

Declining Southwestern Aquatic Habitats and Fishes: Are They Sustainable?

John N. Rinne¹

Abstract — Aquatic habitats and native fishes in the arid American Southwest have declined drastically in the past half century. Physically, changes are attributable to dams and diversions, channelization, and drying of streams. Biologically, the extensive introduction of non-native species of fishes has negatively impacted the native fish fauna through hybridization, competition, and predation. Sustaining both the aquatic and native fish resources will require a combination of securing habitats, changing both species and land management strategies, and continued research on the biology and habitat requirements of native species.

INTRODUCTION

Historically, riparian-stream areas of the southwestern United States supported aquatic habitats critical for survival of native fishes. In the past half to three quarters of a century, these vital resource areas and the native fishes they supported have declined markedly. Extensive aquatic habitats have been modified or lost through construction of major and minor dams, water diversion, channelization, and groundwater mining. Superimposed upon habitat modification have been biological alterations, principally the introduction of non-native fishes. Although the extent of these biological and hydrological alterations has slowed dramatically, in part because of absence of opportunity, their legacy persists.

Extensive research and management effort has been expended over the past quarter century to curb this dramatic loss of habitat and fishes and to reverse its trend. The objective of this paper is to present an overview of both past and ongoing conservation efforts designed to sustain aquatic habitats and native fishes in the Southwest. I will discuss and summarize, through both the literature and case history examples for native fishes principally in Arizona: 1) the nature of the decline of aquatic resources in the region, 2) suggest necessary actions to halt and perhaps reverse this decline, and finally, 3) attempt to answer the question: Are aquatic habitats and fishes sustainable in the American Southwest?

THE FISHES

The native fish fauna in streams in Arizona (Minckley 1973 and the arid American Southwest (Miller 1961, Rinne and Minckley 1991) is depauperate compared to that of drainage further east. Since the late 1800s, only about 30 taxa of fishes have been recorded in the waters of Arizona; several are now extinct (Minckley 1973, Miller et al. 1989, Rinne 1990a). By comparison, that many species may inhabit a single creek in eastern streams. Endemism is high in fishes in the Southwest 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).

The progressive depletion of native fishes resulting from introductions of non-native fishes has endangered many native fish over the entire United States (Kirch 1977, Deacon 1979, Deacon et al. 1979, Williams et al. 1989). Many species of fishes new to the West and Southwest were introduced largely for recreational or sport fishing (table 1). Since the turn of the century, the fish fauna of Arizona has almost tripled through widespread intentional and accidental introduction of non-native fishes (Rinne 1990b). Non-native fish introductions were primarily for sport, bait, or as biological control agents (Miller and Alcorn 1946, Miller 1952, Deacon et al. 1964).

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), hybridization (Rinne 1988, Rinne and Minckley 1985, Rinne et al. 1985) or direct predation (Schoenherr 1983, Meffe et al. 1983, Minckley 1983, Meffe 1985, Blinn et al. 1985).

¹ John N. Rinne is a fisheries research biologist and National Fisheries Research Coordinator with the Rocky Mountain Forest and Range Experiment Station, USDA Forest Service, Flagstaff, Arizona.

As a result, 60% of the native fishes in the Southwest are listed by federal and state agencies as threatened, endangered, or of special concern (Johnson and Rinne 1982, Williams et al. 1989, Rinne, 1990b).

THE HABITATS

In the early 1900s, humans moved westward and began settling in the arid American Southwest. Major (fig. 1) and minor dams, diversions of water for agriculture, and pumping of groundwater were necessary for man to survive. Water development projects vastly altered the hydrologic regimes of the area, and imposed drastic additional demands upon the

naturally changeable rivers and streams and their fishes (fig. 2). These added impacts when combined with the naturally occurring changes of flood and drought, often exceeded the limits of adaptation of many species. The combination of rapid quantitative and qualitative changes of hydrologic conditions, man's continued alteration of aquatic habitats and natural hydrologic cycles, and the introduction of fishes foreign to these waters caused a dramatic decline in the native fish fauna; some species became extinct (Miller et al 1989, Minckley 1973). At present, the remaining fish fauna of the desert Southwest is endangered. Conservation of this valuable natural resource is and will continue to be a strong challenge to fish managers and biologists of the region.

Table 1. — Introduced recreational or sport fishes of Arizona and the lower Colorado River, 1900-1971. Those species currently established are denoted by an asterisk.

COMMON NAME	SCIENTIFIC NAME	YEAR INTRODUCED
White sturgeon	<i>Acipenser transmontanus</i>	1967
Coho salmon	<i>Oncorhynchus kisutch</i>	1967
Sockeye salmon	<i>Oncorhynchus nerka</i>	1957
Cutthroat trout*	<i>Oncorhynchus clarki</i>	ca. 1900
Rainbow trout*	<i>Oncorhynchus mykiss</i>	ca. 1900
Golden trout	<i>Oncorhynchus aguabonita</i>	1971
Brown trout*	<i>Salmo trutta</i>	1924
Brook trout*	<i>Salvelinus fontinalis</i>	1920
Grayling*	<i>Thymallus articus</i>	1943
Northern pike*	<i>Esox lucius</i>	1967
Muskellunge	<i>Esox masquinongy</i>	1970s
Striped bass*	<i>Morone saxatilis</i>	1969
White bass*	<i>Morone chrysops</i>	1960
Yellow bass*	<i>Morone mississippiensis</i>	1929-32
Smallmouth bass*	<i>Micropterus dolomieu</i>	1942
Largemouth bass*	<i>Micropterus salmoides</i>	1935
Rock bass	<i>Ambloplites rupestris</i>	1960
Warmouth*	<i>Lepomis gulosus</i>	1950s
Redear*	<i>Lepomis microlophus</i>	1947
Green sunfish*	<i>Lepomis cynellus</i>	before 1926
Pumpkinseed*	<i>Lepomis gibbosus</i>	1950
White crappie*	<i>Pomoxis annularis</i>	before 1924
Black crappie*	<i>Pomoxis nigromaculatus</i>	1930s
Yellow Perch*	<i>Perca flavescens</i>	1930s
Walleye*	<i>Stizostedion vitreum</i>	1960s
Sargo	<i>Anisotremus davidsoni</i>	1960s
Bairdella	<i>Bairdella icistia</i>	1960s
Orangemouth corvina	<i>Cynoscion xanthalmus</i>	1960s
Mozambique tilapia*	<i>Tilapia mossambica</i>	1960s

