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Fishes

TEN

HISTORICAL CHANGES AND AN IMPERILED NATIVE FAUNA

Introduction

The history of fishes in the San Pedro River basin is an exemplar of the discovery and subsequent extirpation of native fishes throughout southwestern North America (Miller et al. 2005, Minckley and Marsh forthcoming). The San Pedro River and tributaries were historically occupied by a fish fauna comprised of seven minnows (family Cyprinidae), four suckers (Catostomidae), a pupfish (Cyprinodontidae), and a livebearer (Poeciliidae), several of which were endemic to the Gila River basin (table 10.1). This fauna ranged in size from the diminutive desert pupfish and Gila topminnow to the huge Colorado pikeminnow.

The San Pedro River Valley was one of the earliest routes of exploration into Arizona, and the river figured prominently in early ichthyological investigations in the desert Southwest. Six species—spikedace, speckled dace, loach minnow, Sonora sucker, flannelmouth sucker, and desert pupfish—were discovered and originally described based on specimens obtained from the San Pedro and Babocomari Rivers (Minckley 1985). Additionally, razorback sucker, roundtail chub, Gila chub, longfin dace, and desert sucker were present.

TABLE 10.1. Records verified by specimens (X) and probable occurrences due to existence of later records (O) of native and non-native fishes in San Pedro River main stem from before 1840 through 2005.

	Years of occurrence									
Species	pre-1840	1841–1860	1861–1880	1881–1900	1901–1920	1921–1940	1941–1960	1961–1980	1981–2000	2001–2005
NATIVE TAXA										
Colorado pikeminnow (*Ptychocheilus lucius*)	X									
Razorback sucker (*Xyrauchen texanus*)	X	X								
Flannelmouth sucker (*Catostomus latipinnis*)	O	X								
Gila chub (*Gila intermedia*)	O	O	O	O	X					
Desert pupfish (*Cyprinodon macularius*)	O	X	O	O	O	O	X			
Speckled dace (*Rhinichthys osculus*)	O	O	O	O	X	O	O	X		
Roundtail chub (*Gila robusta*)	O	X	O	O	O	O	O	X		
Loach minnow (*Tiaroga cobitis*)	O	X	O	O	O	O	O	X		
Spikedace (*Meda fulgida*)	O	X	O	O	O	X	X	X		
Gila topminnow (*Poeciliopsis occidentalis*)	O	O	O	O	O	O	X	O		
Sonora sucker (*Catostomas insignis*)	O	X	O	O	X	X	X	X	X	X
Longfin dace (*Agosia chrysogaster*)	O	X	O	O	X	X	X	X	X	X
Desert sucker (*Pantosteus clarki*)	O	X	O	O	X	X	X	X	X	X
NON-NATIVE TAXA										
Common carp (*Cyprinus carpio*)				X	O	O	O	X	X	X
Black bullhead (*Ameiurus melas*)						X	O	O	X	X
Green sunfish (*Lepomis cyanellus*)						X	O	X	X	X
Western mosquitofish (*Gambusia affinis*)							X	X	X	X
Rainbow trout (*Oncorhynchus mykiss*)								X		
Goldfish (*Carassius auratus*)								X	O	X
Fathead minnow (*Pimephales promelas*)								X	X	X
Yellow bullhead (*Amerius natalis*)								X	X	X
Channel catfish (*Ictalurus punctatus*)								X	X	X
Bluegill (*Lepomis macrochirus*)								X	X	
Largemouth bass (*Micropterus salmoides*)								X	X	X
Brook trout (*Salvelinus fontinalis*)								X		
Threadfin shad (*Dorosoma petenense*)								X		
Red shiner (*Cyprinella lutrensis*)									X	X
Redear sunfish (*Lepomis microlophus*)									X	

Information from Arizona State University (2002), W. Jackson et al. (1987), J. Stefferud and Stefferud (2003), and R. W. Clarkson (unpublished data).

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TABLE 10.2. Post-1990 distribution of native and non-native fishes in tributaries to San Pedro River.

Fishes/Water	Aravaipa Creek[1]	Bingham Ciéega	Redfield Canyon	Buehman Canyon	Hot Springs Canyon[2]	Paige Canyon	Babocomari River[3]	Lewis Spring	El Sauz	Rservoir near lg. Zaragoza	Cave Canyon[4]	Los Alisos	Los Fresnos	San Rafael	Las Nutrias	La Cieneguita
NATIVE TAXA																
Longfin dace	X		X	X	X		X		X		X	X	X			
Gila chub			X		X		X						X?			X?
Sonora sucker	X		X		X		X									
Speckled dace	X		X		X											
Desert sucker	X				X		X									
Loach minnow	X															
Roundtail chub	X															
Spikedace	X															
Gila topminnow							X									
NON-NATIVE TAXA																
Western mosquitofish	X	X					X	X	X			X		X	X	X
Quitobaquito pupfish							X[5]									
Green sunfish	X		X			X	X	X	X		X					X
Largemouth bass							X		X	X						
Fathead minnow	X						X			X						
Black bullhead						X	X									
Bluegill							X									
Channel catfish	X															
Red shiner	X															
Yellow bullhead	X															

Sources: Information from Arizona State University (2002), Varela-Romero (1992), K. Young and Lopez (1995), Gori (1995), Campoy-Favela (1996), Girmendonk and Young (1997), Voeltz and Bettaso (2003), J. Rorabaugh, D. Duncan, USFWS, personal communication, and unpublished data of authors.

Note: Tributaries are arranged in order of entry into the San Pedro River, from downstream to upstream.

[1]Includes tributaries Turkey Creek, Deer (Hell Hole) Creek, and Oak Spring Canyon.

[2]Includes tributaries Hookers Hot Springs, and Bass, Double R, and Wildcat Canyons.

[3]Includes tributaries Post and O'Donnell Canyons, Turkey Creek, and Finley Tank.

[4]Includes tributaries Lone Mountain and Sycamore Canyons, and Joaquin and Bear Creeks.

[5]In Finley Tank on National Audubon Society's Appleton-Whittell Research Ranch.

During the past 150 years, native fishes have declined and disappeared from the San Pedro River basin and other drainages in the Southwest. Of the original 13 species in the San Pedro River, only 2 consistently remain in the main stem, and an additional 7 persist in tributaries (table 10.2). Losses are a result of geomorphological alteration due to natural and human-induced factors and introduction and spread of non-native fishes (R. R. Miller 1961, W. Minckley 1987). Natural (e.g., earthquakes, precipitation patterns, climate change) and human-caused factors (e.g., mining, grazing, construction of roads, trapping of beaver (*Castor canadensis*), surface water and groundwater use, urbanization) have caused the channel to incise, surface flows to diminish, and aquatic habitats to shrink and become less diverse. Non-native species introduced for food or sport, forage for sport species, public health, or by accident or illegally are established and have largely replaced the native species in many streams. Since the late nineteenth century, at least 15 non-native fishes have been either deliberately stocked into San Pedro River or invaded from downstream waters. Eleven of those now have viable populations in the San Pedro River and its tributaries.

