World Fisheries

Factors Contributing to Collapse yet Maintenance of a Native Fish Community in the Desert Southwest (USA)

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Summary

Data presented indicate that the ratio of population numbers of native to non-native fish species in the Verde River. Arizona fish community is variable but most consistently 85:15. In part. the relative numbers of each component are dependent on river location and species of fish. Characteristic stream hydrography in terms of location. season. and severity and duration of flood events. also appears to be a contributing factor for maintaining this ratio. Although a 7-year flood event collapsed populations of both native and non-native species. the proportions of the two groups changed only slightly (82:18 to 85:15). By comparison. a 50+ year flood event resulted in native species increasing by 11% (86–97%). Reproduction and recruitment of natives is enhanced post-flood. apparently as a result of cleaning and rejuvenation of stream substrates. Based on a decade of data (1986 to 1996). the natural hydrography of the upper Verde River as opposed to biological or native/non-native species interactions. is suggested as the controlling factor in sustaining native fishes in this large. low desert river.

Introduction

Patterns of stream discharge and the presence of introduced fishes have been suggested to interact to influence native fishes and their sustainability in streams of the arid American southwest (Minckley and Meffe 1987; Rinnee and Minckley 1991; Rinne 1993, 1995a; and Stefferud and Rinne 1995). Commencing with the water reclamation era in the early 1900s, dams have been ubiquitously imposed on most rivers in this region (Rinne 1991, 1993, 1995b), drastically and irreversibly altering aquatic habitats (Miller 1960; Rinne and Minckley 1991). Non-native fish introductions commenced before 1900 and have steadily escalated (Rinne 1991, 1993, 1995a). The combination of these two impacts has markedly reduced both the range and numbers of all native species of fishes, rendering some extinct (Minckley and Douglas 1991), yet native fishes persist in most drainage basins in the Southwest. However, where both altered, unnatural stream hydrography and non-native fish exist, native fish generally are either reduced from historic levels or are absent (Minckley and Deacon 1968).

In all but a few streams, these two factors, when combined, have eliminated native fish species and modified community structure and dynamics, often within a few years after the action.

Streams where the native fauna remains predominant are a rarity in the Southwest. The exact mechanism that sustains native species in the presence of non-native species is not understood, but is hypothesized to be related to cycles of extreme droughts and floods that characterize streams in this region. Because of the ever-increasing demand for water for a growing populace, and the generally imperilled status of the southwestern native fish fauna (Rinne and Minckley 1991), clarification of this question is important at this time.

The upper Verde River, central Arizona, from its source at Sullivan Lake to the mouth of Sycamore Creek 60 km downstream is a rarity among southwestern rivers. It is the only reach of large (1.3–7.0 m^3 sec^{-1} annual mean discharge) perennial desert river in Arizona where surface flows are not altered by dams or diversions. Further, this reach of river retains a native fish fauna that is largely intact. Six of the eight native species (desert sucker, *Catostomus clarki*; Sonora sucker, *Catostomus insignis*; roundtail chub, *Gila robusta*; longfin dace, *Agosia chrysogaster*; spikedace, *Meda fulgida* and speckled dace, *Rhinichthys osculus*) are present in viable numbers (Stefferud and Rinne 1995); all are either state or federally-listed species. Two species (Colorado squawfish, *Ptychocheilus lucius* and razorback sucker, *Xyrauchen texanus*), which have been documented in archaeological sites along the Verde (Minckley and Alger 1968) but are no longer to be found, are currently objects of re-introduction and restoration efforts. Nevertheless, an assemblage of non-native fish occurs in this reach of river, including red shiner (*Cyprinella lutrensis*), fathead minnow (*Pimephales promelas*), common carp (*Cyprinis carpio*), green sunfish (*Lepomis cyanellus*), smallmouth bass (*Micropterus dolomieui*), yellow bullhead (*Amerius natalis*), and channel catfish (*Ictalurus punctuatus*). Reasons for complete retention of the native fish are unclear. Whether the native species are maintaining their populations in the presence of non-native species, or whether the non-native species are unable to become dominant due to hydrologic conditions (water quantity and quality) and stream gradient is not known. Few published data are available to document either the history of encroachment by non-native species or trends in the dynamics of southwestern fish communities.

