The Effects of Introduced Fishes on Native Fishes: Arizona, Southwestern United States

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Abstract. — Before Europeans came onto the scene and changed the landscape, fewer than 30 native species of fishes inhabited the rivers and streams of Arizona. From about 1900 to about 1970 over three times that many species were introduced into the waters of the state either intentionally for sport, bait, or biological control or by accident. More than half of these introduced species have become established within the state. Competition for habitat and predation by introduced species combined with marked alteration of habitat drastically affected the native fish fauna. The various mechanisms of interaction between native and introduced fish species in the Southwest is illustrated through case histories. Presently, the native fish fauna is endangered. Future conservation efforts must be innovative, vigilant, and include (1) research into the mechanisms of interactions between native and introduced fishes in the state, (2) conservation and restoration of habitats for native species in an ecosystem or river basin concept, (3) incorporation of a value system for native fishes, and (4) stringent regulations for importation of nonnative fishes. Incorporation of the native fishes into the value systems of society (e.g., sport, biological agents, esthetics) is essential for this fauna to persist in perpetuity.

The native fish fauna in streams in the state of Arizona (Minckley 1973) and the arid American Southwest (Miller 1961) is depauperate compared to that of drainages (e.g., Mississippi River) further east. Since the late 1800s, only about 30 species have been recorded in Arizona; several are now extinct (Minckley 1973; Miller et al. 1989; Rinne 1990). By comparison, that many species may inhabit a single creek in eastern streams (Larimore et al. 1952; Jenkins and Freeman 1972; Evans and Noble 1979). Endemism is high in fishes in the western and southwestern United States, and specialization of forms is the rule. In the Gila River, which drains the major portion of Arizona, almost a third (5 of 17 species) of the native species belong to monotypic genera (Miller 1961; Minckley 1973).

Since the turn of the century, the fish fauna of Arizona has almost tripled through widespread intentional and accidental introduction and establishment of nonnative fishes (Rinne 1991b). Programmed introductions were generally for sport, bait (forage), or as biological control agents (Miller and Alcorn 1946; Miller 1952; Deacon et al. 1964; Table 1). Specific cases abound in the literature that report replacement of native fish species by those introduced, apparently through biological competition (Deacon et al. 1964; Minckley 1973; Deacon and Minckley 1974; Rinne et al. 1981; Courtenay and Meffe 1989) or direct predation (Schoenherr 1981; Meffe et al. 1983; Minckley 1983; Meffe 1985). The progressive depletion of native fishes because of introductions of nonnative species has resulted in an endangerment of the native fauna over the entire United States (Kirch 1977; Deacon 1979; Deacon et al. 1979; Williams et al. 1989). This pattern is especially true in Arizona and the Southwest where by the early 1980's 80% and 60%, respectively, of the native fishes are listed by federal and state agencies as threatened, endangered, or of special concern (Johnson and Rinne 1982; Williams et al. 1989; Rinne, 1991b). At present, all native fishes in Arizona and 80% in the Southwest are on either state or federal protection lists.

This paper reviews several case histories of the interactions of introduced and native fishes in Arizona and delineates the impacts of introductions on the native fauna. I make recommendations for future conservation of this endangered fauna relative to the impacts to date, to the mechanisms of these impacts, and to the widespread alteration of aquatic habitats within the state.

Species Introductions

A list of the species introduced into waters of Arizona and the date and purpose for introduction are given in Table 1. Although some introductions were not successful, several species have become widespread and abundant in both rivers and lakes. In upper elevation streams, rainbow trout *Oncorhynchus mykiss* and brown trout *Salmo trutta* have become widely established. They constitute a major component of the state's coldwater fishery (Arizona Game and Fish 1985). At lower elevations, the catfishes likewise have become widespread, especially channel catfish *Ictalurus punctatus*, black *Amerius melas*, and yellow *A. natalis* bullheads, and flathead catfish *Pylodictus olivaris*. Members of the Centrarchidae (i.e., basses and sunfishes) have probably been the most intensively introduced (10 species) and most widely successful of introductions of nonnative species. Members of this group range from the low desert in the highly modified Colorado River in the extreme southwestern part of Arizona to upper elevations (>1500 m) in montane streams and lakes of the central Arizona mountains. Similar to the trouts for coldwater, they make up a major component of the warmwater fishery in Arizona.