In this chapter we review the ways in which natural and human-induced factors, compounded by additions of non-native fishes, have decimated the native fish fauna of the San Pedro River basin. We emphasize that whereas habitat improvement is necessary, control of non-native fishes is the paramount action needed to initiate restoration of the native ichthyofauna.

Native Fishes of the San Pedro River Basin

The basin's ichthyofauna is well documented through collections and museum records (Minckley and Marsh forthcoming). U.S. and Mexican boundary surveys during 1849–1855 collected fishes in the San Pedro and Babocomari Rivers that were new to science (Baird and Girard 1853, 1854). Documentation continued in 1904 by F. W. Chamberlain (Minckley 1999b) and into the early to mid-twentieth century during the Hubbs-Miller expeditions (Miller et al. 1991). W. L. Minckley's arrival in Arizona in 1963 initiated investigations of ecology and biology of ichthyofauna of Arizona in general (Minckley 1973), and Aravaipa Creek in particular (Stefferud and Reinthal 2005). More recently, monitoring provided information on distribution and status of the fishes in the main stem and tributaries (Gori 1993, 1997, J. Stefferud and Stefferud 2003, Marsh and Kesner 2004). Investigations in the Mexican portion of the drainage have added to this knowledge base (Varela-Romero 1992, Varela-Romero et al. 1992).

All members of the native assemblage were riverine oriented, but some favored quiet habitats of pools, side channels, ciénegas, and backwaters. W. L. Minckley (1987) divided native fishes into four broad categories based on habitat requirements and associations:

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I. Tending to live in large, eroding rivers and associated floodplain habitats;
II. Tending to inhabit perennial, moderate- or small-sized streams of variable erosiveness;
III. Occupying spring-fed or river-associated, aggrading habitats such as backwaters, cutoff pools, or stream margins; and
IV. Ubiquitous and/or variable in habitat use, including occurrences in spatially intermittent systems.

CATEGORY I FISH

"Big river" species (Colorado pikeminnow, flannelmouth sucker, and razorback sucker) were most likely confined to the main stem San Pedro River. Except during spawning forays, their habitat needs and body size probably restricted them from occupying tributaries, although young individuals may have opportunistically exploited smaller habitats. All are long lived and can achieve large to very large size, and all disappeared from the San Pedro River early in recorded history.

Colorado pikeminnow. Colorado pikeminnow is endemic to the Colorado River basin and historically ranged freely among larger rivers from Wyoming to the delta in Mexico. Colorado pikeminnow persists as wild populations only in the upper Colorado River basin above Glen Canyon Dam (Osmundson and Burnham 1998, Mueller and Marsh 2002). High dams block their spawning migrations, and populations of predacious non-native fish have hindered recruitment (Minckley 1991). In the San Pedro River, Colorado pikeminnow occurred upstream to about Fairbank, but were extirpated by the late nineteenth century (Miller 1961), and from the entire Gila River basin by the 1960s (Minckley and Marsh forthcoming). Colorado pikeminnow was an important food source in the region both historically and prehistorically, and Anglo explorers reported using "salmon trout" from the San Pedro River in the mid-1800s for food (Minckley 1965, Minckley and Alger 1968, Davis 1982). Lower San Pedro River incised in the late nineteenth century (see chap. 12), and the disappearance of pikeminnow may have been in response to subsequent habitat changes or loss of strong currents associated with geomorphologic changes caused by incision (Miller 1961, Minckley 1987).

Colorado pikeminnow is North America's largest minnow and the largest native fish in Arizona, attaining lengths approaching 2 m and weights of 45 kg (Osmundson et al. 1997). Individuals exceeding 1 m and 7 kg now are rare, likely a result of blockage by dams of migration routes into warmer, lower basin waters (Mueller and Marsh 2002). Longevity can exceed 40 years (Scoppettone 1988, Osmundson et al. 1997). It is the top predator among native fish in the Colorado River basin and after achieving juvenile size feeds

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almost exclusively on other fishes. The species can make migrations of several hundred kilometers to spawn in high-gradient canyon-bound habitats (Tyus and Karp 1990, Harvey and Mussetter 1993). Spawning areas are a complex of deep pools, eddies, and rapid-velocity water over cobble substrates, and spawning typically occurs near the end of spring runoff (Propst 1999). Post-hatch larvae drift downstream up to hundreds of kilometers before settling in backwaters to grow (Tyus 1990, Tyus and Karp 1990).

Flannelmouth sucker. Flannelmouth sucker, another Colorado River basin endemic, historically dispersed unimpeded among larger rivers of the Colorado River system. The species remains in the Colorado River basin above Lake Powell and in the Grand Canyon but was extirpated from Colorado River below Lake Mead and the Gila River basin before 1970 (Bezzerides and Bestgen 2002, Mueller and Marsh 2002). A repatriated population has persisted in the Colorado River below Davis Dam, Arizona–Nevada, since 1976 (Mueller and Wydoski 2004). Flannelmouth sucker is documented from the San Pedro River by only one specimen, collected in 1846 between Benson and Fairbank; its abundance at that time is not known but was likely low (Minckley 1987). The species probably suffered the same fate as Colorado pikeminnow and razorback sucker in the San Pedro River, as strong currents and deep pools diminished due to geomorphological and hydrological changes (Miller 1961).

Flannelmouth suckers reach 50 cm or more and live 15 to 30 years (Scoppettone 1988). Adults often are found in tributary mouths of larger rivers, which they ascend in springtime to reproduce (Minckley et al. 1991, Douglas and Marsh 1998, Weiss et al. 1998). Spawning is in early spring with multiple males attending a single female, and eggs are deposited over gravel (Weiss et al. 1998). As with most catostomids, larvae drift downstream and congregate in shallow slack-water areas (Childs et al. 1998). Adult flannelmouth suckers can be found in shallow to deep habitats but prefer deep pools with hard substrates (Bezzerides and Bestgen 2002). Flannelmouth suckers are omnivorous, consuming chironomids, copepods, phytoplankton, and organic detritus (Childs et al. 1998).

Razorback sucker. Razorback sucker is another endemic that formerly moved freely among larger streams of the Colorado River system (Mueller and Marsh 2002). It was used as food by aboriginal peoples and was common in the San Pedro River in the 1800s, where it was marketed for food as "buffalo fish" in nearby Tombstone (Minckley and Alger 1968, Davis 1982). It was extirpated from the San Pedro River by the 1860s, either due to mine spillage (Minckley 1999a) or loss of a sizeable, permanent river with strong currents (Miller 1961).

