HYDROLOGY, GEOMORPHOLOGY, AND MANAGEMENT: IMPLICATIONS FOR SUSTAINABILITY OF NATIVE SOUTHWESTERN FISHES

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The southwestern region of the United States is characterized by a desert climate (Dunbier 1968; Green and Sellers 1964; Jaeger 1957) and a highly diverse and complex topography (Chronic 1983, 1987; Nations and Stump 1981). Woven into this rather harsh and highly variable climate and topography are disjunct and precious aquatic habitats (Rinne 1995), many of which contain a single or at best several species of native fishes (Rinne in press a, b). Superimposed upon climate, geology, topography, and hydrology has been a dramatic increase in human population and associated development of the region. Marked changes in the hydrology of the region have resulted from dams, diversions, and groundwater pumping to support the rapid development of the Southwest (Miller 1961; Minckley 1973; Rinne and Minckley 1991; Rinne in press b). These hydrologic changes and associated biological introductions of nonnative species (Rinne 1996; Rinne and Janisch 1995; Rinne et al. 1998) have imposed extensive negative impacts on the native fishes of the region. Currently, the native fish fauna is listed largely as threatened or endangered. Sustainability of this dwindling natural resource (Rinne and Minckley 1991) is intimately linked to the multiple and interacting factors listed above.

HYDROLOGY

Historically, rivers and streams in the Southwest have been subjected to "feast" and "famine" in terms of surface water habitat for fishes; this continues to the present. Feasts in the form of episodic flooding occur at random intervals as a result of either summer monsoon precipitation events (Green and Sellers 1964) or elevated spring runoff resulting from rain on snow events in the montane areas or rapid warming that results in flooding. In summer, these elevated flows often occur as "flash floods" such as illustrated by Rinne

and Minckley (1991). Normally, these events subside very quickly. In contrast, rain on snow events or excessive rains in winter (February–March) also result in more sustained flood events in streams (Figure 1). Floods have been implicated in resorting and re-distributing substrate components and in providing optimum spawning habitat for native fishes (Rinne in press b). Disturbance in form of flooding also creates a greater diversity of aquatic habitats in streams and rivers (Figure 2) that, in turn, enhances native fish diversity.

It was first hypothesized by Meffe (1984), based on laboratory studies, that flooding could be more beneficial to native fishes than nonnatives. Later, Minckley and Meffe (1987) and Rinne and Stefferud (1997) supported this hypothesis based on data collected from naturally flowing environments. Rinne et al. (in press) and Rinne (in press c) demonstrated that differences in the flow regimes of rivers can result in markedly different fish species assemblages. That is, the Gila River headwaters experiences both more frequent and larger-volume flood events than the Verde River headwaters. The former river sustains more native fishes than the latter, including two threatened cyprinid species, spikedace (*Meda fulgida*) and loach minnow (*Rhinichthys cobitis*).

The famine or drought component of Southwest hydrology can result in intermittency of streams and rivers or complete loss of surface waters (Rinne 2000). Intermittent flows can result in limited water quality for fishes in the form of elevated water temperatures and lowered dissolved oxygen; either singularly or in combination, these water quality variables can be lethal to desert fishes (Rinne et al. 2002). Lack of these flooding and drought conditions might be beneficial to nonnative species of fishes rather than natives (Rinne in press b). Stable, low flows during periods of drought enable nonnative fishes to establish and increase in abundance (Rinne 1999). In contrast, variable flow regimes accompanied by

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Figure 1. A large, 10-year sustained flood event in March of 1995 on the Verde River, Arizona. This flood event (and others historically) occur in winter (March–April) and result from extensive winter rains or rain on snow events in the Southwest.

periodic flooding reduce nonnative fish abundance and enhance that of native species (Rinne and Stefferud 1997).

GEOMORPHOLOGY

More than two decades ago, Platts (1979) suggested that geomorphology is an important, overriding determinant in fish community structure. Rinne (2000) documented that parent geology was very important in defining the abundance of salmonids in the White Mountains of east-central Arizona. Differing parent materials result in different stream substrates, some more optimum for Apache trout spawning (Rinne 2001a). Rinne (in press b) has suggested that there are two major geomorphic types of rivers: canyon bound and alluvial valleys (Figure 3). Based on fish assemblages in these two geomorphically different types of river reaches, native species generally predominate in the more broad alluvial valley reaches. In part, this is attributable to greater diversity of habitat,

illustrated in Figure 2, resulting from flooding in these areas and a more broad flood plain for the flood event to create habitat diversity. Further, there are less deep (> 2 m) pool habitats in the broad alluvial valleys compared to the river canyon reaches (Figure 2). Large, nonnative predators such as bass and catfish inhabit these deep pools and prey on native species (Rinne 2001b; Rinne et al. in press). By comparison, these nonnative predatory, pool-inhabiting species become greatly reduced in numbers in alluvial valley reaches where pools are fewer and shallower in depth. Relative distribution and abundance of the threatened spinedace and loach minnow in the upper Gila River (Table 1) further corroborate this hypothesis (Rinne et al. in press). Both diminish in abundance as one moves into these canyon reaches and then reappear and increase in abundance in reaches containing more optimum habitat (Rinne and Deason 2000) below and outside canyon-bound reaches.