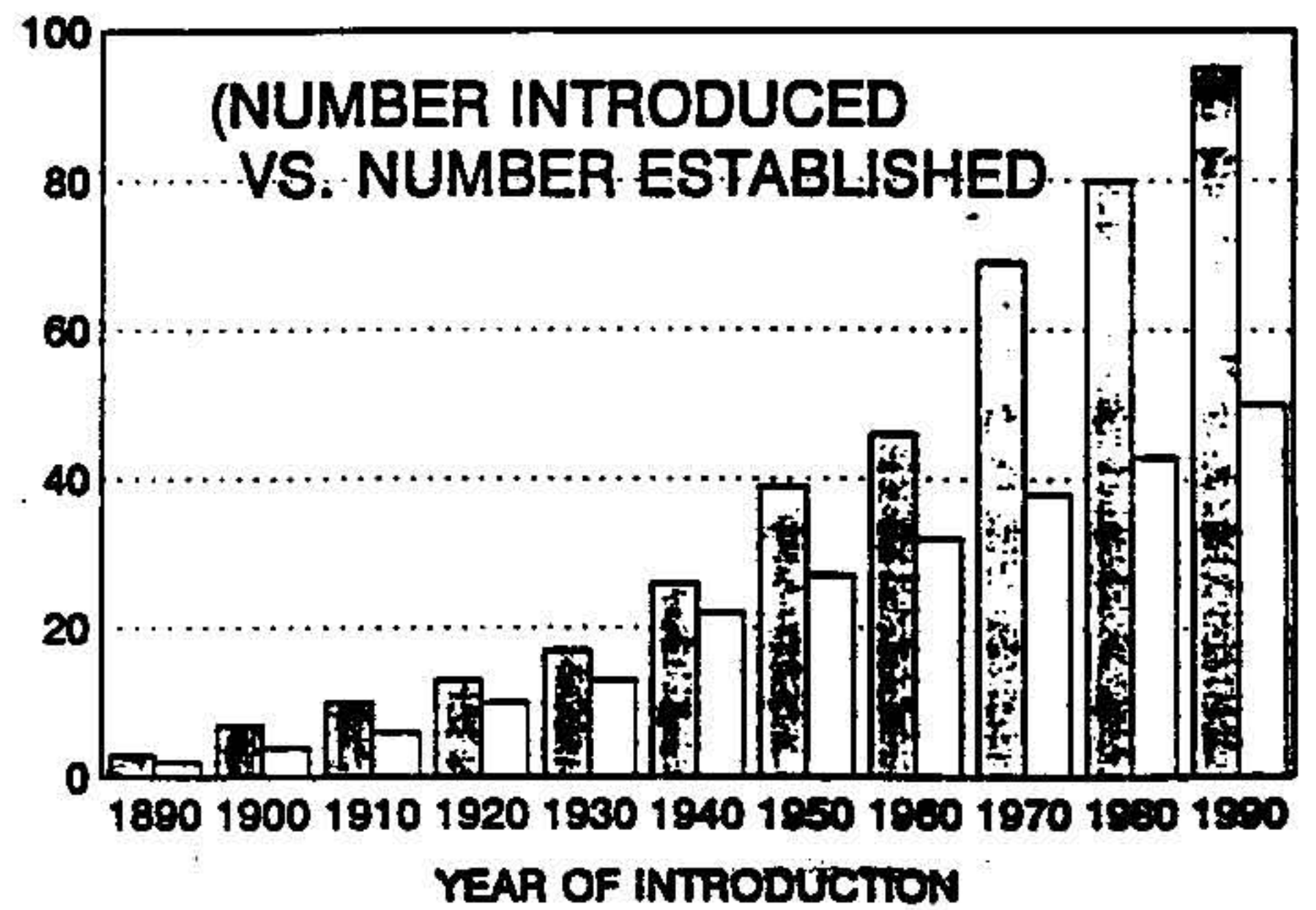


Figure 1. — Chronological history of non-native fishes introduced and ultimately established in the waters of Arizona 1890-1990.

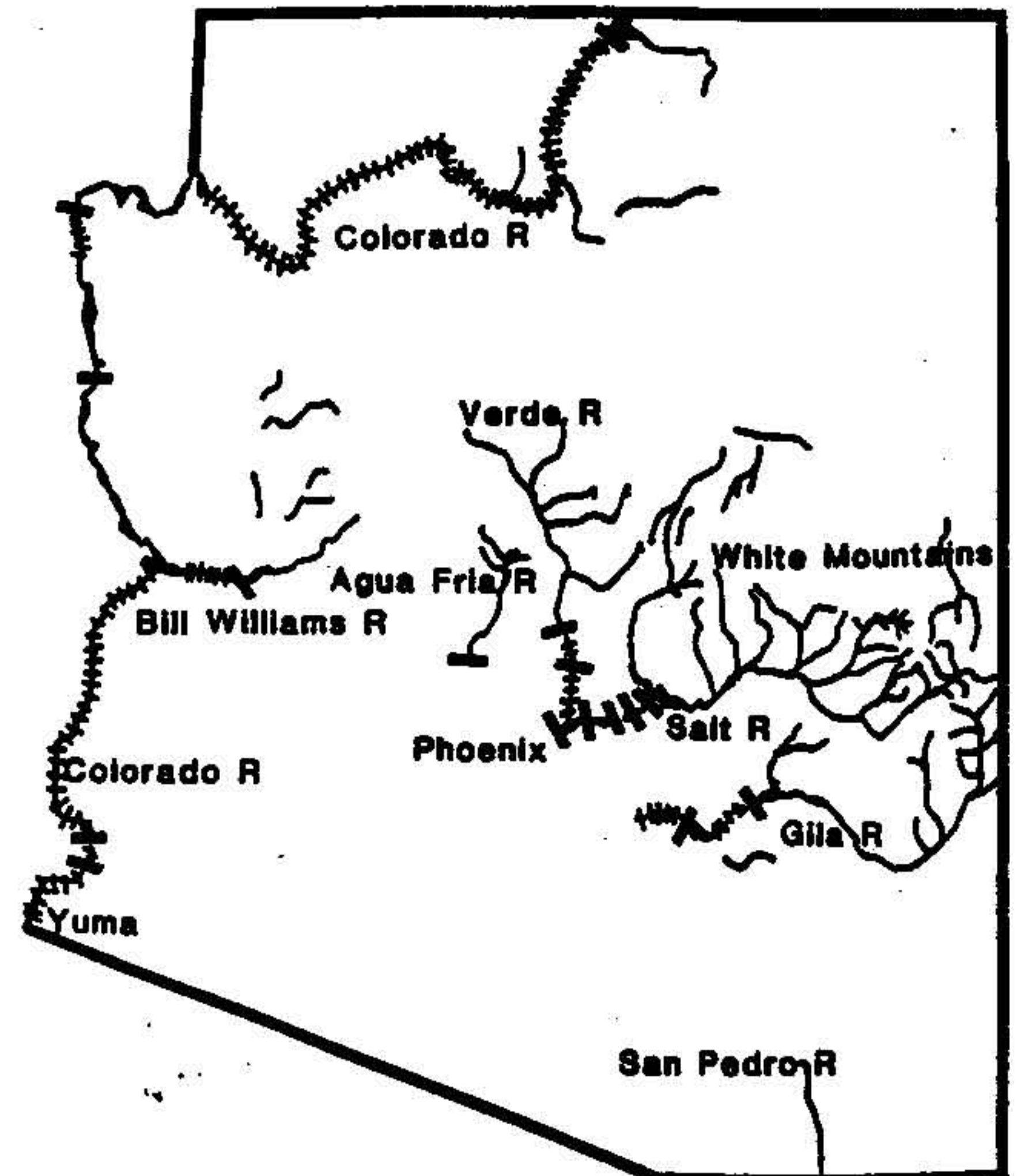


Figure 2. — State of Arizona, indicating major dams (solid bars) and stream habitat modified (cross hatching) by these dams.