Although a number of studies on fishes and their habitats have been undertaken in the Verde River, none have investigated the long-term interrelationships of the native and non-native fish communities relative to flood disturbance events and to each other. The relationship of base and flood flows to sustainability of native fishes in the upper Verde River needs to be determined in order to provide input to water management plans for the system. The headwater Big Chino Valley aquifer is a major source of baseflow for the Verde River above Sycamore Creek; and there are proposals to extract its water to supply municipal needs to towns in the watershed. Depletion of discharge from the aquifer could alter baseflow in the river and affect sustainability of native fish. Other proposals to divert water directly from the Verde River and construction of mainstream dams have been made. However, the unresolved question of their effects on the native fish has deferred approval by resource agencies. Continued growth in the region will probably increase pressure for water development and diversion from the upper Verde. Resource management agencies need to have reliable in time and space to chart a course of action that will co native fish in the river.

In Spring 1994, we initiated a study to define the roles and relative influence of physical (hydrology, geomorphology) and biological (non-native fish population and community dynamics) factors on the sustainability of native fishes in time (10 years) and space (seven localities over 60 km of river) in this reach of free-flowing river. Initiation of the study immediately followed a 50+ year flood event in this reach of river. Although only in the third year of study, the intent of this paper is to provide baseline data and to discuss the role of these two factors in the collapse, re-establishment, and sustainability of the native fish community in a large, perennially-flowing desert river.

Methods

Study sites were located primarily on reasonable access and linear disposition over the 60 km reach. Specific location was based on channel morphology and types of habitat present (Stefferud and Rinne 1995; Rinne and Stefferud 1996). Seven sites were chosen commencing at a point 7.6 km east of Sullivan Lake and ending at the confluence of Sycamore Creek (Fig. 1). Sites were linearly separated by distances of 3.3–16.2 km.

Initially, we proposed to sample 250–300 m of stream at each site; however, exact length was dependent on habitat compl at the site. In general, a riffle-pool sequence was selected, the study site was expanded to include other significant ha types present (Rinne and Stefferud in press). Habitat types were sampled for fish with backpack DC electro-fish units, seines (3.2 mm mesh), dip-nets, and trammel nets progressing from downstream to upstream. All fish captured within a habitat type were identified to species, enumerated and returned alive to the stream. All sites were sampled in Spring; however, only the upper- (Burnt Ranch) and lower-most (Sycamore) sites were sampled in Autumn. Reduced (seven to two) sampling protocol

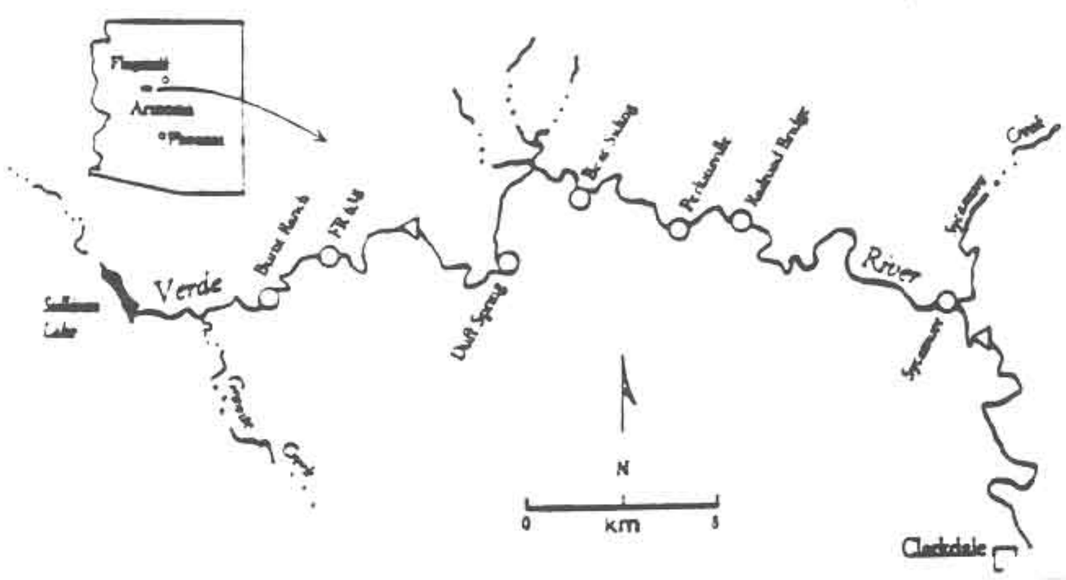

Fig. 1. The upper Verde River indicating the seven sites sampled between 1993 and 1996. Triangles indicate location of the Paulden and Clarkdale stream gauges.

