Immiscibility of Native and Non-native Fishes

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Abstract–Native and non-native fishes in the lower Colorado River overlap broadly in their physical habitat and resource uses, and no attribute of either use-category favors one group of fishes over another. The presence of non-native fishes alone precludes life-cycle completion by the natives. In the absence of non-natives, however, the natives thrive even in severely altered habitats. Compelling evidence supports a recommendation of segregated management of native and non-native fishes. Unabated declines of the imperiled native fish fauna demands expedient action by responsible parties to plan and implement appropriate strategies.

Introduction

Historical habitats of the Colorado River system were comprised of unregulated, free-flowing streams and rivers passing through alternating deep canyons and broad alluvial valleys. It was a river of extremes. Mainstream discharge at Yuma AZ neared 0 during summer droughts to more than 7,000 $m^3 s^{-1}$ at times of major flood, and annual sediment loading averaged a remarkable 10^8 metric tons from 1925 through 1935 (U.S. Geological Survey 1973). Temperatures ranged from freezing in headwater streams to more than 30º C in low desert channels (Deacon and Minckley 1974).

The native fish fauna of this dynamic system consisted of only 36 species, with most of these occupying smaller habitats such as streams, springs, and cienegas or marshes (Minckley 1985). The major rivers were home to a relatively depauperate ichthyofauna, including those we refer to as the “big-river” fishes: bonytail *Gila elegans*, humpback *G. cypha* and roundtail *G. robusta* chubs, Colorado squawfish *Ptychocheilus lucius*, and flannelmouth *Catostomus latipinnis* and razorback *Xyrauchen texanus* suckers (Miller 1961, Minckley et al. 1986).

The present-day Colorado River is physically altered and hydrologically regulated (Fradkin 1981, Carlson and Muth 1989), affecting the mainstream, its tributaries, and the watershed. Modifications include dams, diversions and withdrawals, bank and channel modifications, and riparian destruction. Also included are impoundments, tailwaters below dams, and channelized, canalized or otherwise artificialized segments. Some reaches are polluted, and others have been desiccated. Watershed-level perturbations include destructive mining, timber, livestock, and agricultural practices, and urbanization, all of which impact aquatic systems and their biota. Few free-flowing reaches remain, and none are in historical condition.

Nonetheless, most available habitats now are home to an appreciably greater number of fish species than historically recorded and approximately 70 of the more than 100 species are introduced, non-natives (Minckley and Deacon 1991). These non-natives evolved in far-off places including Africa and Asia, the salt oceans, and outside the basin elsewhere in the United States. Among others, there are representatives from the minnow (Cyprinidae), bass-sunfish (Centrarchidae), trout-salmon (Salmonidae), sucker (Catostomidae) and catfish (Ictaluridae) families. Top billing includes a number of large predatory sport species, such as channel *Ictalurus punctatus* and flathead *Pylodictis olivaris* catfishes, striped bass *Morone saxatilis*, largemouth bass *Micropterus salmoides* and other sunfishes, northern pike *Esox lucius*, walleye *Stizostedion vitreum*, and some trouts. However, a fish does not have to be large to be an important predator. For example, the green sunfish *Lepomis cyanellus* is small, but is known as a voracious predator on the young of native fishes (Marsh and Langhorst 1989).

This non-native ichthyofauna overwhelmingly dominates the natives in altered habitats even though evidence from literature and case studies maintain that these areas should support self-sustaining native fish populations (Pacey and Marsh 1998). However, the native fish community of the lower river has been reduced to a only a few imperiled species in isolated reaches (Minckley 1979, U.S. Fish and Wildlife Service [FWS] 1980), and a similar situation exists in the upper basin (Tyus et al. 1982, Tyus and Saunders 1996). The current array of non-native fishes apparently have life history attributes that allow them to displace, replace, and exclude the natives independent of physical habitat features.

Inquiries into relationships between native and non-native species have been long-standing and in the present context were initiated by the FWS Biological Opinion (BO) on lower Colorado River operations (FWS 1997). The objective of this paper is to provide data supporting the premise that it is the presence of non-native fish and not habitat alterations that substantially impact the existence and survival of native fishes in the lower Colorado River. The data presented herein were derived in part from

TABLE 1.–Illustrative surrogate of a larger series of matrices comprised of 40 lower Colorado River fish species (columns) by 200 life history and biological, chemical and physical habitat features (rows) used to compare resource and habitat uses of native and non-natives fishes. Individual tabulations were developed incorporating appropriate life history functions and environmental variables for each life stage (i.e., larva, juvenile, adult). See text for further explanation.