HYDROLOGIC IMPACTS

Salt River

The hydrology of the Southwest has been altered dramatically. In Arizona, 80% of mainstream river habitats have either been physically and chemically altered or completely lost through drying (fig. 3). The first U. S. Bureau of Reclamation dam, Roosevelt, was completed on the Salt River in 1911. This dam and a series of 3 more (Stuart Mountain, Morman Flat, and Horse Mesa) within the next 25 years effectively dried the Salt River at Tempe. Horseshoe and Bartlett reservoirs soon followed on the Verde River, a tributary of the Salt. In the late 1800s more than a dozen native fishes swam in the waters of the Salt River at the Tempe Bridge (Deacon and Minckley 1968). Presently, only an assemblage of introduced species such as carp, catfish, sunfishes, and cyprinids from the bait industry can be collected in the few remaining artificial aquatic habitats created by gravel mining, developments, and sewage effluent in the reach of the Salt in the greater Phoenix metropolitan area.

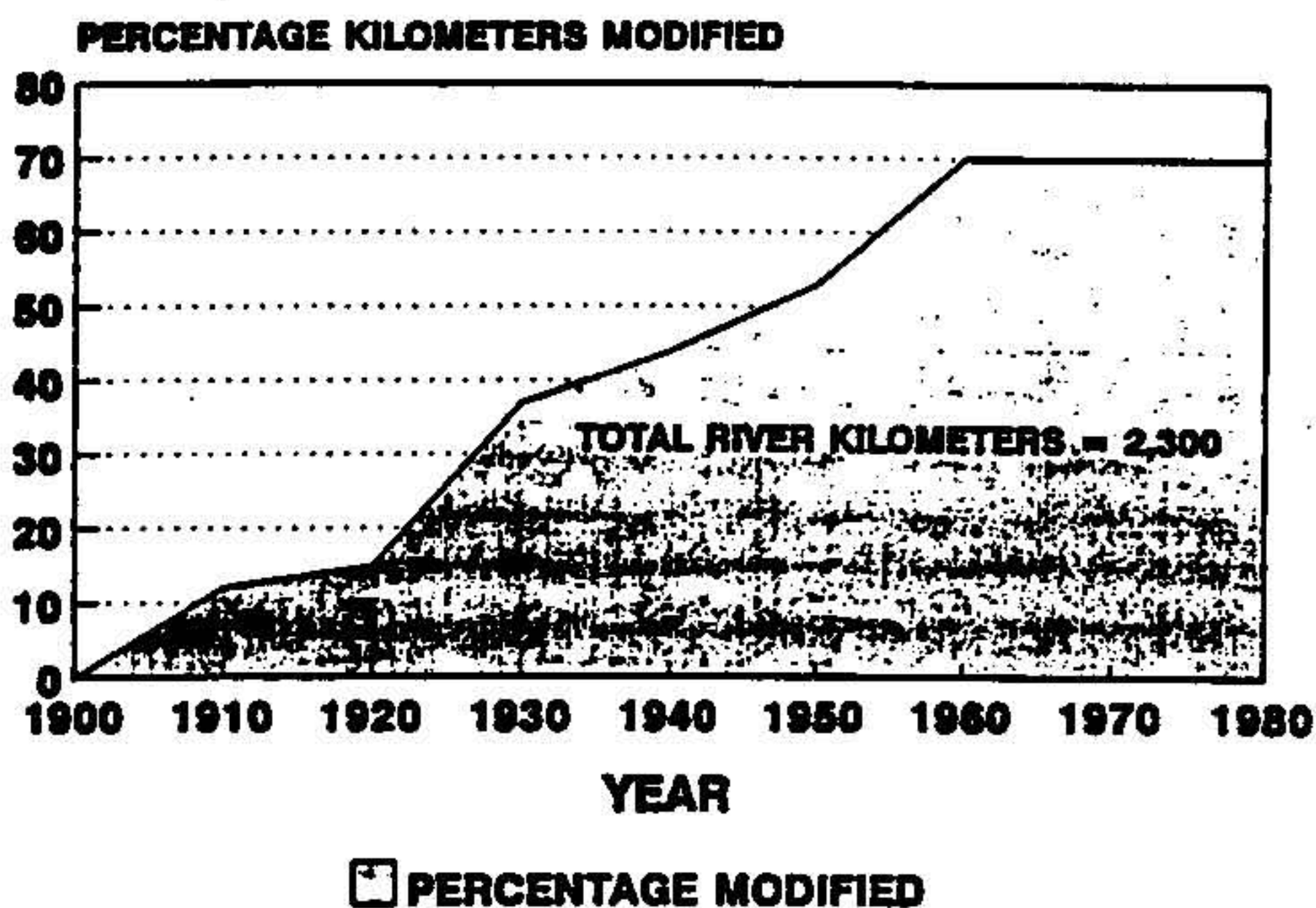


Figure 3. — Percentage of mainstream river habitat modified by major dams in Arizona, 1900-1980.

Gila and Colorado Rivers

Similar to the Salt, the Gila River was dried following completion of Coolidge Dam. Historically, the Gila River was navigable and was comprised of large marshy areas and oxbow lakes that would become several kilometers wide in flood (Rea 1983). Gila topminnow (*Poeciliopsis occidentalis*) and desert pupfish (*Cyprinodon macularius*) (see below) once abounded in these waters. The large Colorado salmon or squawfish (*Ptychocheilus lucius*) once ran in spawning schools up the Gila River, and in the late 1800s penetrated upstream at least as far as Ft. Thomas, over 200 km southeast of Phoenix (Kirsch 1889,

Minckley 1973). Except for local convectional monsoon runoff and periodic flooding from winter storms and runoff, these once extensive and diverse aquatic habitats are rivers of sand characterized by intermittent or subsurface only.

The taming of the Colorado River began in 1935 with completion of Boulder Dam impounding Lake Mead. Again, successive dams below (Parker and Davis) and above (Glen Canyon Dam) initial structure completely controlled and altered this diverse and hydrologically variable aquatic habitat, which was home for four large river cypriniform fishes: razorback sucker (*Xyrauchen texanus*), Colorado squawfish, and bonytail (*Epiplatys elegans*) and humpback (*G. cypha*) chubs (see below) (Fausch and Minckley 1991). The Colorado is perhaps the most controlled and modified river in the world, presently consisting of dams, diversions, canals, and channelized waterways.

By comparison, very few streams such as Aravaipa in southeast Arizona support an intact assemblage of native fishes (Barber and Minckley 1966, Rinne 1992). Streams in the Southwest such as Aravaipa that are generally unmodified by dams or diversions will effectively sustain a native fish fauna. Although non-natives are introduced accidentally from tanks on the watersheds during storms, subsequent floods are used to remove introduced fishes while sustaining native species.