Table 1. Fish community dynamics in the upper Verde River, Spring 1994–96. Values in ( ) and [ ] are percent change from previous Spring, and bold numbers are native : non-native proportions. Species abbreviations are shown and are the same for Tables 2 and 3

Species	Spring 1994	Spring 1995 (%)	Spring 1996 (%)
Native species			
Desert sucker (CACL)	2644	247 (–90)	471 (+90)
Sonoran sucker (CAIN)	1810	322 (–82)	654 (+103)
Roundtail chub (GIRO)	776	341 (–56)	259 (–24)
Longfin dace (AGCH)	1319	12 (–99)	282 (+2250)
Spikedace (MEFU)	428	72 (–83)	140 (+94)
Speckled dace (RHOS)	171	25 (–85)	68 (+172)
Total (%) [%change]	7148 **(82)**	1019 **(85)** [–86]	1874 **(85)** [+714]
Introduced Species			
Red shiner (CYLU)	1473	97 (–93)	275 (+183)
Common carp (CYCA)	23	6 (–74)	13 (+117)
Smallmouth bass (MIDO)	14	10 (–28)	32 (+220)
Green sunfish (LECY)	5	29 (+480)	6 (–79)
Yellow bullhead (AMNA)	36	32 (–11)	6 (–84)
Fathead minnow (PIPR)	6	0 (–100)	0 (—)
Total (%) [% change]	1558 **(18)**	174 **(15)** [–89]	332 **(15)** [+71]

was based on both consideration of impact to fishes and to address the potential relative influences of summer monsoon *versus* winter flood events.

RESULTS

Numbers of most fish species decreased markedly between Spring 1994 and 1995 sampling; only green sunfish increased (Table 1). Native fish decreased by between 56 and 99% (mean, 83%) non-natives by 11 to 100%. Yellow bullhead was reduced only 11% and smallmouth bass 28%. Red shiner decreased by 93%, and no fathead minnows were found in Spring 1995.

Bi-annual sampling at the upper- and lower-most sites in the river offers a more detailed picture of population dynamics (Table 2). All native species, except roundtail chub, declined from Spring 1994 to Autumn 1994 at the Burnt Ranch site, decreased further by Spring 1995 before increasing in Autumn 1995 and Spring 1996. Most non-native species varied little between samples. The introduced red shiner population at Burnt Ranch held stable between Spring and Autumn 1994 sampling and then declined markedly (>80%) by Spring 1995 only to then increase markedly (95%) by Autumn 1995. By comparison, at the Sycamore site, red shiner increased over 100-fold between Spring and Autumn 1994 only to collapse (-99%) to very low population levels in 1995 and 1996. At Sycamore, common carp numbers were low from Spring 1994 to Spring 1996. Similarly, smallmouth bass numbers remained low during all sample periods, disappeared at Sycamore in Spring 1995, only to increase slightly by Autumn 1995 at this site. Green sunfish were absent at these two sites in 1994, increasing at the Burnt Ranch site by Autumn 1995. Numbers of yellow bullhead were generally low and declined steadily from Spring 1994 to Spring 1995 before increasing in Autumn 1995. Fathead minnows were essentially absent from all sampling.

At all seven sites, native fishes predominated (82 to 85%) in numbers over the non-native species (15 to 18%) (Table 1; Fig. 2). However, such predominance of native species was variable, comprising 54% of the fish community in Autumn 1994 and increasing to 85% over the entire study area by Spring 1995. By Autumn 1995 the native fish community had increased to comprise 88% of the total fish community. Fish population data collected in an independent study of the Verde River in 1986 (USFWS 1989) indicated that native species comprised 88% of the fish community (Table 3). Sampling by the Arizona Game and Fish Department immediately after the 50+year flood event in Spring 1993 (Fig. 3) indicated natives were the dominant component (96%) of the fish community by Autumn 1993 (Table 3).

