cultures, and the health benefits of fish are positively linked to cardiac health and even brain development. Nearly all capture fisheries have peaked, and nations still remain over-capitalized with high fish demands (U.S. Commission on Ocean Policy 2004). AFS has provided several policy analyses and statements about the overharvest of long-lived species and bycatch problems, and has been actively engaged in helping nations, especially in North America, interpret the science and identify sound policy in this area. Capture fisheries have value for animal protein sources as food, and indirectly as fish meal and fish oils that are used for a variety of food and other important uses.

In 1990, AFS provided a policy analysis and statement regarding the development of commercial aquaculture (Robinette et al. 1991) that advocated for increased support for aquaculture research centers, information dissemination, and education. It supported the orderly development of aquaculture, with protection of the integrity of native aquatic communities, and advocated several principles, including that federal, state, and provincial agencies should cooperate to ensure the health of aquatic organisms, and to inspect them. The policy encouraged the use of native species for aquaculture development, and stressed that it was important to maintain genetic integrity of native stocks used for stocking for supplementation. The analysis acknowledged that aquaculture was a form of agriculture, and that it should be developed within the private sector with governmental support for research and development, inspection certification, mediating resource user conflicts, and coordinating the diversity of government departments. A decade before this AFS policy statement, the U.S. Congress had passed the Aquaculture Act of 1980 that gave the lead to the U.S. Department of Agriculture, but also formed the Joint Subcommittee on Aquaculture.

Since 1990, the aquaculture segment of animal protein production in the world has increased more than 10% annually and this increase is more than twice that of the growth of other animal commodities (Table 1). Although the current public press would lead you to think otherwise, the bulk

Table 1. Annual growth in world animal production by source, data are from FAO.

Source	1990 Million tons	2002 Million tons	Annual growth
Aquaculture	13	38	10.2%
Poultry	41	72	4.8%
Eggs	38	58	3.6%
Pork	70	94	2.5%
Mutton	10	12	1.5%
Oceanic fish catch	86	91	0.5%
Beef	53	58	0.8%

of this growth in aquaculture has been in species that are vegetarian or lower tropic level species such as shellfish, carps, and tilapias (Tidwell and Allan 2001). In many countries, aquaculture has provided highly nutritious animal protein inexpensively, and has helped in improving food security and alleviating poverty.

However, aquaculture in the United States has grown more slowly partly because of a lack of a cohesive advocate group to help provide funding for research and development, due to the difficulty of addressing the diversity of the industry. There are many species, environments, and engineered systems used for fish culture. Another component not well recognized by the AFS policy analysis in 1990 was the difficultly of developing a new animal agriculture infrastructure within the regulatory infrastructure. The understanding of the aquaculture industry within regulatory agencies has continued to improve with assistance from the Joint Subcommittee on Aquaculture, but the progress is slow. I often ask people to think about regulatory issues to be addressed if we had never before had cattle production and a new industry was proposing rearing animals for part of their lives on public lands!

Efficiency of energy transfer

Fish are efficient converters of resources. Poikiliotherms are capable of using the ambient conditions and converting energy efficiently, and fish do not use energy to keep a stable body temperature. Moreover, the water environment provides important body support so that fish put few resources into skeletal systems for support. In addition the usable portions of fish are very high, especially when compared with cattle in which less than 50% can be used for meat. The entire physiological system for waste elimination in fishes further conserves energy. When put in direct comparison, the yield of fish per pound of feed will likely win in any circumstances. Table 2 provides a summary of conversions from several sources.

Water demands for traditional animal protein production

Domestication of animals for animal protein was an important step in providing food security for agrarian people. However, the recent global trend to concentrate and centralize agriculture and animal production operations into the ultimate factory farms has changed the dynamics, increased energy demands, and caused large localized environmental impacts.

Land-based animal protein production has many direct and indirect environmental economic and social impacts. There is some confusion as to the liability for animal wastes in direct production of the commodity, including water use, pollution of surface and ground water, air pollution, and the use of chemicals and drugs. In the United States, direct use of water by livestock is only 1.3% of the total water budget. The rest of the water is used for forage and grain. To produce a kilogram of grain-fed beef, 100,000 liters of water are used (Table 3). Estimates of these metrics for typical species of fish and shellfish need to be calculated for comparison and they could be estimated by making assumptions of the diet constituents, water sources, and conditions of rearing, as was done for the animal products in Table 3.