The most widespread nonsport fishes to become established are the mosquitofish *Gambusia affinis* and red shiner *Cyprinella lutrensis*. The former was introduced for biological control of mosquito larvae and the latter accidentally by the baitfish industry and intentionally as a forage fish. Both of these small fish have penetrated many habitats where rare native species persist. Other species introduced accidentally or for biological control are members of the family Cichlidae *Tilapia*. Other species occur only sporadically and in isolated habitats and have not yet become a major negative influence on the native fish fauna.

Mechanisms of Interactions

Hybridization

Hybridization between native and introduced fishes in Arizona is best illustrated with salmonid fishes. Rainbow, brown, and brook trout *Salvelinus fontinalis* were first introduced from about 1900 to 1924 (Table 1). The rainbow trout has probably been the most widely stocked salmonids in Arizona and is the only one of the three that, because of its spring spawning habits, freely hybridizes with the native Apache

TABLE 1.—Introduced fishes of Arizona and the lower Colorado River, 1881–1981, listed by the primary reason for their introduction. Those species currently established are denoted by an asterisk.

	Sport	
White sturgeon	*Acipenser transmontanus*	1967
Coho salmon	*Oncorhynchus kisutch*	1967
Sockeye salmon	*Oncorhynchus nerka*	1957
Cutthroat trout*	*Oncorhynchus clarki ca.*	1900
Rainbow trout*	*Oncorhynchus mykiss ca.*	1900
Golden trout	*Oncorhynchus aguabonita*	1971
Brown trout*	*Salmo trutta*	1924
Brook trout*	*Salvelinus fontinalis*	1920
Grayling*	*Thymallus arcticus*	1943
Northern pike*	*Esox lucius*	1967
Muskellunge	*Esox masquinongy*	1970s
Striped bass*	*Morone saxatilis*	1969
White bass*	*Morone chrysops*	1960
Yellow bass*	*Morone mississippiensis*	1929–32
Smallmouth bass*	*Micropterus dolomieui*	1942
Largemouth bass*	*Micropterus salmoides*	1935
Rock bass	*Ambloplites rupestris*	1960
Warmouth*	*Lepomis gulosus*	1950s
Redear*	*Lepomis microlophus*	1947
Green sunfish*	*Lepomis cynellus* before	1926
Pumpkinseed*	*Lepomis gibbosus*	1950
White crappie*	*Pomoxis annularis*	before 1924
Black crappie*	*Pomoxis nigromaculatus*	1930s
Yellow Perch*	*Perca flavescens*	1930s
Walleye*	*Stizostedian vitreum*	1960s
Sargo	*Anisotremus davidsoni*	1960s
Bairdella	*Bairdella icistia*	1960s
Orangemouth corvina	*Cynoscion xanthalus*	1960s
Mozambique tilapia*	*Tilapia mossambica*	1960s
	Accidental	
American eel	*Anguilla rostrata*	unknown
Mexican tetra*	*Astanax mexicanus*	1950
Goldfish*	*Carassius auratus*	1930s
Silver carp*	*Hypophthalmichthys molitrix*	1972
Utah chub*	*Gila atrana*	1940s
Leatherside chub	*Gila copei*	1940s
Redside shiner	*Richardsonius balteatus*	1960s
Sand shiner	*Notropis stramineus*	1938
Beautiful shiner	*Notropis formosus*	1971
Smallmouth buffalo*	*Ictiobus bubalus*	1918
Black buffalo*	*Ictiobus niger*	1918
Mountain sucker	*Catostomus platyrhynchus*	1940s
Rio Grande sucker	*Catostomus plebius*	1940s
Walking catfish	*Clarias batrachus*	1969
Plains killifish	*Fundulus zebrinus*	1930s
Guppy*	*Poecilia reticulata*	1960s
Mexican molly*	*Poecilia mexicana*	1960s

contd.