WATERSHED IMPACTS

The upper elevation, more mesic forested areas of central Arizona and the White Mountains have sustained extensive timber harvest and grazing (Rinne and Medina, in press). The post war (1950s-60s) westward movement of the human population increased use of the national forests through hunting, fishing, and general recreational activity. The 1960 Multiple Use and Sustained Yield Act, along with other environmental legislation in general, resulted in more emphasis for all uses of public lands (Rinne and Medina, in press). Accompanying the environmental movement was the paradigm that all uses of the landscape are interrelated, and that one use affects the others.

The concepts of the intimacy of the watershed and its relationship to the functioning and health of riparian-stream systems (DeBano and Schmidt 1989) and the disciplines of hydrology and fisheries (Heede and Rinne 1990) are paramount in sustaining native fishes. The idea of approaching natural resource management on a watershed/ecosystem basis developed in the late 1980s (Szaro and Rinne 1988). Extensive literature generated in the 1980s on the effects of grazing on stream habitats and fishes (Platts 1979, 1981, 1982, Kauffman and Knueger 1984, Rinne 1985, 1988). The Clean Water Act placed increased scrutiny of the quality of water issuing from watersheds into streams supporting native fishes.

Hybridization

Hybridization between native and introduced fishes in Arizona is best illustrated with salmonids. Rainbow (*Oncorhynchus mykiss*) and cutthroat (*clarki*) trout were first introduced from around the turn of the century (table 1). The rainbow trout has probably been more widely stocked in Arizona, and because of its spring spawning habits, freely hybridizes with the native Apache trout (*apache*). As a result, the native trout has been reduced drastically in range and numbers (U. S. Fish and Wildlife Service 1979, Rinne 1988), and its present distribution in pure form is negatively correlated with past stocking records of rainbow trout (Rinne and Minckley 1985). The native Apache trout had become restricted to less than 5% of its former range in Arizona (Harper 1978). 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).

In part, 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 a dozen of 10 streams examined in the White Mountains of Arizona between 1977 and 1982 contained Apache trout populations that 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 F₁ hybrids, Rinne et al. (1985) suggested that either pre- or post-mating isolating mechanisms may be present between the two species. Hybrids, however, have been readily produced by the U. S. Fish and Wildlife Service, Williams Creek National Fish Hatchery (Bob David, USFWS, pers. comm.). Further, much of the hybridization that occurred between Apache and rainbow trouts historically has diminished with the cessation of stocking of fingerling rainbow trout. Trout planted as fingerlings grew to adulthood in the wild and presumably more readily interbred with the native trout (Rinne 1985). Recently, utilizing state of the art genetic techniques, Dowling and Childs (1992) reported hybridization between rainbow and the native trout to be regulated and dampened maternally by the latter. Based on a genetic analysis of introgression, Carmichael et al (1993) paint a bleak picture for the sustainability of the rare native trout in the White Mountains. Nevertheless, the combination of either using "catchables" or prohibition of stocking of rainbow trout in streams containing Apache trout and the apparent innate genetic trait suggested by Dowling and Childs (1992) have dampened the historic, more extensive hybridization effect.

Competition is another major mechanism of interaction that results from the extensive non-native salmonid introductions. Both brown and brook trouts have replaced the native trout in Ord Creek, Fort Apache Indian Reservation. Despite attempted stream restorations with fish toxin (1977 and 1981), and reintroduction of Apache trout to Ord Creek, brook trout continue to dominate the fish population in this stream. In 1977 they comprised 85% of the total number and 78% of the total biomass of adult trout (Rinne et al. 1981). Relative abundance of non-native to native trout could result in competition for food and space. Preliminary laboratory experiments have demonstrated that adult brook trout are more aggressive than Apache trout, and could interfere with feeding and spawning success of the native trout.

Competition as a negative impact on native fish populations is also demonstrated in the cyprinid or minnow family. The red shiner (*Cyprinella lutrensis*) has been both accidentally introduced by the bait industry and intentionally as a forage species. In Midwestern streams where it is native, the red shiner occupies intermittent and constantly flowing streams with an assemblage of other minnows. However, it survives admirably under intermittent flow conditions characterized by stressful levels of pH and dissolved oxygen, and high turbidities and temperatures (Metcalf 1966, Cross 1967, Matthews and Hill 1977). The red shiner, a habitat generalist, typically becomes abundant and dominates fish assemblages in Midwestern streams that have sustained habitat degradation (e.g., increased turbidity and temperatures). This dominance usually occurs to the detriment of more specialized fishes (Matthews and Maness 1979). The low faunal diversity of streams in the arid Southwest, combined with natural variations of aquatic habitat conditions and those induced through extensive habitat alteration, provide more suitable conditions for establishment and proliferation of the red shiner.

The red shiner is presently widespread in aquatic habitats of the Southwest. It has been suggested to have contributed significantly to the decline of native fish populations in Arizona (Minckley and Carufel 1967, Minckley 1973) and the Southwest (Minckley and Deacon 1968). For example, this cyprinid has an inverse distribution pattern in Arizona to two native, federally threatened cyprinid species, spikedace (*Meda fulgida*) and loach minnow (*Taroga cobitis*) (Minckley 1973). The mechanism of displacement or competition is not known, but, Rinne (1991) suggested utilization of the same physical habitat in the Verde River, Arizona, by adult red shiner and juvenile spikedace may be one mode of competition. Similarly, the red shiner has increased in lowermost reaches of the Virgin River, Arizona, while the native, endangered woundfin (*Plagopterus argentissimus*) has decreased (Cross 1978, Deacon 1988).

Predation

Evidence of the importance of predation on natives by introduced fishes is increasing. Recently, Blinn et al. (1993) demonstrated that rainbow trout have a significant impact on the native Little Colorado spinedace, *Lepidomeda vittata vittata*.

Laboratory and field experiments have shown effective predation upon small (50 mm) spinedace. Inverse, linear and site specific distributional patterns in the field also indicate the negative impact of this introduced trout on the native cyprinid.

Centrarchids have been widely introduced for sport fishing in Arizona. In the lower Colorado River, species of this family have almost displaced the native fish fauna, presumably through predation on the eggs and young of native species (Minckley 1979). The green sunfish (*Lepomis cyanellus*) appears to be a strong contributor to replacement of the native Gila chub (*Gila intermedia*), presumably via predation. The sunfish is abundant in downstream reaches of Sycamore Creek, Prescott National Forest. Although the chub is abundant in the headwaters where the sunfish is absent, it is totally absent in the lower reaches where sunfish abound. A similar pattern of replacement has been documented in Sabino Canyon, Coronado National Forest, by J. A. Stefferud (Tonto National Forest, pers. comm.).