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Razorback sucker can grow to 75 cm and exceed 50 years of age (Minckley 1983, McCarthy and Minckley 1987, Marsh et al. 2003). It is mostly a slack-water specialist, where it filter-feeds on small invertebrates and detritus from the water column (Marsh 1987). Spawning is in swift water over sand and gravel substrate. No nest is built and no parental care is given (Minckley 1983, Tyus and Karp 1990).

Recovery efforts. Colorado pikeminnow was listed as endangered in 1967 (USFWS 1991a) and razorback sucker as endangered in 1991 (USFWS 1998). Critical habitat, designated in 1994 for both, does not include areas within the San Pedro River basin. Recovery plans are available for Colorado pikeminnow and razorback sucker (USFWS 2002a, 2002b). Flannelmouth sucker was a candidate for listing under the Endangered Species Act of 1973 and is included in a multi-agency, range-wide conservation agreement (USFWS 1994a, Utah Dept. of Natural Resources 2004).

Recovery efforts in Arizona for Colorado pikeminnow have included the stocking of hundreds of thousands of mostly larvae and fingerling-size individuals into the Salt and Verde Rivers beginning in the 1980s, and for the razorback sucker, reintroductions into the main stream and larger tributaries of the Gila River both above and below the San Pedro River. This effort has achieved little success (Hyatt 2004), primarily due to predation on stocked individuals by non-native fishes (Marsh and Brooks 1989). An introduced population of razorback sucker was present in an artificial off-channel pond near Dudleyville (Desert Fishes Team 2003). In Arizona, recovery efforts for flannelmouth sucker have been limited to the 1976 successful repatriation of a population in the Colorado River below Davis Dam (Mueller and Wydoski 2004). There have been no recovery efforts for any of these three species in the San Pedro River basin (Desert Fishes Team 2006).

CATEGORY II FISH

Roundtail chub, loach minnow, and spikedace occupy rivers and moderate- to small-sized, hard-bottomed tributaries. In the San Pedro River basin, the three species are now only in Aravaipa Creek.

Roundtail chub. Roundtail chub historically was widespread in the Colorado River drainage (Miller et al. 2005, Minckley and Marsh forthcoming). In the Gila River basin, it now occupies only about 20 percent of its historical range (Voeltz 2002). Roundtail chub was last collected from the San Pedro River in 1931 (Arizona State University 2002) but persists in Aravaipa Creek (unpublished data of authors). Its disappearance from the San Pedro River was likely due to loss of pools (Miller 1961, Minckley 1987).

Roundtail chub is a medium-sized cyprinid that can grow to 40 cm or

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more (Bestgen 1985) and live 20 years or more (Scoppettone 1988). It inhabits pools, eddies, and swift waters below rapids and riffles. They are opportunistic and show no apparent preferences in foods, consuming a variety of insects, algae, gastropods, crayfish, fish, and even small lizards (Vanicek and Kramer 1969, Neve 1976, Schreiber and Minckley 1981, Bestgen 1985, Rinne 1992). In the absence of Colorado pikeminnow, roundtail chub when large occupies the "top carnivore" position (Minckley 1973, Schreiber and Minckley 1981). Spawning occurs in May when chubs deposit eggs over clean gravel at the head of a riffle. Reproductive success is positively influenced by large flood events, which rejuvenate spawning and nursery areas by churning substrates and removing fine sediments. Abundance of age-1 roundtail chubs is typically higher the year after large winter-spring events than in years following periods with small or no floods (Bestgen and Propst 1989, Brouder 2001).

Loach minnow. Loach minnow is endemic to the Gila River basin, including the upper San Pedro River in Mexico (Miller et al. 2005, Minckley and Marsh forthcoming). The species is extirpated from greater than 75 percent of its historical range and in the San Pedro River basin remains only in Aravaipa Creek (USFWS 1985a). Loach minnow persisted in the upper San Pedro River until the 1950s (Miller and Winn 1951) and until 1961 near Charleston (Arizona State University 2002). Sedimentation of riffle habitats may have contributed to its loss (Minckley 1987), as perhaps did elevated water temperatures (Widmer et al. 2006).

Loach minnow is a small (<60 mm), short-lived (2 years or less), current-loving species, primarily inhabiting interstices of gravel and rubble in shallow, well-defined stream riffles (Rinne 1989, 1992, Propst and Bestgen 1991). Foods are predominantly ephemeropteran nymphs and simuliid larvae (Schreiber and Minckley 1981). Spawning occurs in riffles, where eggs are emitted by the female and then fertilized, retrieved, and affixed in clumps to the underside of rocks by the male (Johnston 1999, Childs 2004). Under experimental conditions, loach minnow exhibited thermal stress when water temperatures rose above 30°C (Widmer et al. 2006).

Spikedace. Spikedace is endemic to the Gila River basin and occurred in the San Pedro River basin into Mexico (Miller et al. 2005, Minckley and Marsh forthcoming) but is extirpated from over 90 percent of its historical range (USFWS 1985b). It was common in the San Pedro River until the 1950s and was last documented near Charleston in 1965 (Minckley 1999a), its disappearance likely due to drying of significant portions of the river (Minckley 1987). In the basin, it persists only in Aravaipa Creek. This species is arguably the most endangered fish in the Gila River basin due to its specialized habitat

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preferences, need for relatively high baseflows, and vulnerability to competitive and/or predatory non-native fishes (USFWS 1994b). Elevated stream temperatures also may be exacting a toll (Carveth et al. 2006).

Spikedace is small (<70 mm), short-lived (ca. 2 years), and occupies flowing pools generally less than 1 m deep over sand and gravel bottoms below riffles or in eddies. Spawning occurs over sand-gravel substrates with no parental care given (Barber et al. 1970, Propst et al. 1986, Rinne 1991, 1992). Foods are primarily ephemeropteran nymphs and dipteran larvae, but winged adults of these groups and trichopterans also are taken (Schreiber and Minckley 1981, Barber and Minckley 1983). In experimental conditions, water temperatures above 28°C caused thermal stress in spikedace (Carveth et al. 2006).

Recovery efforts. Loach minnow and spikedace were listed as threatened in 1986, and uplisting to endangered is warranted (USFWS 1994b). Critical habitats for both species have been designated and withdrawn twice (1994 and 2000) and were again designated in 2007 (USFWS 2007). Aravaipa Creek was included in all designations for both species, and the 2000 designations included long reaches in both the upper and lower San Pedro River and Redfield, Bass, and Hot Springs Canyons. The current designations include Aravaipa Creek and the San Pedro River between Aravaipa Creek and Gila River. Spikedace and loach minnow have recovery plans, which have been inadequately implemented (USFWS 1991b, 1991c, Desert Fishes Team 2006).