	Species / Life Stage					
	Native			Non-native		
	A	B	C	D	E	F
Life history function:						
Feeding	X	X	X			
Spawning				X	X	X
Resting				X	X	X
Physical habitat:						
Depth	X	X	X	X	X	X
Current	X	X	X	X	X	X
Substrate	X	X	X	X	X	X

our work for U.S. Bureau of Reclamation (BR) on behalf of the BO's Reasonable and Prudent Alternative No. 4 (Pacey and Marsh 1998).

Methods

We compared resource use-attributes of native and non-native species that presently occupy the system. We first performed a comprehensive, computer-based key word literature search using terms such as common and scientific fish names, physical and chemical habitat descriptors, and life functions. This broad initial search generated almost 100,000 citations from which we identified about 8,500 that were related to the question at hand. We reviewed each title (and abstract and keywords, as available) for content and selected approximately 400 papers for evaluation. Quantitative data and qualitative information from these selections were organized into a series of 21 matrices by species (native vs non-native), life stage (larva, juvenile, adult), environmental variable (daily and seasonal habitat, temperature), and functional/behavioral attributes (food habits, feeding mode and habitat [including piscivory and cannibalism], territoriality, spawning [including staging, seasonality, habitat and thermal requirements], and mode of reproduction). Each matrix was examined for patterns and matches as shown in the example presented in Table 1.

Results and Discussion

We found native and non-native fishes overlapped broadly in their physical habitat uses, resource uses, and life functions – they were for the most part comparable. However, there were two important distinctions. First, the non-native fauna included a greater number and proportion of piscivores, whereas the majority of native fishes were functional generalists. Second, the native fishes, with few exceptions, were broadcast spawners providing no parental care, while the non-natives were predominated by nest-builders that gave at least some level of parental care to their eggs and young. Based upon the analysis, it was concluded that the array of non-native fishes now present have feeding and reproductive attributes that allow it to displace, replace, or otherwise exclude the native fishes. No evidence was found that habitat *per se* was responsible for the degraded status of the native fish community. Results are detailed in their entirety in Pacey and Marsh (1998).

Non-native predation on early life stages is the single most important factor in the decline of the native Colorado River fishes, and there is ample evidence in this regard. Table 2 represents a compilation of data from the recovery plan for razorback sucker (FWS 1998). Other examples include largemouth bass, "sunfish" (genus *Lepomis*) and other non-native fish impacts on bonytail chub and razorback suckers at Lake Mohave (Mueller and Burke this volume) and documentation of green sunfish effects on larval-to-juvenile recruitment by razorback suckers (Brooks unpublished data). These all demonstrate that non-native fishes consume the natives, in the laboratory, in artificial habitats, and in natural habitats.

It is the overlap in physical habitat and resource uses that opens the door for issues of competition (see Douglas et al. 1994). While we do not discount the important role of competition in structuring fish communities, the finding of a greater number of piscivores among lower Colorado River fishes pales the potential effects of competitive factors.

The school of thought persists that physical habitat alteration is largely responsible for the decline of the western big-river fishes. If true, then one might ask what would occupy the altered habitats, reservoirs and channelized stream reaches and the like, if the non-native fishes were absent? Would they be devoid of fish? These places, altered and terrible though they may be, would be occupied by native fishes – in fact, we predict that native fishes would not only survive, but would successfully complete all of their life functions in most altered and managed habitats of the system.

A substantial and growing body of evidence derived from case studies supports our prediction that natives will flourish in the absence of non-natives (Table 3). The habitats that characterize these locations scarcely represent pristine Colorado River conditions. Indeed, most are simply earthen depressions filled with water. They generally are small and of variable water quality, suffering at times from dissolved oxygen depletion or extremes of temperature and pH. Yet two of the native big-river fishes, bonytail chub and razorback sucker, successfully complete their life cycles here, noteworthy in that bonytail is thought among the most habitat-specific native fishes.

TABLE 2.–Summary of citations for direct evidence of predation by non-native fishes on razorback suckers (adapted from U.S. Fish and Wildlife Service 1998; see document for complete references).