Table 1 (continued)

Variable platyfish*	*Xiphophorus variatus*	1960s
Green swordtail*	*Xiphophorus helleri*	1960s
Convict cichlid*	*Cichlasoma nigrofasciatum*	1969
Firemouth cichlid*	*Cichlasoma meeki*	1968
Rio Grande cichlid	*Cichlasoma cyanoguttatum*	1969
Mottled sculpin	*Cottus bairdi*	1940s
Longjaw mudsucker*	*Gillichthys mirabilis*	1940s
	Forage	
Threadfin shad*	*Dorosoma petenense*	1953
Red shiner*	*Cyprinella lutrensis*	1953
Fathead minnow*	*Pimephales promelas*	1950s
Bluegill*	*Lepomis macrochirus*	1936
	Food	
Common carp*	*Cyprinus carpio*	1881–91
Bigmouth buffalo*	*Ictiobus cyprinellus*	1918
Flathead catfish*	*Pylodictus olivaris*	1940s
Channel catfish*	*Ictalurus punctatus*	1892–93
Blue catfish	*Ictalurus furcatus*	1972
Yaqui catfish	*Ictalurus pricei*	1899
Brown bullhead*	*Amerius nebulosus*	1900s
Black bullhead*	*Amerius melas*	1900s
Yellow bullhead*	*Amerius natalis*	1890s

trout *Oncorhynchus apache*. As a result, the native trout has been reduced drastically in range and numbers (U. S. Fish and Wildlife Service 1979; Rinne 1988; Carmichael et al. 1993), and its present distribution in pure form can be correlated only with past stocking records of rainbow trout (Rinne and Minckley 1985). Harper (1978) stated that the native Apache trout has been reduced to less than 5% of its former range in Arizona. In the late 1800s anglers could easily catch 100 per hour (U. S. Fish and Wildlife Service 1979). Presently, fishing is carefully regulated in some of the streams containing this "featured species" of sportfish (Arizona Game and Fish 1985).

Part of the massive range reduction of the Apache trout can be attributed to habitat alteration and competition with brown and brook trouts. Nevertheless, because less than 12 of over 46 streams examined in the White Mountains of Arizona between 1977 and 1982 contained Apache trout populations which had not hybridized with other salmonid species (Rinne 1985), hybridization can be offered as a valid and major factor responsible for the marked decline of this once abundant native species. Based on hatchery produced F_1 hybrids, Rinne et al. (1985) suggested that either pre- or post-mating isolating mechanisms may be present between the two species. However, hybrids have been readily produced by the U. S. Fish and Wildlife Service, Williams Creek National Fish Hatchery (Bob David, USFWS, personnel communication). Much of the hybridization that occurred between Apache trout and rainbow trout in the past has diminished with the cessation of stocking of fingerling rainbow trout. Trout planted in this manner grew to adults in the wild and readily interbred with the native trout (Rinne 1985). However, based on mitochondrial DNA analyses Dowling and Childs (1992) suggested hybridization may be regulated and dampened by assortative mating and selective gene exchange between rainbow and Apache trout. Nevertheless, both the prohibition of stocking of rainbow trout in streams containing native trout and the use of "catchables" have reduced the extensive hybridization that once occurred.