Few on-the-ground activities have occurred for conservation of roundtail chub (Desert Fishes Team 2003). It is included in a multi-agency, range-wide conservation agreement that sets out plans for actions to benefit the species (Utah Dept. of Natural Resources 2004). In Arizona, roundtail chub is a sport species with special angling regulations. Concerns about its decline in the Gila River basin resulted in a petition requesting federal listing, which was denied due to non-biological reasons (USFWS 2006).

All three species have benefited from construction of barriers on Aravaipa Creek to prevent upstream invasion by non-native fishes (Desert Fishes Team 2003). No other recovery actions specifically for any of these species have occurred in the San Pedro River basin.

CATEGORY III FISH

Species that typically occupied relatively stable habitats, such as deep pools in streams, ciénegas, springs, cutoff channels or spatially unstable habitats such as stream margins, floodplain marshes, and backwaters in the San Pedro River basin, included Gila chub, desert pupfish, and Gila topminnow. Gila chub is still present in tributaries of the San Pedro River. Desert pupfish and Gila topminnow were extirpated by the mid- to late twentieth century but have been stocked into a few isolated waters in the basin.

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Desert pupfish. Desert pupfish was widespread among main river backwaters, springs, ciénegas, and slow-flowing streams in lower elevations of the Gila River basin, including the Colorado River delta and its overflow sinks, and Salton Sink, California (Miller et al. 2005, Minckley and Marsh forthcoming). It was extirpated from the Gila River drainage but has been repatriated to a few isolated waters therein (Voeltz and Bettaso 2003). Desert pupfish was first collected in the San Pedro River in a marshy canyon near Benson in the mid-1800s. It was not found again until 1950, when it was detected in Mexican headwaters of the San Pedro River above a dam, where it was soon extirpated (Miller 1961, Minckley 1987). Reasons for its extirpation are probably tied to the draining of marshy areas and ciénegass that accompanied arroyo cutting (Miller 1961, Hendrickson and Minckley 1984).

Desert pupfish rarely exceed 30 mm and probably do not live longer than 2 years. Reproductive males are brightly colored blue, black, and yellow-orange and are highly territorial. Dominant males gather on a patch of silt-free bottom and try to lure females to spawn. Although diminutive in size, pupfish are highly pugnacious and aggressively defend oviposition sites from both smaller males and other species (Loiselle 1994). They forage primarily on small invertebrates and algae picked off the substrate and occasionally off their own eggs and young (Schoenherr 1988). They can resist almost any natural environmental extreme known in aquatic systems of the Sonoran Desert, tolerating water temperatures between 7° and 45°C, salinities from fresh water to twice sea water (68 ppt), and oxygen from saturation down to 0.1–0.4 mg/liter (Lowe et al. 1967).

Gila topminnow. The range of Gila topminnow extends south from the Gila River basin to the Río Mayo in Sonora. Historically it was one of the most common species below 1500 m elevation in the Gila River drainage, where it inhabited springs, streams, ciénegass, and margins of main rivers (Miller et al. 2005, Minckley and Marsh forthcoming). Loss of range began early in the twentieth century due to lowering water tables and arroyo cutting (Hendrickson and Minckley 1984). Introduction and spread of non-native fishes, particularly western mosquitofish in the 1930s–1940s, accelerated the decline and is the primary reason for its endangerment (Meffe et al. 1983, Meffe 1985, Minckley 1999b). Currently, fewer than a dozen natural populations remain in the United States, with all but one confined to the Santa Cruz River basin (Voeltz and Bettaso 2003).

In the San Pedro River basin, there were two known natural occurrences of Gila topminnow: a collection from San Pedro River in 1943 about 3 km downstream from Aravaipa Creek (Barber and Minckley 1966) and a population found in 1978 in the outflow of an artesian well 13 km southeast of Mammoth that was extirpated when the pipe was capped the following year

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(McNatt 1979). Absence of Gila topminnow from collections from the San Pedro River remains an enigma, as the entire river is well within the elevational range of the species, and suitable habitats would have been present, notwithstanding incision and sedimentation (Minckley 1987).

Gila topminnow is a small (males <35 mm, females <50 mm), live-bearing fish, and longevity is less than 1 year (Schoenherr 1974). It feeds on a variety of small plants and macroinvertebrates. Reproduction may occur any time water temperatures are suitable but typically is during spring through summer. Brood size varies with female size, nature of habitat, and season. Females can store spermatozoa for several months and are capable of superfetation, where two or more groups of embryos develop simultaneously at different developmental stages, with births occurring at about 21-day intervals. Broods consist of 14–49 embryos (Schoenherr 1977). Sexual maturity is as early as two months, and up to 10 broods per year can be produced under laboratory conditions (Schultz 1961).

Gila chub. Gila chub was widespread and locally common in suitable habitat throughout the Gila River basin, where it is endemic (Minckley and Marsh forthcoming). It occurred in the upper San Pedro River until the early 1900s (Minckley 1987), but much of its habitat was lost and only remnant populations in tributaries persist today (DeMarais 1986, Weedman et al. 1996). Reasons for its loss in the San Pedro River are tied to loss of deep pools in ciénega habitats (Minckley 1987). Gila chub were relatively common in the San Pedro River main stem for nearly 50 years after roundtail chub essentially disappeared, which may indicate that habitat changes in the late 1800s resulted in replacement of large and deep habitats favored by roundtail chub with smaller, slower habitats favored by Gila chub (Minckley, deceased, personal communication). Recent surveys in Mexico have failed to find Gila chub in locations where it occurred in the late 1990s (Rorabaugh, Duncan, USFWS, personal communication).

Gila chub is smaller and thicker-bodied than the closely related roundtail chub and is characteristic of deeper pools in small streams, ciénegas, and springs. Females grow to 25 cm, whereas males seldom exceed 15 cm. Life span is four years or more. The species is omnivorous with a significant amount of insects consumed. Reproduction takes place throughout much of the year except the coldest months, and young are found from early spring through autumn. Gila chub is reclusive, hiding in deep water among roots and other cover (Griffith and Tiersch 1989, Minckley and Rinne 1991).

Recovery efforts. Recovery plans are available for desert pupfish and Gila topminnow (USFWS 1984, 1993). Desert pupfish was listed as endangered in 1986 with critical habitat, which did not include waters within the San Pedro

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River basin. In the San Pedro River basin, pupfish were stocked into artificial ponds near Dudleyville in the early 2000s and continue to thrive there, but other reintroductions were unsuccessful (Voeltz and Bettaso 2003).

Gila topminnow was classified as endangered in 1967 without critical habitat. During the 1970s–1980s, hundreds of natural and artificial habitats were stocked with this species in a recovery attempt, but most sites failed (Voeltz and Bettaso 2003). Other than an introduced population in O'Donnell Canyon (stocked in 1974 and not found again until 2003 [J. Stefferud and Stefferud 2004]), sites stocked in the San Pedro River basin were unsuccessful (Voeltz and Bettaso 2003). In 2005, desert pupfish and Gila topminnow were stocked into three small springs in Aravaipa Canyon (D. Duncan, USFWS, personal communication), where they currently persist.