The drastic decline of the razorback sucker in the lower Colorado River has been attributed in part to predation on razorback ova, larvae, and fry by catfish (Minckley 1983). Marsh and Brooks (1989) reported predation effects by flathead and channel catfish when an attempt was made to re-establish the now-threatened razorback sucker in its native range. In one 2-day period it was estimated that up to 900 juvenile razorback suckers (45-168 mm SL) were eaten by these two introduced ictalurids in the Gila River, Arizona. Other formerly abundant, but now rare, native species (spikedace, loach minnow, Colorado squawfish of the Gila River, the lower Salt River, the Verde River, and the lower Colorado River have been replaced by introduced fishes. Channel and flathead catfish are abundant in all these waters. These inverse patterns of distribution of native species and the two catfishes combined with the data of Marsh and Brooks (1989) is strong evidence 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 endangered native Gila topminnow (Minckley 1973, Minckley et al. 1977, Meffe, et al. 1983). The topminnow and the native desert pupfish were formerly widespread, and both were undoubtedly quite effective in mosquito control. Topminnow began to decline in the early 1900s with alteration of habitat by humans (Miller 1961). Nevertheless, topminnow was considered to be yet 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 being sustained as a result of high carbonate waters in upstream, springhead refugia.

Because of the similarity of life history characteristics of topminnow and mosquitofish, competition for resources appeared to be 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 effectively eliminate topminnow by predation on the fry and, secondarily, by reducing survivorship of adult females. Further, Meffe (1984) demonstrated that coexistence of topminnow with mosquitofish may be dependent on habitat complexity. In this same paper, he 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 mosquitofish replaces the native topminnow largely through predation. Based on the above case histories, predation, as a mechanism of interaction between native and introduced fishes, may be the primary reason for decline of native fish diversity in Arizona and the Southwest.

CONSERVATION EFFORTS TO SUSTAIN NATIVE FISHES

Conservation efforts for native fishes in desert environments of North America had their inception in the late 1960's and early 1970's. The National Environmental Policy Act (NEPA) of 1969, the Endangered Species Preservation and Conservation Acts of 1966 and 1969, and ultimately the 1973 Endangered Species Act laid the legislative groundwork for conservation and sustaining of all threatened and endangered species and their habitats. Although legislation laid the groundwork, it remained for agencies and individuals to implement of these Acts.

Individuals interested in desert fishes as a resource immediately took a stand to preserve species being rapidly and markedly impacted by the demand for water for agricultural and housing developments. In April 1969, a group of a less than a dozen individuals from several agencies gathered in Death Valley to prevent the potential loss of a group of rare species of desert fishes as a result of pumping of aquifers and drying desert springs in the Ash Meadows system. Out of these efforts, the Desert Fishes Council was founded in November 1969 and now numbers over 300 members (Pister 1981, 1990, 1991). This group presently addresses the conservation of desert fishes and their habitats throughout western United States, and northern Mexico, and has recently become more international in scope. A little over two decades after founding of the Council, a book ("Battle Against Extinction, Native Fish Management in the

merican West," Minckley and Deacon 1991) was published documenting the struggle to conserve (and often preserve) native fishes, mostly in arid environments of the American West.

In the past, conservation efforts in the southwestern United States for the recovery and sustaining of native fishes in their native habitats have taken one or a combination of approaches. Conservation activities are normally outlined in "Recovery Plans" for species, which are documents for federally listed species drafted by a recovery team composed of multi-agency personnel. To address the extensive loss of aquatic habitat through hydrologic alteration, most recovery plans for listed fish species include objectives and activities that will secure, maintain, and enhance habitats (Rinne and Turner, 1991).

Removal of non-native fishes, a common practice in efforts to restore and sustain native fishes (especially salmonids), usually involves treatment with piscicide (Rinne and Turner 1991). The success of habitat renovation attempts is often reduced because of size and/or complexity of habitat, lack of security of habitat through ownership or special management, variable conditions of habitats from year to year, and the ever-present threat of reestablishment of introduced species.

Johnson and Rinne (1982) first expressed the need to move from protection and listing of native Southwestern species, as dictated by the 1973 Act, to active recovery. Large-scale rearing of fishes in hatchery environments (Rinne et al. 1986), coupled with intensive, long-term re-introduction into what is deemed "favorable habitat" in the wild, also has been used extensively in conservation efforts (Johnson 1985, Simons 1987, Minckley and Deacon 1991). Several extensive re-introductions of razorback sucker into un-renovated streams and rivers in Arizona (Johnson 1985) have failed largely because of predation by non-native species as discussed above. Over 10 million razorback suckers were stocked in waters of the Gila River Basin, Arizona in the 1980s; fewer than 120 have been recaptured, mostly within two weeks of stocking.

The apparent "successful recovery" of the Sonoran topminnow through extensive and widespread introductions similar to efforts for razorback sucker is questionable because of unprotected habitats (Simons et al. 1989). Purchase and management of riparian/stream habitats by private agencies such as The Nature Conservancy have been a boon to desert fishes.

Improving aquatic habitat through instream improvements has become a common practice for recovery of salmonids (Rinne 1981). However, because such instream, site specific improvement is often conducted without regard to surrounding land use and resultant condition of the supplying watersheds (Szaro and Rinne 1988, Lafayette and Rinne 1991), the probability of failure increases.

THE SUSTAINABILITY QUESTION

The above discussed literature and case histories of individual species of fishes and the overall activity to sustain them bring us to the bottom line, "Can native Southwestern fishes and their

habitats be sustained?" In part, the answer to this question lies in 1) securing habitats, 2) species management strategies, and 3) ecosystem or landscape versus project or target management of natural resources.

First, we must undertake conservation activities where the habitat is secure (e.g., federal, state, and private conservation lands and special management areas), or relatively so, and where we can reasonably be most effective. Acquisition of large, important habitats such as the San Bernadino Ranch (U.S. Fish and Wildlife Service), White Mountain Hereford Ranch (Arizona Game and Fish Department), and numerous riparian-stream areas (The Nature Conservancy) has been and will continue to be critical to sustaining native fish species. Recent land exchanges by the U. S. Forest Service on Nutrioso Creek and purchase of private lands along the Little Colorado River, both important habitats for the threatened Little Colorado spinedace, are prerequisite to sustaining native fishes in the wild. Special designation and management of riparian-stream areas by federal agencies, such as the San Pedro National Conservation Area and Bonita Creek Riparian Conservation Area (U. S. Bureau of Land Management) are both timely and critical. Species on federal lands are afforded protection from negative impacts by the Endangered Species Act. Finally, cooperative interagency management that is synergistic in recovering species and sustaining biodiversity in our streams and rivers should be adopted (Williams and Rinne 1992). Multi-disciplinary approaches incorporating hydrologists, biologists, geneticists, geologists, and botanists that address the overall ecosystem, or biodiversity philosophy of conservation, must be formulated.

Secondly, too often, past management and conservation efforts for native desert fishes were, of necessity, undertaken under crisis situations and were narrowly focused and monospecific in nature. In some cases, isolated desert springs leave no alternative to a species-by-species approach to recovery.

On the other hand, conservation of desert fishes in the future must consider the total diversity (i.e., genetic, species, ecosystem, and landscape) of the fauna relative to alteration of aquatic systems (Rinne 1990). Where possible, conservation activities must begin to move away from single-species management toward ecosystems (i.e., river systems) or groups of species (Johnson and Rinne 1982, Rinne 1984, Williams et al. 1985, Rinne 1990b). Further, species not currently on official federal lists (i.e., state lists, U. S. Fish and Wildlife Service candidate species list, American Fisheries Society special concern list, U. S. Forest Service sensitive species lists) should be the object of our immediate conservation. Successful strategies for sustaining native fishes must include the multitude of fish species that are becoming rare but are not yet federally listed.