The Food and Agriculture Organization of the United Nations reported that 37% of the world grain harvest, or nearly 700 million tons, was used to produce animal protein. The potential for more efficient grain use is large. In the United States, approximately 7 billion livestock animals consume five times as much grain as is consumed by the human population—41 million tons of plant protein are fed to land-based livestock to produce 7 million tons of animal protein for consumption, for an average conversion ratio of 1 to 8. Twenty-six million tons of this livestock feed comes from grains, and 15 comes from forage crops. By increasing this conversion ratio, we can reduce the relative impacts to the land and water systems by these factors.

Table 2. Pounds of feed/pound of meat produced for different animals (from Moffitt 2004).

Animal	Pounds of feed/pound of meat produced
Cattle	8
Pig	3
Poultry	2
Catfish	1.5–2.0
Salmon	1.1–1.2

Table 3. Amount of water needed to produce one kg of product. Data are from Pimentel.

One kg of product	Use of water in liters
Grain fed beef	100,000
Broiler chickens	3,500
Beef cattle	43,000
Pigs	6,000
Soybeans	2,000
Alfalfa	1,000
Rice	1,600
Wheat	900
Potatoes (dry)	630

Risks of diseases from animals, and human aspects of animal production

Human disease risks are generally lower the more phylogenic distance there is between the animal eaten and grown and the consumer (humans). There are very few zoonotic diseases with aquaculture compared with bovine agriculture or in recent studies, the risks of transmitting the avian flu virus through pigs and humans. In aquaculture few antibiotics are used and none are used as growth promoters.

Another consideration of animal protein production is the human aspects of animal protein production. Mammals and birds have highly-evolved sensory systems and there is increasing concern about the humane aspects of rearing, transportation, and slaughter. With centralized systems for production, the personal attention known in agriculture during the past century is less likely to occur. Farm size and regimented production reduces the human contact with these domesticated animals.

Differences in central nervous system structure underlie basic neurobehavioral differences between fishes and humans. Fishes lack essential regions of the brain and any functional equivalent that would allow them to be aware of pain (Nickum et al. 2004). Fear depends on cerebral cortical structures that are absent from fish brains, and Rose (2003) concluded that awareness of fear is impossible for fishes. In fish production, analgesics such as ice can be used humanely prior to slaughter.

The need for more careful analysis

I suggest that we in AFS help provide an updated analysis of the comprehensive factors surrounding fish protein production and identify the scientific expertise to help understand the relative costs and benefits of aquaculture methods for producing animal protein for our human populations. The technology of environmentally friendly aquaculture could provide assistance to developing and developed countries of the world. The advantages of energy transfer efficiency of fish, the more complete conversion to consumable product, and decrease in consumptive water use for rearing are obvious factors to consider. In addition, as with other agricultural operations, there is an opportunity to provide a rurally based economy.

A Note from the Economic Growth Forum Editors:

One might ask how this article relates to the Economic Growth Forum. There are at least three connections. First, it points out how the demand for animal protein is driven at the most basic level by increasing human population, and economic growth entails increasing population times per capita consumption. Second, it describes some of the environmental impacts of animal protein production, with or without aquaculture. All else equal, the growth of an economy entails the growth of its various sectors, including the related impacts on aquatic ecosystems and fish populations (Rose 2005). Third, it demonstrates how fish protein production may be more efficient than other forms of animal protein production from an ecologically-economic perspective. The third point has a subtle relationship to economic growth. As Herman Daly, a leading figure in economic growth theory, pointed out in a speech titled "Sustainable Development: Definition, Principles, and Policies" in 2002 at the World Bank (available on the World Bank website), efficiency is most relevant to that field of economics that deals with "allocation" (i.e., the allocation of resources), while frugality is a standard more relevant to the issue of economic "scale," or the size of the economy relative to its containing and sustaining ecosystem. Daly emphasised that frugality is sufficient to induce efficiency (thereby affecting the allocation of resources), but efficiency is not sufficient to induce frugality (thereby not addressing the challenge posed by economic growth). In this context C. Moffitt's article provides "food for thought" on the implications of economic growth to the maintenance of capture fisheries and the rise of aquaculture.

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