Gila chub is listed as endangered due to habitat loss and establishment of non-native fishes throughout much of its range. Critical habitat in the San Pedro River basin includes portions of O'Donnell, Bass, Hot Springs, and Redfield Canyons, and Turkey Creek (USFWS 2005a). It was unsuccessfully stocked into Gardner Canyon in 1988 (Weedman et al. 1996). O'Donnell Creek was treated with a piscicide in 2002 to remove green sunfish, and salvaged Gila chub repatriated (Blasius 2002), where they persist in low numbers. In 2005, Gila chub were reintroduced to Turkey Creek (D. Foster, AGFO, personal communication).

CATEGORY IV FISH

These are primarily generalist species that occupy a variety of habitats in perennial or intermittent streams. Speckled dace, longfin dace, Sonora sucker, and desert sucker are widely distributed in the Gila River basin. Longfin dace and desert sucker persist in the San Pedro River main stem and tributaries, but Sonora sucker and speckled dace are restricted to tributaries. All are experiencing range-wide declines in distribution, and all at one time were on the Endangered Species Act candidate list (USFWS 1994a).

Speckled dace. Speckled dace is a bottom-dwelling minnow typical of swiftly flowing riffles and runs in tiny headwater creeks to large rivers. It ranges widely across most of the western United States and is represented in all major drainages of Arizona (Minckley et al. 1986, Minckley and Marsh forthcoming). However, like the rest of Arizona's native fishes, speckled dace has suffered local declines in distribution and abundance (Fagan et al. 2005). Speckled dace in the San Pedro River were considered rare by 1904. A combination of channel entrenchment, loss of riparian vegetation, rising water temperatures, and declining streamflows likely caused its disappearance from the river soon thereafter (R. R. Miller 1961). The species persists in the San Pedro River basin only in Aravaipa Creek and Bass, Hot Springs, and Redfield Canyons.

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Speckled dace is small (<60 mm), with a life span of 2 to 3 years. Whereas closely related loach minnow inhabits interstices of rubble bottoms, speckled dace typically occupies the water column immediately above those substrates (Rinne 1992). Speckled dace spawns in response to summer rains and other substrate-disturbing events, and spawning occurs in gravel riffles where females deposit eggs into nests excavated by the male (John 1963, Mueller 1984). Foods are predominantly ephemeropteran nymphs and dipteran larvae (Schreiber and Minckley 1981).

Longfin dace. Longfin dace is among the most common native fishes in the San Pedro River basin (J. Stefferud and Stefferud 2003, Marsh and Kesner 2004) and other lower-elevation (<2000 m) streams of the Gila River basin (Miller et al. 2005, Minckley and Marsh forthcoming). Its love for shallow, sandy-bottomed streams allows it to persist in areas where most other species (native or non-native) do not (Miller 1961). Despite this adaptation, longfin dace has disappeared from many stream segments in the Gila River basin, especially large rivers (Fagan et al. 2005), and its range in the San Pedro River basin has declined (Stefferud and Stefferud 2003). Longfin dace has the habit of moving both up- and downstream into formerly dry stream reaches during flood events. Although mortality typically results, this behavior can occasionally establish new populations. In addition to the main stem river, longfin dace persists in Babocomari River; Aravaipa Creek; Buehman, Hot Springs, Redfield, and Cave Canyons in Arizona; and El Sauz, Los Alisos, and Los Fresnos in Sonora. Longfin dace was extant in O'Donnell Creek as late as 1997, but none were found during renovation efforts in 2002. However, during post-treatment surveys in 2004, a single longfin dace was found (D. Foster, AGFD, personal communication); its current status is uncertain. Green sunfish have invaded its range in Mexico (J. Rorabaugh, D. Duncan, USFWS, personal communication), and its future there is problematic.

Longfin dace is small (<75 mm) and short-lived (2 to 3 years). It typically occupies moderately shallow waters with moderate velocities over sand-gravel substrates (Rinne 1992). It is omnivorous, consuming both algae and aquatic invertebrates according to availability (Fisher et al. 1981, Schreiber and Minckley 1981). Reproduction can occur throughout the year (Minckley and Barber 1971, Kepner 1982) but typically is in spring to late summer in sandy-bottomed, quiet-water areas along stream margins, where actions by spawning individuals excavate saucer-shaped depressions into which eggs are deposited.

Sonora sucker. Sonora sucker is endemic to the Gila and Bill Williams Rivers drainages of Arizona, New Mexico, and Sonora (Miller et al. 2005, Minckley and Marsh forthcoming). It disappeared from the San Pedro River above

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Benson by 1950, likely a result of the filling of deep pools with sand (Miller 1961), and is now functionally extirpated from the lower river also (Marsh and Kesner 2004), its presence supported only by dispersal from Aravaipa Creek. The species occurs in Aravaipa and O'Donnell Creeks, and Hot Springs and Redfield Canyons.

Sonora sucker is large and robust (up to 80 cm, 2 kg) and frequents deep pools in medium-sized streams and rivers between 300 and 2000 m elevation, where it primarily consumes a variety of benthic invertebrates (Schreiber and Minckley 1981, Clarkson and Minckley 1988). Spawning occurs in gravel riffles in late winter or early spring, similar to desert sucker with which it occasionally hybridizes (Clarkson and Minckley 1988). Spawning is typical of cyprinoids, with two or more males and a larger female swimming in a tight circle until all individuals pause and emit gametes. Release of gametes is usually accompanied by agitation of substrates by spawners' fins, which may clean the gravel and bury eggs within the substrate (Reighard 1920, W. Minckley 1981). Larvae of Sonora sucker comprise a major component of stream drift in Gila River basin waters (Bestgen 1985, Remington 2002). Adults were used as food by aboriginal inhabitants (W. Minckley and Alger 1968).

Desert sucker. Desert sucker tends to occupy smaller, higher-elevation streams compared with Sonora sucker, but the two species are broadly sympatric in the Gila and Bill Williams Rivers drainages (Minckley and Marsh forthcoming). Desert sucker remains common in these basins but is locally extirpated from some river and tributary reaches (Fagan et al. 2005). The species persists in the San Pedro River and tributaries but is declining in range and abundance in the main river (J. Stefferud and Stefferud 2003, R. W. Clarkson, unpublished data).

Desert sucker attains >40 cm in length. Habitat is riffles with laminar flow over gravel substrates (Rinne 1992). It is largely herbivorous, scraping algae and detritus off rock surfaces in riffles and runs with specialized cartilaginous sheaths on its upper and lower jaws (Schreiber and Minckley 1981, Clarkson and Minckley 1988). Spawning of desert sucker is similar to that described for Sonora sucker (J. A. Stefferud, unpublished data). As with Sonora sucker, a significant life history feature of desert sucker is its proclivity to enter stream drift as larvae (Bestgen 1985, Remington 2002).