Management and research activities that consider such candidate, vulnerable, restricted, sensitive, or special species lists will become more proactive. For example, in the Southwest Region of the Forest Service (Arizona and New Mexico), there are more than 230 sensitive vertebrate species, 15 of which are fishes. Unfortunately, much endangered species management and research has adopted a "flagship" philosophy, wherein most

SUMMARY AND CONCLUSIONS

budgeting and effort are directed toward a few high-profile species (e.g., bald eagle, grizzly bear, whooping crane, and currently in the Southwest, Mexican spotted owl). Although flagship efforts may indirectly spill over and affect other species needing immediate conservation attention, this is a serendipitous but less desirable way to manage ecosystems (Rinne and Medina, in press). Granted, we cannot direct intensive conservation efforts at 230 species, but through timely conservation we can increase the probability that many of these species will never be listed as threatened or endangered. Further, if we design our conservation efforts on an ecosystem basis (see below), a greater number of species in need of help will automatically be addressed.

Thirdly, because of occurrences such as the Virgin River, Ord Creek, and numerous past renovations with specific agency goals (Binns 1967, Holden 1991, Rinne and Turner 1991), a philosophy of management should be adopted that considers the ecosystem and its total diversity (Williams et al. 1985, Rinne 1990). To be successful, such a philosophy necessitates a multi-agency and multi-disciplinary approach (Pister 1990, Rinne 1990b, Williams and Rinne 1992). That is, the broader the landscape a recovery or conservation plan addresses, the greater the probability that more than one agency will be involved in management. Equally important, the probability is greater that a larger component of total fish diversity rather than single, indicator, or threatened and endangered species will be addressed (Rinne 1984). Recovery teams and plans such as those of the Colorado Fishes and the Desert Fishes Recovery teams nominally address this philosophical approach to conservation of desert fishes. However, because of the extent of the Colorado River Basin, for example, (and other major desert rivers), its drastic physical alteration, and agency jurisdiction that divides conservation efforts and philosophies into upper and lower basin entities, a holistic or ecosystem approach has not been realized.

Finally, agency targets and recovery plan objectives, although well-intentioned, often can be detrimental to the recovery of a rare fish over the long term. Although goals for delisting the Apache trout and Sonoran topminnow may be quantitatively obtainable, they may be qualitatively unsound (Rinne 1990). A recent chemical renovation of the Virgin River with piscicide to remove the introduced red shiner and restore the endangered woundfin minnow further illustrates this point. Placing a higher priority on completion of the operation on schedule rather than insuring that all components of this large-scale, multi-agency activity were in place, resulted in treatment of excessive reaches of river and negative impacts on other native species. The lack of success of chemical renovation of Ord Creek to recover the native Apache trout strongly suggests that no matter how well-intentioned or planned the project, success is not easily achieved (Rinne et al. 1981), and indeed as occurred in the Virgin River and in Ord Creek (Minckley and Mihalik, 1981), non-piscine aquatic biodiversity also is impacted.

Great strides have been made in understanding the issues of conservation and perpetuation of biodiversity of fishes in the American Southwest since enactment of the Endangered Species Act. Case histories discussed demonstrate the successes, but at great cost in time and money. Although piscine diversity of this xeric region is low, the uniqueness of the taxa dictates continued efforts to sustain fishes in their natural environments. Minimal success in conserving native fishes has been largely attained at a species level; genetic and ecosystem levels only now are emerging as important components of the effort to conserve this unique native fish fauna. A landscape biodiversity approach to conserving desert fishes has the least probability of being realized because of the often disjunct and isolated nature of aquatic ecosystems interposed with the continued development of the arid regions of the Southwest.

It behooves us to adopt innovative approaches in future conservation efforts for this regional fish fauna. To do less would discredit extensive efforts by agencies and individuals in the past that frequently were necessarily crisis management endeavors to secure the very existence of rare fishes. Indeed, it is time to move from "saving" (Johnson and Rinne 1982) native fishes in the arid Southwest to "recovering" and sustaining them in their native habitats. Many of these fishes occur in isolated habitats in a region characterized by the lack of the basic life medium of fishes—water. We have come far, yet have far to go. Only if the overall aquatic and influencing resources are given priority in our conservation efforts will aquatic habitats and native fish biodiversity be maintained for perpetuity.

LITERATURE CITED

- Arizona Game and Fish Department. 1985. Arizona cold water fisheries strategic plan, 1985-90. Phoenix, Arizona. 50 p.
- Barber, W. E., and W. L. Minckley. 1966. Fishes of Aravaipa Creek, Graham and Pinal Counties, Arizona. *Southwest. Nat.* 11:313-324.
- Blinn, D. W., C. Runck, D. A. Clark, and J. N. Rinne. 1993. Effects of rainbow trout predation on Little Colorado Spinedace. *Trans. Amer. Fish. Soc.* 122(1): 139-143.
- Binns, N. A. 1967. Effects of rotenone treatment on the fauna of the Green River, Wyoming. *Wyo. Game and Fish Comm. Fish. Tech. Bull.* 1: 1-114.
- Carmichael, G. J., J. N. Hanson, M. E. Schmidt, and D. C. Morizot. 1993. Introgression among Apache, cutthroat, and rainbow trout in Arizona. *Trans. Amer. Fish. Soc.* 122(1): 121-130.