Non-native predator	References
Channel catfish	Medel-Ulmer 1983, Minckley 1983, Bozek et al. 1984, Brooks 1985, Langhorst 1987, Marsh and Langhorst 1988, Marsh and Brooks 1989, Marsh and Minckley 1989
Common carp	Jonez and Sumner 1954, Medel-Ulmer 1983, Minckley 1983, Bozek et al. 1984, Brooks 1985, Langhorst 1987, Marsh and Langhorst 1988, Marsh and Brooks 1989, Marsh and Minckley 1989
Green sunfish	Langhorst and Marsh 1986, Medel-Ulmer 1983, Minckley 1983, Bozek et al. 1984, Brooks 1985, Langhorst 1987, Marsh and Langhorst 1988, Marsh and Brooks 1989, Marsh and Minckley 1989
Sunfishes	Mueller 1995, Mueller and Burke this volume Largemouth bass Mueller 1995, Mueller and Burke this volume
Flathead catfish	Medel-Ulmer 1983, Minckley 1983, Bozek et al. 1984, Brooks 1985, Langhorst 1987, Marsh and Langhorst 1988, Marsh and Brooks 1989, Marsh and Minckley 1989

TABLE 3.–Case studies in which native Colorado River fishes were raised alone or in mixed communities with non-native fishes, and observations on native fish life functions (growth, maturation, and reproduction) supported at each site. Also indicated are those cases where native fish survival was impacted by non-native fishes.

	Species		Native fish	
Study site	Native	Non-native	life function(s)	References
ASU Golf Course	bonytail, razorback sucker	suite	growth, maturation	Unpublished data
ASU Research Park	bonytail, Colorado squawfish, razorback sucker	suite	growth, maturation	Marsh 1990, Minckley et al. 1991
BC Golf Course	razorback sucker	none	growth	Burke, unpublished data
BC Wetlands Ponds	razorback sucker	none	growth	Burke, unpublished data
Buenos Aries NWR	bonytail	none	growth, maturation	Marsh 1990, Minckley et al. 1991
	razorback sucker	none	growth, maturation, reproduction	Marsh 1990, Minckley et al. 1991
Cibola High Levee Pond	bonytail	none	growth, maturation, reproduction	CO Minckley, unpublished data
CRIT Native Fish Ponds	razorback sucker	none	growth, maturation, reproduction	CO Minckley, unpublished data
Davis Cove	razorback sucker	sunfish, largemouth bass, channel catfish	survival impaired	Mueller and Burke, this volume
Dexter NFH	bonytail	none	growth, maturation, reproduction	FWS files
Emerald Canyon Golf Course	razorback sucker	green sunfish	survival impaired	Brooks, unpublished data
	bonytail	none unpublished data	growth	CO Minckley,
	razorback sucker		growth	CO Minckley, unpublished data
Mohave Backwaters	bonytail, razorback sucker	none	growth, maturation	NFWG
	bonytail, razorback sucker	suite	survival impaired	NFWG
Page Golf Course	razorback sucker	none	growth	Mueller and Wick 1998

And what these experimental sites also have in common is that either bonytail or razorback sucker, or both, when stocked into predator-free habitats, survived as young, grew from juvenile to adult life stage, matured, and in some cases reproduced and recruited. Bonytail chub are especially prolific and at times it has been a challenge to find suitable homes for all of the offspring (B. L. Jensen FWS, C.O. Minckley FWS personal communications). Other big-river fishes might respond similarly, but those experiments by and large have yet to be performed.

Call to Action

We believe the evidence argues strongly for segregated management of native and non-native fishes. Native fish management should focus first and foremost on providing aquatic habitats free of, and protected from, non-native fishes, and populated with native fish populations or assemblages derived from appropriate, genetically defined stocks.

Despite tremendous expenditures of time and money in the decade of the 1990s, in particular under auspices of the Upper Colorado River Recovery Implementation Program (FWS 1987), the status of the imperiled native fish fauna of the Colorado River unarguably continues to deteriorate. Populations are stable in few places but continue to decline in most. Within this context and armed with data referenced here, we challenge the suggestion that these natives can somehow persevere and co-exist in the company of a non-native component (see, for example, Holden et al., Modde this volume).