Recovery efforts. None of the four species is federally or state-listed; however, all were recommended for listing due to their declining range-wide status and persistence of threats (USFWS 1994a). Conservation activities in the San Pedro River basin have included repatriation of Sonora sucker into O'Donnell Creek after it was renovated (Blasius 2002) and repatriation of longfin dace

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into Turkey Creek in 2005, from where it had disappeared after 1993 (D. Foster, AGFD, personal communication). As with many of the other native fishes, these species have benefited from barrier construction in Aravaipa Creek (Desert Fishes Team 2004).

Arrival and Spread of Non-native Fishes

The introduction and spread of non-native fishes is of local, regional, and national significance in natural resource management and conservation biology (USFWS 1980, Fuller et al. 1999, W. Minckley and Marsh forthcoming). Non-native fishes can alter populations and assemblages of native species, as well as ecosystem functioning—a capacity that is well demonstrated in the San Pedro River basin.

At least 15 non-native fishes have been introduced into the San Pedro River basin during the past 100+ years (table 10.1). There now are established populations of nearly a dozen non-native fish species in the main river and tributaries. These species were brought to Arizona mostly from other parts of the United States and a few from Europe (Minckley and Meffe 1987), and their intended destination likely was not the San Pedro River, nor was conservation of native fishes a consideration when they were brought to the region.

Earliest transplants of non-native fishes were to establish reliable food sources for humans; thus, common carp was brought to the Colorado River drainage in the late 1800s and later stocked into ponds at St. David (Minckley 1987). Over the years, other non-native fishes were widely distributed by state or federal resource management agencies, or private parties, to develop or improve recreational angling by adding new sport species or by providing forage for sport fish. Other species were introduced accidentally in shipments of desired species (Fuller et al. 1999), and a few were likely brought in surreptitiously. The presence of western mosquitofish is a result of public health officials assuming native fishes were ineffective at controlling mosquitoes, even though Gila topminnow was an efficient insectivore (Childs 2006).

Among other non-native animal taxa that were brought in or invaded the San Pedro River, several likely affect native fish stocks, including northern crayfish (*Orconectes virilis*), American bullfrog (*Rana catesbeiana*), and spiny softshell turtle (*Trionyx spiniferus*). These species adversely affect fishes through direct predation, habitat alteration, inhibition of spawning, or competition for food and other resources (Boyd 1975, Fernandez and Rosen 1996, Robinson et al. 1998, Bryan et al. 2002, Carpenter 2005).

Mpoame and Rinne (1983) detected no non-native parasites in fishes from Aravaipa Creek. Since then, great Asian tapeworm (*Bothriocephalus opsarichthy-*

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dis) has spread to fish in all river basins of Arizona, including the San Pedro (Arizona Game and Fish Department, unpublished data), and is a chronic threat to native fish health (Clarkson et al. 1997). Another non-native, the external parasitic anchor worm (*Lernaea cyprinacea*), is established in the San Pedro River and can adversely affect native fishes in heavy infestations (A. Robinson et al. 1998).

Decline and Loss of Native Fish

The large-scale change in biodiversity of aquatic fauna of the San Pedro River basin in the recent past is a complex, cumulative, and synergistic interaction of human-induced and naturally occurring stochastic factors. Streams are a product of their watersheds, and almost any change within the watershed can affect the stream and its inhabitants. Time frames are highly variable, ranging from immediate (e.g., water diversion) to decades or centuries (e.g., vegetation removal on ridges of upper watersheds). Effects of all change are modified, magnified, diminished, accelerated, or decelerated by interactive factors in complex patterns (see chap. 13). But viewed simply, decline of native fishes in the San Pedro River can be attributed to (1) alteration and destruction of aquatic habitats, and (2) introduction and spread of non-native fishes and other aquatic species (Miller 1961, Minckley and Deacon 1968, Minckley 1987, Deacon and Minckley 1991, Minckley and Rinne 1991, Marsh and Pacey 2005).

Southwestern fishes persisted for millennia in the severe climate and highly fluctuating river systems of southwestern North America. Over that period, geologic and climatic changes likely caused major local and regional alterations in aquatic habitats (W. Minckley 1983, W. Minckley et al. 1986), but the fauna survived into the historic period. However, natural and human-induced events that have occurred since the arrival of European man have significantly affected the ichthyofauna in the San Pedro River basin.

CHANGES IN AQUATIC HABITATS

Prior to the early nineteenth century, most river systems in the Southwest were perennially or seasonally connected by surface water, and fish could freely move between the various watercourses (Rinne 1993). Historical accounts of the San Pedro River suggest that prior to the 1850s the upper river was not incised but meandered through marshy areas and pond complexes constructed by beavers, and the banks of the lower river were plentifully timbered with cottonwood and willow (see chaps. 12 and 19). Aquatic habitats in the San Pedro River and tributaries would, depending on gradient, likely have been a series of large deep pools separated by reaches of shallow, rapidly flowing runs and riffles, interspersed with a diverse mix of shallow to deep,

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slow- to fast-moving aquatic habitats, including marshes, ciénegas, backwaters, cutoff channels, stream margins, eddies, springs, canyons, and other forms of riverine habitats.

A decrease in the diversity of aquatic habitats probably began in the late 1600s when domestic livestock arrived in the San Pedro River Valley (see chap. 11). The presence of surface water and lush vegetation would have encouraged cattle to spend an inordinate amount of time in the riparian area, where they would have trampled the streambanks, consumed the vegetation, and altered aquatic habitats, particularly those associated with stream margins and in shallow reaches (see Belsky et al. 1999). Trapping-out of beaver colonies beginning in the early nineteenth century and into the twentieth century would have led to the loss of their flow- and channel-stabilizing dams, particularly degrading pool habitats. Channel incision in the late 1800s following an earthquake and several very large floods exacerbated by land uses would have caused massive changes in aquatic habitats, essentially changing the river from one with a diverse mix of aquatic habitats to one of wide and shallow homogenous habitats (Miller 1961, Minckley 1987; and see chap. 12). During this period, Colorado pikeminnow, razorback sucker, and flannelmouth sucker, very large fish that needed deep water and connected habitats, disappeared from the San Pedro River.