- Cray, W. R., and G. K. Meffe. 1989. Small fishes in range places: A review of introduced poeciliids. P. 319-331. In G. K. Meffe and F. F. Snellson (eds), Ecology and evolution of livebearing fishes (Poeciliidae). Prentice Hall, Englewood Cliffs, New Jersey. 453 p.
- Cross, F. B. 1967. Handbook of the fishes of Kansas. Misc. Publ. Mus. Nat. Hist. Univ. Kansas 45. 357 p.
- Cross, J. N. 1978. Status and ecology of the Virgin River roundtail chub *Gila robusta seminuda* (Osteichthyes: Cyprinidae). Southwest. Nat. 23: 519-528.
- Deacon, J. E. 1979. Endangered and threatened fishes of the West. Great Basin Nat. Mem. 3: 41-64.
- Deacon, J. E. 1988. The endangered woundfin and water management in the Virgin River, Utah, Arizona, and Nevada. Fisheries 13(1): 18-24.
- Deacon, J. E., C. Hubbs, and B. J. Zahuranec. 1964. Some effects of introduced fishes on the native fish fauna of southern Nevada. Copeia 1964: 384-388.
- Deacon, J. E., G. Kobetich, J. D. Williams, and S. Contreras. 1979. Fishes of North America, endangered, threatened, or of special concern, 1979. Fisheries 4(2): 29-44.
- Deacon, J. E., and W. L. Minckley. 1974. Desert fishes. P. 385-488. In G. W. Brown, Jr. (ed.), Desert Biology. Vol 2. Academic Press, New York.
- Eng T. E. and M. R. Childs. 1992. Impact of hybridization of a threatened trout of the southwestern United States. Conservation Biology 6(3): 355-364.
- Harper, K. C. 1978. Biology of a southwestern salmonid, *Salmo apache*, (Miller 1972). P. 99-111. In J. R. Moring (ed.), Proc. wild trout-catchable trout symp., Eugene, Oregon, February 15-17, 1978. Oregon Dept. Fish Wildl. Res. Dev. Sec. Corvallis, Oregon.
- Heede, B. H. and J. N. Rinne. 1990. Hydrodynamics and fluvial morphologic processes: Implications for fisheries management and research. N. Amer. J. Fisheries Manage 10: 249-268.
- Holden, P. R. 1991. Ghosts of the Green River: impacts of Green River poisoning on management of native fishes. pp. 55-68. In: Minckley, W. L. and J. E. Deacon. (eds.), Battle against extinction—native fish management in the American West. Univ. Ariz. Press, Tucson, Az. 517 pp.
- Hubbs, C. L., and R. R. Miller. 1941. Studies of the fishes of the order Cyprinodontes. XVII. General and species of the Colorado River System. Occ. Pap. Mus. Zool. Univ. Michigan 433: 1-9.
- Johnson, J. E. 1985. Reintroducing the natives: razorback sucker. Proc. Desert Fishes Council 13 (1981): 73-79.
- Johnson, J. E., and J. N. Rinne. 1982. The Endangered Species Act and Southwest fishes. Fisheries 7(2): 1-8.
- Kuffman, J. B. and W. C. Krueger. 1984. Livestock impacts on riparian ecosystems and streamside management—implications—A Review. J. of Range Management 37(5): 430-438.
- Kirch, W. E. 1977. Endemic fishes of the Colorado system: A status report. Colorado River. Wildl. Council 1977: 1-15.
- Kirsch, P. H. 1889. Notes on a collection of fishes obtained in the Gila River at Fort Thomas, Arizona. Proc. U. S. Nat. Mus 11: 555-558.
- Marsh, P. C., and J. E. Brooks. 1989. Predation by ictalurid catfishes as a deterrent to re-establishment of hatchery-reared razorback suckers. Southwest. Nat. 34(2): 188-195.
- Matthews, W. J. and L. G. Hill. 1977. Tolerance of red shiner, *Notropis lutrensis*, (Cyprinidae) to environmental parameters. Southwest Nat. 22: 89-99.
- Matthews, W. J., and J. D. Maness. 1979. Critical thermal maxima, oxygen tolerances and success of cyprinid fishes in a southwestern river. Am. Midl. Nat. 102: 374-377.
- Meffe, G. K. 1984. Effects of abiotic disturbance on coexistence of predator-prey fish species. Ecology 65(5): 1525-1534.
- Meffe, G. K. 1985. Predation and species replacement in American southwestern fishes: a case study. Southwest. Nat. 30: 173-187.
- Meffe, G. K., D. A. Hendrickson, W. L. Minckley, and J. N. Rinne. 1983. Factors resulting in decline of the endangered Sonoran topminnow (*Atheriniformes: Poeciliidae*) in the United States. Biol. Conserv. 25: 135-139.
- Metcalf, A. L. 1966. Fishes of the Kansas River system in relation to zoogeography of the Great Plains. Publ. Mus. Nat. Hist. Univ. Kansas 17: 23-189.
- Miller, R. 1952. Bait fishes of the lower Colorado River, from Lake Mead, Nevada, to Yuma, Arizona, with a key for their identification. California Fish and Game 38: 7-42.
- Miller, R. R. 1961. Man and the changing fish fauna of the American Southwest. Pap. Michigan Acad. Sci. Arts. Letts. 46: 365-404.
- Miller, R. R., and J. R. Alcorn. 1946. The introduced fishes of Nevada, with a history of their introduction. Trans. Am. F. Fish. Soc. 73: 173-193.
- Miller, R. R., J. D. Williams, and J. E. Williams. 1989. Extinctions of North American fishes during the past century. Fisheries 14(6): 22-38.
- Minckley, W. L. 1969. Attempted reestablishment of the Gila topminnow within its former range. Copeia 1969: 193-194.
- Minckley, W. L. 1973. Fishes of Arizona. Arizona Game and Fish Department, Phoenix, Arizona. 293 p.
- Minckley, W. L. 1979. Aquatic habitats and fishes of the lower Colorado River, southwestern United States. Rep. U. S. Bur. Reclamation Contr. No. 14-06-300-2529. Arizona State Univ., Tempe.
- Minckley, W. L. 1983. Status of the razorback sucker, *Xyrauchen texanus*, (Abbott) in the lower Colorado River basin. Southwest. Nat. 28: 165-187.
- Minckley, W. L., and L. H. Carufel. 1967. The Little Colorado River spinedace, *Lepidomeda vittata*, in Arizona. Southwest. Nat. 13: 291-302.
- Minckley, W. L., and J. E. Deacon. 1968. Southwestern fishes and the enigma of "endangered species." Science 159(3882): 1424-1432.