Competition

Competition also is evidenced indirectly with salmonid introductions. Both brown and brook trouts have replaced Apache trout in Ord Creek, Fort Apache Indian Reservation. Despite attempted stream renovation with fish toxin in 1977 and reintroduction of Apache trout to Ord Creek, brook trout currently dominate the fish population in this stream, comprising 85% of the total number and 78% of the total biomass of adult trout (Rinne et al. 1981). Relative abundance alone could result in competition for food and space. Laboratory experiments designed by Ken Harper (unpublished manuscript) to delineate more direct interspecific interaction showed that adult brook trout were more aggressive than Apache trout. Such dominance could interfere with feeding and spawning success of the native trout.

Based on laboratory studies, the introduced brown trout is less influenced by the lack of food or cover than is the native Apache trout (Mesick 1988). Brown trout feed more efficiently at lower light intensities than do Apache trout (Robinson and Tash 1979). Further, adult brown trout are highly piscivorous and potentially can prey on juvenile Apache trout. Temperature tolerances of adults (17–20 cm) of Apache trout and all three introduced trout are the same (Lee and Rinne 1980). Although temperature tolerances of juveniles have not been tested, thermal data confirm that the introduced species of trout can occupy all waters inhabited by the native trout, both historic and current.

The red shiner, introduced accidentally by the bait industry and intentionally as a forage species, is presently widespread in aquatic habitats in Arizona. It has been implicated as having contributed significantly to the decline of native fish populations in Arizona (Minckley and Carufel 1967; Minckley 1973) and the Southwest (Minckley and Deacon 1968). In its native range, the red shiner occupies constant flowing streams with an assemblage of other minnows, but it persists admirably under intermittent flow conditions characterized by stressful environmental conditions of pH, dissolved oxygen, and high turbidities and temperatures (Metcalf 1966; Cross 1967; Matthews and Hill 1977). The red shiner is a generalist in habitat use and often becomes abundant and dominates fish assemblages in its native range in midwestern streams that have sustained habitat degradation (e.g., increased turbidity and temperatures). This usually occurs to the detriment of more specialized fishes inhabiting midwestern streams (Matthews and Maness 1979). The low faunal diversity of streams in the West and Arizona specifically, combined with natural variations of aquatic habitat conditions and that induced through habitat alteration, provide more suitable conditions for establishment and proliferation of the red shiner.

The red shiner has an inverse distribution pattern in Arizona to two native, nonsalmonid, federally threatened species, spikedace *Meda fulgida* and loach minnow *Tiaroga cobitis* (Minckley 1973). In general, where the red shiner is present, these and other native species are absent. The mechanism of displacement or competition is not known. Rinne (1991a) suggests utilization of the same physical habitat in the Verde River, Arizona, by adult red shiner and juvenile spikedace may be one mode of competition. Both the spikedace and loach minnow may be threatened by red shiner in Aravaipa Creek, south-central Arizona. The introduced shiner was recently recorded (September 1990) in this "refugium" stream for native fishes.

In lowermost reaches of the Virgin River, Arizona, the red shiner population increased while the native, endangered woundfin *Plagopterus argentissimus* has decreased (Cross 1978). The woundfin is restricted to the Virgin River in Arizona, Utah, and Nevada. Successful recruitment of this native cyprinid in the Virgin River is influenced by adequate flows in spring and low flows characteristic of periods of drought in the Southwest (Deacon and Hardy 1984; Deacon 1988). Recent drought in the region and resultant reduced streamflow and construction of Quail Creek Dam in the basin reduced peak flows. These factors resulted in a similar pattern of replacement of woundfin by red shiners in upstream reaches. Stream renovation with fish toxicant (rotenone) in 1988, 1989, and 1990 along with barrier construction were employed to recover the endangered native minnow in the Virgin River. At present, success of these renovations is unknown. However, inadequate detoxification resulted in the unplanned loss of many woundfin and other native fishes inhabiting this desert river.