We also note that ambitious repatriation programs initiated to re-establish populations of Colorado pikeminnow and razorback sucker in central Arizona rivers (Brooks 1986, Marsh and Brooks 1989, Hendrickson 1993) and of the latter species in the lower Colorado River (Langhorst 1988) have met with limited success. Predation by non-native fishes was identified in each case as a major mortality factor affecting repatriates, and we expect this to be a continuing problem wherever attempts are made to fit native fishes into existing communities that include a non-native component. Even the Lake Mohave razorback sucker repatriation program, by most measures an acknowledged success, was forced from inception in the 1980s to deal with constraints imposed by non-native predation (Marsh and Langhorst 1989, Minckley et al. 1991), and that struggle continues (see contributions to the Native Fish Workgroup Session, this volume).

Resource managers should aggressively develop comprehensive management plans to implement our recommendation of segregated native fish management, in cooperation with species experts and other interested parties. This currently is being done in parts of the basin (Native Fish Work Group papers, this volume). In other parts of the basin, managers are investigating alternative mechanisms to overcome the problems of non-native fishes. Such action will not recover the native fishes, but it will greatly increase their likelihood for survival until successful recovery strategies finally are defined and implemented.

Recent events in the lower basin native fishes recovery arena include the redundant, simultaneous pursuit of a multiplicity of parallel planning programs by BR, FWS, and others, under their own auspices and under the struggling lower basin Multi-Species Conservation Program. If process and perception have become more important than genuine progress (Gunderson 1999) the situation is no better in the upper basin (see FWS 1987). It is our hope that among the outcomes of this gathering and its proceedings is a unity of purpose and practice toward sound native fish management.

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References

Brooks, J.E. 1986. Reintroduction and monitoring of Colorado squawfish *Ptychocheilus lucius* in Arizona, 1985. Annual report, U.S. Fish and Wildlife Service, Albuquerque NM. Arizona Game and Fish Department, Phoenix. 15 pages.

Carlson, C.A. and R.T. Muth. 1989. The Colorado River: Lifeline of the American Southwest. Pages 220-239 *in* D.P. Dodge, editor. Proceedings of the International Large Rivers Symposium. Canadian Special Publication in Fisheries and Aquatic Sciences 106.

Deacon, J.E. and W.L. Minckley. 1974. Desert Fishes. Chapter VII, pages 385-388 in G.W. Brown, editor. Desert Biology, Volume II. Academic Press, Inc., New York and London.

Douglas, M.E., P.C. Marsh and W.L. Minckley. 1994. Indigenous fishes of western North America and the hypothesis of competitive displacement: *Meda fulgida* (Cyprinidae) as a case study. Copeia 1994: 9-19.

Fradkin, P.L. 1981. A River No More – the Colorado River and the West. Knopf, New York. 360 pages.

Gunderson, L. 1999. Resilience, flexibility, and adaptive management – antidotes for spurious certitude? Conservation Ecology 3:7. [online] url: http://www.cousecol.org/vol3/iss1/art7.

Hendrickson, D.A. 1993. Evaluation of the razorback sucker *Xyrauchen texanus* and Colorado squawfish *Ptychocheilus lucius* reintroduction programs in central Arizona based on surveys of fish populations in the Salt and Verde rivers from 1986 to 1990. Arizona Game and Fish Department, Phoenix. 166 pages.

Holden, P. B., P.D. Abate, and J.B. Ruppert. 2005. Razorback suckers in Lake Mead: The role of habitat in determining the effect of non-native predation. Pages 99 - 103 *in* M.J. Brouder, C.L. Springer, and S.C. Leon, editors. Proceedings of two symposia: Restoring native fish to the lower Colorado River: Interactions of native and non-native fishes. July 13-14, 1999, Las Vegas, Nevada, and Restoring natural function within a modified riverine environment: The lower Colorado River. July 8-9, 1998. U.S. Fish and Wildlife Service, Southwest Region, Albuquerque, NM.

Langhorst, D.R. 1988. A monitoring study of razorback sucker *Xyrauchen texanus* reintroduced into the lower Colorado River in 1987. Final Report, Contract number FG-7494, California Department of Fish and Game, Blythe. 76 pages.

Marsh, P.C. 1990. Native fishes at Buenos Aires National Wildlife Refuge and Arizona State University Research Park, Arizona: Opportunities for management, research, and public education on endangered species. Proceedings of the Desert Fishes Council 19 (1987): 67-78.

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

Marsh, P.C. and D.R. Langhorst. 1989. Feeding and fate of wild larval razorback suckers. Environmental Biology of Fishes 21: 59-67.

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

Minckley, W.L. 1979. Aquatic habitats and fishes of the lower Colorado River, southwestern United States. U.S. Bureau of Reclamation Contract Number 14-06-300-2529. Arizona State University, Tempe. 478 pages.