- Minckley, W. L. and P. Mihalik. 1981. Effects of chemical treatment for fish eradication on stream-dwelling invertebrates. *J. Ariz-Nev. Acad. Sci.* 16: 79-82.
- Minckley, W. L. and J. E. Deacon. 1991. Battle against extinction: Native fish management in the American West. Univ. Ariz. Press, Tucson. 517 pp.
- Minckley, W. L., J. N. Rinne, and J. E. Johnson. 1977. Status of the Gila topminnow and its co-occurrence with mosquitofish. USDA Forest Service Res. Pap. RM-198, Rocky Mountain For. Range Exp. Stn., Fort Collins, Colorado. 8 p.
- Myers, G. S. 1965. *Gambusia* the fish destroyer. *Tropical Fish Hobbyist* 13: 31-32, 53-54.
- Pister, E. P. 1981. The conservation of desert fishes. pp. 411-435 In: Naiman, R. J. and D. L. Soltz (eds.), *Fishes in North American Deserts*. John Wiley and Sons, New York, N. Y.
- Pister, E. P. 1990. Desert fishes: an interdisciplinary approach to endangered species conservation in North America. *J. of Fish Biology* 37: 183-188.
- Pister, E. P. 1991. Desert Fishes Council: catalyst for change. pp. 55-68. In: Minckley, W. L. and J. E. Deacon (eds.), *Battle against extinction—native fish management in the American West*. Univ. Ariz. Press, Tucson. 517 pp.
- Platts, W. S. 1979. Livestock grazing and riparian-stream ecosystems: An overview, p. 39-45. In, O. B. Cope (ed.), *Grazing and riparian-stream ecosystems: A forum*. Trout Unlimited, Inc.
- Platts, W. S. 1981. Effects of sheep grazing on a riparian-stream environment. USDA For. Serv. Res. Note INT-307: 1-6. Intermtn. For. and Range Exp. Stn., Ogden, Utah.
- Platts, W. S. 1982. Livestock and riparian fishery interactions: what are the facts? *Trans. N. A. Wildl. and Nat. Res. Conf.* 47: 507-515.
- Rea, A. M. 1983. Once a river: Bird life and habitat changes on the middle Gila. Univ. Ariz. Press, Tucson.
- Rinne, J. N. 1981. Stream habitat improvement and native SW trout. USDA, For. Serv. Res. Note RM-409: 1-4.
- Rinne, J. N. 1985. Variation in Apache trout populations in the White Mountains, Arizona. *N. Am. J. Fish. Manage.* 5: 146-158
- Rinne, J. N. 1988. Native southwestern (USA) trouts: status, taxonomy, ecology and conservation. *Pol. Arch. Hydrobiol.* 34(5/6).
- Rinne, J. N. 1990a Biodiversity and native fish management: Arizona, southwestern United States. *Proc. West Assoc. Fish and Wildl. Agen.* 70: 152-165.
- Rinne, J. N. 1990b. An approach to management and conservation of a declining regional native fish fauna: Southwestern United States, pp 56-60. In, N. Maruyama et al. (eds). *Wildlife Conservation: Present trends and perspectives for the 21st Century*. Int. Symp. Wildl., 5th Int. Congress Zool., August 21-25, 1990, Tskuba and Yokohama, Japan.
- Rinne, J. N. 1991. Habitat use by spikedace, *Meda fulgida* (Pisces: Cyprinidae) in southwestern (USA) streams with reference to probable habitat competition by red shiner, *Notropis lutrensis* (Pisces: Cyprinidae). *Southwest. N.* 36(1): 7-13.
- Rinne, J. N. 1992. Physical habitat utilization of fishes in Sonoran Desert stream, Arizona, southwestern United States. *Ecol. Freshwater Fish* 1992 (1): 35-41.
- Rinne, J. N. In press. The effects of introduced fishes on native fishes: Arizona, southwestern United States. World Fisheries Congress, Athens, Greece, May 1992.
- Rinne, J. N., and W. L. Minckley. 1985. Patterns of variation and distribution in Apache trout (*Salmo apache*) relative co-occurrence with introduced salmonids. *Copeia* 1985(2): 285-292.
- Rinne, J. N. and R. Lafayette. 1991. Southwestern Riparian ecosystems: Research complexity, design, and opportunity. USDA Research paper RM-199, Rocky Mountain Forest and Range Experiment Station, Fort Collins Colo.
- Rinne, J. N., and W. L. Minckley. 1991. Native fishes in arid lands: Dwindling resources of the desert Southwest. USD Forest Service Gen. Tech. Rep. RM-206. Rocky Mountain For. Range. Exp. Stn., Fort Collins, Colorado. 45 p.
- Rinne, J. N. and R. Lafayette. 1991. Southwestern Riparian ecosystems: Research complexity, design, and opportunity. USDA Research paper RM-199: 1-8. Rocky Mountain Forest and Range Experiment Station, Fort Collins Colo.
- Rinne, J. N. 1984. Indicator or diversity of species management: the case of native southwestern fishes, pp. 79-92. In, W. L. Minckley (ed.). *Proc. Workshop on management of nongame species and ecological communities*. Univ. of Kentucky, Lexington.
- Rinne, J. N. and W. L. Medina. In Press. U. S. Forest Service Multiple Use policy: Implications and recommendations for research and management of rare southwestern (USA) fishes. *World Fish. Congress, Athens, Greece, May 4-8, 1992*.
- Rinne, J. N. and P. R. Turner. 1991. Reclamation and alteration as management techniques, and a review of methodology for stream renovation. Chp. 14. pp. 219-246. In: Minckley, W. L. and J. E. Deacon (eds), *Battle against extinction: Native fish management in the American West*. Univ. Ariz. Press, Tucson.
- Rinne, J. N., W. L. Minckley, and J. N. Hanson. 1981. Chemical treatment of Ord Creek, Apache County, Arizona, to re-establish Arizona trout. *Ariz.-N. Mexico. Acad. Sci.* 16: 74-78.
- Rinne, J. N., R. Sorenson, and S. C. Belfit. 1985. An analysis of F₁ hybrids between Apache, (*Salmo apache*) and rainbow trout, (*Salmo gairdneri*). *J. Ariz.-Nev. Acad. Sci.* 20: 63-66.
- Rinne, J. N., J. E. Johnson, B. L. Jensen, A. W. Ruger, and I. Sorenson. 1986. The role of hatcheries in the management and recovery of threatened and endangered species. P. 271-285. In: Stroud, R. H. (ed.), *Fish Culture in Fisheries Management*. Am. Fish. Soc., Bethesda, MD.

- Benherr, A. A. 1974. Life history of the topminnow *Poeciliopsis occidentalis* (Baird and Girard) in Arizona and an analysis of its interaction with mosquitofish *Gambusia affinis* (Baird and Girard). Ph.D. dissertation, Arizona State University, Tempe.
- Benherr, A. A. 1981. The role of competition in the replacement of native fishes by introduced species. P. 173-203. In R. J. Simons, L. H. 1987. Status of Gila topminnow (*Poeciliopsis occidentalis*) in the United States in 1987. Rep. to U. S. Fish and Wildl. Serv., Albuquerque, N. Mex.
- Simons, L. H., D. A. Hendrickson, and D. Papoulias. 1989. Recovery of Gila topminnow: A success story? *Biol. Conserv.* 3(1): 11-15.
- Szaro, R. C. and J. N. Rinne. 1988. Ecosystem approach to management of southwestern riparian communities. *Trans. 53rd N. A. Wildl. & Nat. Res. Conf.* 53: 502-511.
- U. S. Fish and Wildlife Service. 1979. Arizona Trout Recovery Plan. U. S. Fish Wildl. Serv., Albuquerque, New Mexico. 36 p.
- Williams, J. E. and J. N. Rinne. 1992. Biodiversity management on multiple-use Federal lands: an opportunity whose time has come. *Fisheries* 17(3): 4-5.
- Williams, J. E., D. B. Bowman, J. E. Brooks, A. A. Echelle, R. J. Edwards, D.A. Hendrickson, and J. J. Landye. 1985. Endangered aquatic ecosystems in North American deserts with a list of vanishing fishes of the region. *J. Ariz.-Nev. Acad. Sci.* 20:1-62.
- Williams, J. E., J. E. Johnson, D. A. Hendrickson, S. Contreras-Balderas, J. D. Williams, M. Navarro-Mendoza, D. E. McAllister, and J. E. Deacon. 1989. Fishes of North America endangered, threatened, and of special concern: 1989. *Fisheries* 14(6): 2-21.



Sustainable Ecological Systems: *Implementing an Ecological Approach to Land Management*

July 12-15, 1993

Flagstaff, Arizona

Technical Coordinators:

W. Wallace Covington
Northern Arizona University

Leonard F. DeBano
USDA Forest Service
Rocky Mountain Forest and Range Experiment Station

**Rocky Mountain Forest and Range
Experiment Station**
U.S. Department of Agriculture
Fort Collins, Colorado