Predation

Evidence of the importance of the effect of predation between native and introduced fishes is increasing. The Centrarchidae have been widely introduced for sport fishing in Arizona. In the lower Colorado River, members of this family have almost displaced the native fish fauna, presumably through predation on the eggs and young of native species (Minckley 1979). The drastic decline of the razorback sucker *Xyrauchen texanus* in the lower Colorado River is attributed to predation on razorback ova by catfish and common carp and on larvae and fry by centrarchids (Minckley 1983). The green sunfish *Lepomis cyanellus* appears to be a strong contributor to replacement of the native Gila chub *Gila intermedia*, presumably via predation. It has been collected in abundance in downstream reaches of Sycamore Creek (Rinne, unpublished data). Despite being very abundant in the headwaters where the sunfish is absent, ~~the native chub~~ is totally absent in the lower reaches where sunfish abound. A similar pattern of replacement of Gila chub by green sunfish has been documented in Sabino Canyon by J.A. Stefferud (Tonto National Forest, personnel communication). Results of preliminary laboratory experiment suggest green sunfish is also an effective predator on juveniles of the threatened Little Colorado spinedace *Lepidomeda vittata*. Laboratory and field experiments have demonstrated rainbow trout to be a major predator on young-of-year and juvenile of the threatened spinedace (Blinn et al. 1993).

Marsh and Brooks (1989) reported predation effects by flathead and channel catfis when an attempt was made to reestablish razorback sucker in its native range. In on 2-day period it was estimated that up to 900 juvenile razorback suckers (45–168 mı SL) were eaten by these two introduced ictalurids in the Gila River, Arizona.

Other formerly abundant, but now rare native species (e.g., spikedace, loac minnow, Colorado squawfish *[Ptychocheilus lucius]*) of the Gila River, the low Salt River, the Verde River, and the lower Colorado River have been replaced introduced fishes. Channel and flathead catfish are abundant in all these waters. Tl lack of coexistence between the native species and these two large predators in the larger river systems implicates these catfishes as contributors to the negative impa on native fish diversity. These inverse patterns of distribution of native species aı the two catfishes combined with the data of Marsh and Brooks (1989) is eviden that predation is occurring.

The mosquitofish *Gambusia affinis*, which Myers (1965) labeled the "fish destroyer," has been introduced worldwide as a biological control agent for mosquito larvae (Shoenherr 1981). Such introductions often are conducted despite the presence of native fish species that consume mosquito larvae. In Arizona, the mosquitofish has been implicated as a competitor responsible in large part for the drastic reduction of the range of the native Gila topminnow *Poeciliopsis occidentalis occidentalis* (Minckley 1973; Minckley et al. 1977; Meffe, et al. 1983). The topminnow and the native desert pupfish *Cyprinodon macularius macularius* were formerly widespread, and both were undoubtedly quite effective in mosquito control. Although not demonstrated, competition was suggested as the mechanism causing the decline of the two native species. The topminnow began to decline in the early 1900s with alteration of habitat by humans (Miller 1961). Nevertheless, the topminnow was considered to be one of the most common native fish species in the lower Colorado River Basin in the 1930s (Hubbs and Miller 1941). Mosquitofish were introduced in California in 1922 and were collected from the Salt River at Tempe, Arizona, in 1926. Replacement of the topminnow by mosquitofish is usually rapid (Minckley and Deacon 1968; Minckley 1969); however, in the 1970s, the two species were reported to co-occur in southern Arizona in the Santa Cruz River system and Sonoita Creek (Minckley et al. 1977). In both instances, it appeared that topminnows were coming from upstream, springhead refugia characterized by high carbonate waters.

Because of the similarity of life history characteristics of topminnow and mosquitofish, it could be assumed that competition for resources was the mechanism of replacement of the former by the latter (Shoenherr 1981). However, extensive studies both in the laboratory and in the wild by Shoenherr (1974) suggest mosquitofish eliminate topminnow by predation on the fry and, secondarily, by reducing survivorship of adult females. Meffe (1984) demonstrated that coexistence of topminnow with mosquitofish may be dependent on habitat complexity. Meffe (1984) also discussed flood disturbance as a factor permitting persistence of topminnow in presence of mosquitofish. Meffe's (1985) field and laboratory studies corroborated Shoenherr's earlier (1974) results indicating replacement of the native topminnow by the mosquitofish occurs largely through predation. Predation, as a mechanism of interaction between native and introduced fishes, may ultimately be demonstrated to be the primary reason for decline of native fish diversity in Arizona and the Southwest.