During and following the period of river incision, human activities along the river and on the uplands continued to contribute to alteration of aquatic habitats. Mine spills made the water toxic (Eberhardt 1981), grazing continued to destabilize streambanks and prevent reestablishment of vegetation, and timbering, roads, and agricultural development exacerbated sediment movement off the uplands (see chap. 12). Excessive erosion can overwhelm a river's capacity to process sediment, which results in the depth of pools being reduced, coarser substrates being covered and filled with fine sediments, and lateral channel erosion being increased (D. Wood et al. 1990), causing a reduction in abundance, biomass, and biodiversity of native fish assemblages (Shields et al. 1994). Loss of native species in the San Pedro River continued in the first half of the twentieth century, as speckled dace, roundtail chub, Gila chub, and desert pupfish disappeared, likely a result of the homogenization of diverse habitats caused by degradation of the stream channel (Miller 1961, Hendrickson and Minckley 1984, Minckley 1987) and perhaps elevated stream temperatures (Widmer et al. 2006, Carveth et al. 2006).

The mid- to late 1900s saw the advent of deep wells punched into the aquifer of the San Pedro River and extensive urbanization of the uplands (see chaps. 11 and 15). Pumping from deep wells decreased the extent and amount of surface flow in the river and many of its tributaries and restricted the amount of habitat available for fish. In addition to depletion of ground-

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water, urbanization affected the San Pedro River by changing runoff patterns, increasing erosion and sedimentation, and increasing pollutants (see chaps. 11 and 17). The increase in human population brought with it demands for "improved" recreational angling opportunities in the San Pedro River, which were answered with introduction of a suite of non-native sport fishes. During this period, loach minnow, spikedace, and Gila topminnow disappeared, and the presence of Sonora sucker was severely reduced in the main river (Minckley 1987).

Today, populations of native fish in the Southwest are isolated from each other by stream channels that are fragmented by dams and diversions, and long reaches sucked dry by groundwater pumping (Rinne 1993). The San Pedro River remains undammed, but diversions and groundwater pumping have depleted its surface flow (see chaps. 12 and 19). Aquatic habitat in the San Pedro River is mostly shallow runs over sand with infrequent large pools, and surface water is intermittent and interrupted. Areas of double or braided channel are common. The substrate is deeply embedded with sand and fine gravel, and many deeper water habitats are filled with sand (Velasco 1993, J. Stefferud and Stefferud 2003). Similar conditions exist in the tributaries where human-caused impacts have occurred.

INTRODUCTION OF NON-NATIVE FISHES

Native fishes were profoundly affected by additions of non-native fish to the San Pedro River basin. Non-native species can alter population, community, and ecosystem structure and function through direct predation, habitat alteration, competition for food and other resources, changes in behavior of native fishes, and other effects (Taylor et al. 1984, Moyle and Light 1996, Fuller et al. 1999, Marchetti and Moyle 2001, Marchetti et al. 2004). Precisely how they cause decline and replacement of native fauna is a complex mix of individual, cumulative, and synergistic actions, but the result is unequivocally a loss of native species.

Native fishes evolved in a relatively simple community that included only one obligate piscivore and were influenced by, and adapted to, extreme conditions of periodic droughts and floods typical of the region. They occupied a free-flowing river system characterized by heterogeneous habitats that ranged from mainstream runs and riffles to sluggish pools and ciénegas. Use of available habitats was relatively well partitioned among species (Minckley 1981, Rinne 1992, Childs et al. 1998).

The native fauna persisted for millennia in part because local populations lost to stochastic events were either repopulated by fish from unaffected areas within the basins of the interconnected San Pedro, Gila, and Colorado Rivers or by individuals that survived during periods of extreme conditions by moving temporarily into other habitats (Rinne 1993). Conditions in the

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San Pedro River today make natural recolonization of local population losses unlikely (Minckley 1999b, Marsh et al. 2000, Clarkson et al. 2005).

Differences between native and non-native fishes in behavioral patterns, competitive ability, and habitat use help explain the changes that have occurred within the fish community. Native species have behavioral adaptations that allow them to withstand extreme flows, both droughts and floods (Meffe and Minckley 1987, Minckley and Meffe 1987). Few native fishes are particularly cover-oriented, preferring instead to move into the water column away from perceived dangers or disturbances. All have relatively simple life histories. Most provide no or only minimal preparation or parental protection of spawning sites or care of young (Kodric-Brown 1977, Schoenherr 1977, Constantz 1980, Kepner 1982, Minckley and Rinne 1991, Rinne 1992, Weiss et al. 1998, Johnston 1999, Johnson 2002, Childs 2004, Marsh and Pacey 2005). Differences in piscivory and predator avoidance are important factors in native–non-native fish relationships. Most native fishes are predator-naive and co-existed with only Colorado pikeminnow and occasionally roundtail chub as predators. Many show no fear or flight reaction in the presence of predators (Johnson and Hines 1999, Johnson 2002).

In contrast, most non-native fishes are from the species-rich environment of the Mississippi River system where intense competition and habitat-use constraints kept populations in dynamic balance such that co-evolved species were able to co-exist (Pflieger 1975, Trautman 1981, Ross 2001). These species evolved in predominately lentic habitats with deep, slow-moving pools, and where flooding increased volume and discharge but resulted in little increase in velocity or turbulence (Minckley and Meffe 1987). Most species prefer deep pools with abundant in-channel or bank-associated cover and have complex life histories (Unmack and Fagan 2004, Marsh and Pacey 2005). Parental care is given in the forms of nest building and aggressive protection of young. When these species were imported to Arizona's rivers, they were released from population-limiting factors such as interspecific competition and highly specific resource partitioning, which allowed them to flourish (Minckley and Douglas 1991, Douglas et al. 1994).

Most non-native fishes in the San Pedro River basin are piscivorous and capable of feeding on all life stages of the natives. Agonistic behaviors of non-native predators induce energetically costly responses by native species that can result in decreased growth, fecundity, swimming ability, and alteration of habitat use. These extra energy outlays may indirectly contribute to higher levels of mortality (Tollrian and Harvell 1999), especially to young-of-year during winter (Thompson et al. 1991).

The large predators (largemouth bass, green sunfish, yellow and black bullheads) are probably the most destructive to native fishes (Marsh et al.

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1989). Abundance and distribution of non-native species vary substantially throughout the basin, although the trend in both parameters is upward. Most non-natives are relatively long-lived (5 to 10+ years), and their adult populations do not fluctuate greatly. But the impact of non-native species on natives is highly disproportionate to their relative abundance in the assemblage (Tyus and Saunders 2000), and they may in fact preferentially consume native catostomids (Schwemm and Unmack 2001). Although native fish may be numerically predominant, each predator will consume many individual prey and can have a significant impact on total abundance of prey species and perhaps even survival of entire taxa in the system (Leslie et al. 2005, Velez et al. 2005).

Even the non-predatory non-native species can impact native populations. They are highly competitive for space and foods and will displace native species into less-desirable habitats (Taylor et al. 1984, Brown and Moyle 1991, Douglas et al. 1994). Of the smaller omnivores, red shiner has been implicated as a factor in decline of spikedace (Abarca-Gonzales 1989, Douglas et al. 1994) and can impact recruitment of native fish (Gido et al. 1999). Fathead minnow and red shiner prey on larvae of native fishes (Ruppert et al. 1993, Brandenburg and Gido 1999). Common carp increase water turbidity by dislodging plants and rooting around in the substrate, and they prey on eggs of other fish species (Taylor et al. 1984).