Minckley, W.L. 1985. Native fishes and natural aquatic habitats in U.S. Fish and Wildlife Service Region II west of the continental divide. Report, U.S. Fish and Wildlife Service, Albuquerque NM. Department of Zoology, Arizona State University, Tempe. 158 pages.

Minckley, W.L. and J.E. Deacon, editors. 1991. Battle Against Extinction: Native Fish Management in the American West. University of Arizona Press, Tucson. 517 pages.

Minckley, W.L., D.A. Hendrickson and C.E. Bond. 1986. Geography of western North American freshwater fishes: description and relationship to intracontinental tectonism. Chapter 15, Pages 519-614 *in* C.H. Hocutt and E.O. Wiley, editors. The Zoogeography of North American Freshwater Fishes. John Wiley & Sons, New York.

Minckley, W.L., P.C. Marsh, J.E. Johnson, J.E. Brooks and B.L. Jensen. 1991. Management toward recovery of the razorback sucker. Chapter, 17, Pages 303-357 *in* W.L. Minckley and J.E. Deacon, editors. Battle Against Extinction: Native Fish Management in the American West. University of Arizona Press, Tucson.

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

Mueller, G. and T. Burke. 2005. Survival of young razorback sucker in relation to stocking rates (fish/ha) and in the presence or absence of predator communities in Lake Mohave, Arizona-Nevada. Pages 155 - 16 *in* M.J. Brouder, C.L. Springer, and S.C. Leon, editors. Proceedings of two symposia: Restoring native fish to the lower Colorado River: Interactions of native and non-native fishes. July 13-14, 1999, Las Vegas, Nevada, and Restoring natural function within a modified riverine environment: The lower Colorado River. July 8-9, 1998. U.S. Fish and Wildlife Service, Southwest Region, Albuquerque, NM.

Mueller, G. and E. Wick. 1998. Testing of golf course ponds at Page, Arizona for suitability as grow-out facility for razorback sucker using surplus fish from Ouray National Fish Hatchery. Report, U.S. Geological Survey, Denver CO. 12 pages.

Pacey, C.A. and P. C. Marsh. 1998. Resource use by native and non-native fishes of the lower Colorado River: Literature review, summary, and assessment of relative roles of biotic and abiotic factors in management of an imperiled indigenous ichthyofauna. Final Report, U.S. Bureau of Reclamation Agreement No. 7-MT-30-R0012. Arizona State University, Tempe. 1086 pages.

Tyus, H.M. and J.F. Saunders, III. 1996. Nonnative fishes in the upper Colorado River basin and a strategic plan for their control. Final Report, U.S. Fish and Wildlife Service contract number 14-48-0006-95-923. Center for Limnology, University of Colorado, Boulder. 84 pages.

Tyus, H.M., B.D. Burdick, R.A. Valdez, C.M. Haynes. T.A. Tuttle, and C.R. Berry. 1982. Fishes of the upper Colorado River basin, distribution, abundance, and status. Pages 12-70 *in* W.H. Miller, H.M. Tyus and C.A. Carlson, editors. Fishes of the upper Colorado River system: present and future. American Fisheries Society, Bethesda MD.

U.S. Fish and Wildlife Service. 1980. Aquatic study – Colorado River from Lees Ferry to Southern International Boundary and selected tributaries, Arizona, California, Nevada. Special Report of distribution and abundance of fishes of the lower Colorado River. U.S. Bureau of Reclamation contract number 9-07-03-X0066. U.S. Fish and Wildlife Service, Phoenix AZ. 157 pages.

U.S. Fish and Wildlife Service. 1987. Recovery implementation program for endangered fish species in the upper Colorado River basin. U.S. Fish and Wildlife Service, Denver CO. 82 pages.

U.S. Fish and Wildlife Service. 1997. Biological and conference opinion on lower Colorado River operations and maintenance – Lake Mead to Southerly International Boundary. U.S. Fish and Wildlife Service, Albuquerque NM. 196 pages.

U.S. Fish and Wildlife Service. 1998. Razorback sucker *Xyrauchen texanus* recovery plan. U.S. Fish and Wildlife Service, Denver CO. 76 pages.

U.S. Geological Survey. 1973. Surface water supply of the United States – Part 9, Colorado River Basin. U.S. Geological Survey Water-Supply Paper 3: 1-634.