Current Status and Proposed Conservation of Native Fishes

Over the past century, the fish fauna of the state of Arizona has been drastically altered. Species diversity of rivers and streams has nearly tripled through introductions of nonnative species. In addition, the hydrological and aesthetic setting in the state has been drastically altered or lost through damming and diversion of streams (Rinne 1990; Rinne 1994) and groundwater mining. As a consequence, available space in terms of aquatic habitats for native fishes has become severely limited. In larger downstream rivers where an assemblage of native fishes once occurred (e.g., Salt River at Tempe; *cf* Minckley and Deacon 1968), only several species of suckers genus *Catostomus* and a minnow longfin dace, *Agosia chrysogaster* now co-occur with an almost exclusively introduced fauna. Indeed, the native fish fauna of the state is endangered (Johnson and Rinne 1982; Rinne and Minckley 1991). The current status of the native fishes in Arizona is virtually irreversible; the introduced fauna is established and cannot be removed easily in either economic or practical terms.

For the native fish fauna of Arizona to persist, innovative and progressive approaches to future conservation must be adopted (Rinne 1990, 1991b; Rinne in press). Through education, native fishes should be demonstrated to be of value to our society in the same manner that a rationale was provided for introduction of nonnative species. For example, the two rare native trouts should be managed with the philosophy of future sport fisheries. The Gila topminnow rather than the mosquitofish should be promoted to state health departments for mosquito control. Some of the native minnows and suckers, which are yet abundant in streams and rivers, could be used locally as bait species. The Colorado squawfish could be managed as a sport species to enhance its status where introduced.

Land managers must continually strive to maintain and protect aquatic habitats where an assemblage of native fishes occurs. For example, Aravaipa Creek, Graham and Pinal Counties, Arizona, has 7 of the original 17 native Gila River fishes (Barber and Minckley 1966). If one excludes the four large river species (humpback chub *Gila cypha*, bonytail chub *Gila elegans*, Colorado squawfish and razorback sucker), which have not been recorded in this stream, over half of the native fauna of this river basin that drains the majority of Arizona is intact in this single small, upper Sonoran Desert stream. Aravaipa Creek is, in part, protected by water rights, by private groups (The Nature Conservancy, Defenders of Wildlife), and by a public agency (U. S. Bureau of Land Management). The approach of managing native fishes on an ecosystem or watershed basis and thereby conserving a group of native species in one effort needs to be adopted when and where such opportunities arise Acquisition and protection of aquatic habitats as demonstrated by the purchase o San Bernardino, (U. S. Fish and Wildlife Service) and White Mountain and establishment of San Pedro River National Riparian Conservation Area (U. S. Bureau of Land Management), both in Cochise County, Arizona, should be an importan future management strategy to conserving native fish diversity (Rinne, 1991b).

Conclusions

The native fish fauna of the state of Arizona has been drastically altered, in par because of chronic, extensive, and widespread introduction of nonnative species fc sport, bait, or as biological agents. Other than locally, in a practical sense this si uation cannot be reversed. To preserve this endangered fish fauna, management (these species must be innovative and include (1) an ecosystem or basin approac to management of native fishes; (2) incorporation of native species into the valu systems of our society (e.g., bait, sport, biological control, aesthetics); (3) results research on native species; and (4) stringent regulations for importation of nonn tive fishes into the state. The native fishes of Arizona and the Southwest, in gener are a valuable, renewable resource and should be managed as such (Rinne 199 Rinne and Minckley 1991).

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