Figure 2. Diversity of habitat as illustrated here from the Gila River at Redrock, New Mexico results from flood events in alluvial valleys which result in D-type channels and greater diversity of aquatic habitats. These in turn increase fish diversity and abundance in specific reaches.

MANAGEMENT

Commencing in 1911 with completion of Roosevelt Dam on the Salt River northeast of Phoenix, Arizona, aquatic habitats in the Southwest have been increasingly and markedly altered by mainstream dams. The U. S. Bureau of Reclamation has constructed dozens of mainstream dams on southwestern rivers (Figure 4). These dams controlled flows, altered water quality, and dried up some rivers such as the Gila below San Carlos Reservoir (Rea 1983) and the Salt below Granite Reef Dam. In Arizona, Rinne (1994) calculated that 75 percent of

mainstream river habitat has been lost through modification by dams alone; there have also been diversions for irrigation and groundwater pumping (Rinne and Minckley 1991; Rinne in press b). Some rivers, such as the upper Verde in Arizona, currently have a high probability of losing surface flow due to planned housing developments in the Chino Valley area (Neary and Rinne 2001; Wirt and Hjalmarson 2000). Water management to facilitate development in an arid, desert environment has had a major impact on native fishes in the area.

Accompanying the dramatic hydrologic management in the form of storage reservoirs behind major, mainstream dams has been widespread and intensive introduction of nonnative species of fishes, largely for sport fishing (Rinne in press a; Rinne and Janisch 1995; Rinne et al. 1998). In Arizona, more than 100 nonnative species have been introduced in the century of time between 1890 and 1990 (Rinne 1996; Rinne in press a). Almost half have become established in the waters of Arizona, resulting in a 100 percent increase in fish

Table 1. Distribution and abundance of two threatened species in the upper Gila River relative to canyon-bound and alluvial valley reaches, 1999.

Reach and Type		Spikedace	Loach Minnow
I	Both	65	74
II	Canyon bound	0	0
III	Canyon bound	0	0
IV	Alluvial valley	750	104
V	Both	84	22

Figure 3. Southwestern rivers are encompassed by two types of geomorphic structuring: canyon bound (top, Salt River Canyon, northeast of Globe, Arizona) and wide alluvial valleys (bottom, Gila River below Cliff, New Mexico).

Figure 4. Large mainstream dams such as Hoover or Boulder Dam on the Colorado River dramatically alter flow regimes, water quality, and fish assemblages in major southwestern rivers.

species diversity in aquatic habitats. These transplanted, nonnative species in reservoir habitats soon moved up and downstream into lotic or riverine habitats where native species yet persisted. In a period of 25 to 50 years, many species have become much reduced in numbers, listed as federally threatened or endangered, or extirpated in some reaches of rivers. Two native fishes in Arizona are now extinct (Rinne in press a). Several large river species such as Colorado pikeminnow (*Ptychocheilus lucius*) and razorback sucker (*Xyrauchen texanus*) once migrated for spawning up these river systems. Mainstream dams precluded such migrations and these species became extirpated from the Gila River Basin within 50 years.

CONCLUSIONS AND MANAGEMENT IMPLICATIONS

Natural hydrology and geomorphology have been keystone factors in delimiting and sustaining

native fish distribution and abundance in southwestern rivers and streams. The marked alteration of natural hydrologic regimes has been devastating to native fishes. These changes coupled with introduction of nonnative fish species have resulted in the fish fauna of the Southwest being largely listed as threatened and endangered. Sustaining native southwestern fishes will necessitate a focus on maintaining reaches of river that still contain native fish assemblages. That is, respective river reaches need to be designated as "native management reaches" (Rinne in press a). Normally these are headwater reaches above dams, diversions, and extensive groundwater removal areas. On the other hand, more downstream reaches with their predominance of nonnative species should be designated as nonnative, or sport fishing reaches. The two groups of fish species are like oil and water—one cannot mix them and hope for a favorable solution.

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