Flood-dominated hydrographs of erosive tributary streams may contribute to the security of native assemblages there and help keep non-native species from establishing. Streams that are isolated from the main river and have hydrographs and habitats closer to historical conditions are more likely to resist invasion by non-native species (Marchetti and Moyle 2001). However, although characteristic floods still occur and are known to differentially displace many non-native species, they usually do not eliminate non-native populations (Meffe and Minckley 1987, Minckley and Meffe 1987). For example, Aravaipa Creek, the largest tributary, retains seven native fish species and has only limited populations of six non-natives. However, despite large floods, non-natives are increasing in distribution and abundance and may be causing gradual loss of natives (Eby et al. 2003). History demonstrates that over time, we can expect all tributaries unprotected by natural or constructed barriers to upstream fish movement to become dominated by non-native fishes, with few if any native fish remaining (Clarkson et al. 2005).

The ubiquitous, persistent, and increasing presence of non-natives in the San Pedro River basin is a significant impediment to long-term survival of the native fishes. Where non-native fish become established, natives invariably wane or disappear, as has occurred in the San Pedro River and its tributaries (Unmack and Fagan 2004, Marsh and Pacey 2005).

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Conservation Actions

Recovery plans for the listed fishes outline a suite of conservation actions that could be applied in the San Pedro River (Desert Fishes Team 2006) and which would benefit the entire assemblage of native species, listed or not. Additionally, numerous restorations of native fishes into both the main river and tributaries have been recommended in state and federal management plans, but the few that have been implemented were limited to tributaries. Attempts to control non-natives similarly have been limited, and restricted to tributaries.

Land acquisition and conservation in the San Pedro River basin by governmental agencies, The Nature Conservancy (TNC), or other public and private entities have been the most significant activities from a general conservation perspective. Significant reaches of stream in the San Pedro River basin are under conservation-oriented management, most notably on the lower and upper main river, Aravaipa, O'Donnell, and Turkey Creeks, Redfield and Hot Springs Canyons, Bingham Ciénega, and Los Fresnos. Passive benefits have included riparian restoration and amelioration of detrimental human activities such as irrigated agriculture and domestic livestock grazing (Krueper et al. 2003; and see chap. 19). Other actions within the basin have secondarily benefited native fishes. For example, mine tailings at Cananea were reconfigured to avoid pollution of the San Pedro River, roads and bridges at a number of sites were reconstructed to minimize or avoid channel impacts, and erosion control in ephemeral tributaries may reduce sediment inputs.

However, habitat protection has yet to demonstrate benefits to native fishes in the San Pedro River. There has been remarkably little in-stream habitat recovery despite striking improvements in riparian condition. Streamside vegetation has rebounded from earlier decimation, but aquatic habitats have not. Ciénegas and beaver ponds once characteristic of the river are rare, substrates are dominated by sand and fine gravel instead of a diversity of materials, riffles are scarce, long sandy runs are common, and infrequent deep pools that are not filled with sand are usually turbid. Other parameters of aquatic habitat types (e.g., depth, length, width, cover) have not substantially changed since the 1988 establishment of the San Pedro Riparian National Conservation Area on the upper river (Velasco 1993, J. Stefferud and Stefferud 2003).

Efforts to protect instream flow have occurred in tributaries, such as Aravaipa Creek, through legal recognition of instream flow rights (USBLM 1998a). Land acquisition has retired irrigation water rights and returned those flows to the river. Ways to prevent desiccation of upper portions of the river from groundwater pumping are being discussed (Hess 2005; and see chap. 21).

Construction of barriers on Aravaipa Creek is inarguably the single most

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important action to directly benefit native fish that has been taken in the watershed. Barriers do, of course, also stop upstream migration of native fish, so their benefits versus detriments need to be carefully considered in an ecosystem context. However, they are the only way available at present to protect existing populations of native fish, and they are widely used for this purpose, primarily for cold-water species but increasingly for warm-water assemblages also (Carpenter 2005). In Aravaipa Creek specifically, the effects of restricting any potential upstream migration of natives is far outweighed by the benefits of protecting the existing assemblage above the barrier.

Beaver were repatriated into the upper portion of the river in 1999 (USBLM 1998b), an action which will likely prove detrimental to native fishes, primarily due to the presence of non-native fish. The two native fish species remaining in the San Pedro River are primarily riffle-dwellers, a habitat type locally decreased by activities of beaver. The mechanism is straightforward: beavers construct dams, dams impound water to form pools or ponds that back up behind the dam, and flowing stream habitat that was there previously is inundated (Collen and Gibson 2001). Compounding this loss of habitat, the non-native predatory species present do well in pools, where they prey on native fish seeking refuge during drought or low-flow periods (Stefferud and Stefferud 2003).

There are few options for native fish management in the San Pedro River basin. Many of the fishes are extirpated locally and declining range-wide; the entire fauna is biologically imperiled. Most species are federally listed, but efforts to manage or recover these species are rare. The single most important conservation action to benefit native fishes—control or elimination of non-natives—has rarely been implemented, and other actions, while benefiting other resources, do little to improve conditions for native fishes. In fact, in the face of the continuing presence of detrimental non-native species, habitat improvements are likely to contribute to further losses of natives by enhancing conditions for non-natives as well.

Summary

The San Pedro River has experienced a staggering loss of its once-rich native fish fauna. Originally an assemblage of 13 native fish species, all but 2 have been replaced by a suite of non-native fishes in the main river. Perturbations to the watershed and channel and declining streamflows have contributed to the loss of native fishes, but it is the persistent, ubiquitous, and expanding presence of non-native fishes that precludes hope for recovery of the native fauna. Tributary streams retain 9 native species, but not all in any one stream. Even these streams are vulnerable to invasion by non-native fishes and are experiencing declines in number of native species present.

Conservation actions directed toward habitat protection or improvement

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by themselves are insufficient to recover native fishes. Even if ongoing and future water depletion and habitat alteration issues can be resolved, chronic presence and unceasing invasion of an abundance of non-native fishes in the main river, tributaries, ponds, and stock tanks may prevent even persistence of the remaining native fish fauna and rules out the likelihood of re-establishment of extirpated native species. The most urgent conservation need of native San Pedro River basin fishes is control or elimination of non-native fishes (Marsh and Pacey 2005, Clarkson et al. 2005).

The San Pedro River has been described as one of America's "most endangered rivers" and "last great places" (respectively, American Rivers 1999 and The Nature Conservancy 1991). Its true potential as a "last great place" can never be realized until its endangered native fish fauna is restored.

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