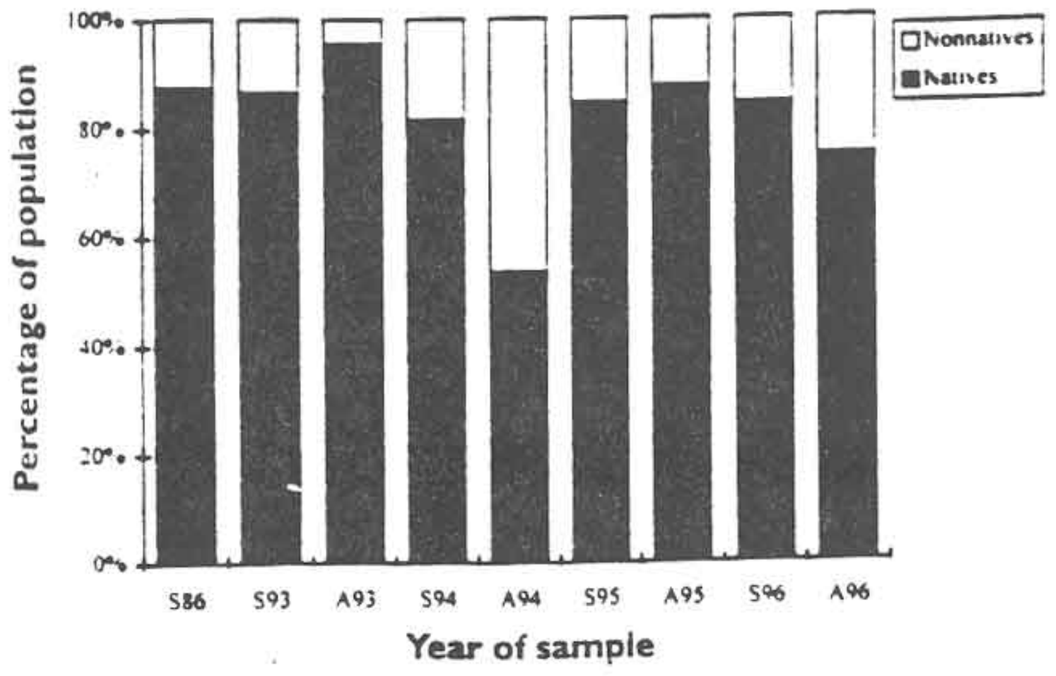

Fig. 2. Proportional numbers of native to non-native species of fishes in the upper Verde River, 1986–1996. Ratios for 1993 through 1995 are for Spring (S) and autumn (A), respectively.

Table 2. Fish community dynamics based on Spring 1994, Autumn 1994, Spring 1995, Autumn 1995, and Spring 1996 sampling at Burnt Ranch (BR) and Sycamore Creek (SC) study sites. The total number at the two sites is indicated. Order of species as in Table 1

	Spring 94			Autumn 94			Spring 95		
Species	BR	SC	Total	BR	SC	Total	BR	SC	Total
Native species									
CACL	339	379	718	31	93	124	15	29	44
CAIN	278	223	551	214	25	239	60	37	97
GIRO	15	165	180	50	17	67	3	104	107
AGCH	1072	1	1073	94	0	94	0	0	0
MEFU	257	92	349	93	0	93	33	17	50
RHOS	0	19	19	0	1	1	0	0	0
Introduced species									
CYLU	39	3	42	50	395	445	7	5	12
CYCA	1	4	5	67	1	68	0	2	2
MIDO	2	3	5	2	3	5	3	0	3
LECY	0	0	0	0	0	0	0	2	2
AMNA	2	10	12	1	6	7	2	1	3
PIPR	0	0	0	5	0	5	0	0	0

	Autumn 95			Spring 96		
Species	BR	SC	Total	BC	SC	Total
Native species						
CACL	44	77	121	79	38	117
CAIN	103	93	196	92	41	133
GIRO	40	6	46	23	25	48
AGCH	397	0	397	91	1	92
MEFU	290	0	290	33	51	84
RHOS	0	12	12	0	0	0
Introduced species						
CYLU	151	7	158	88	9	97
CYCA	3	0	3	1	1	2
MIDO	0	9	9	5	0	5
LECY	7	0	7	1	0	1
AMNA	5	8	13	1	0	1
PIPR	0	0	0	0	0	0

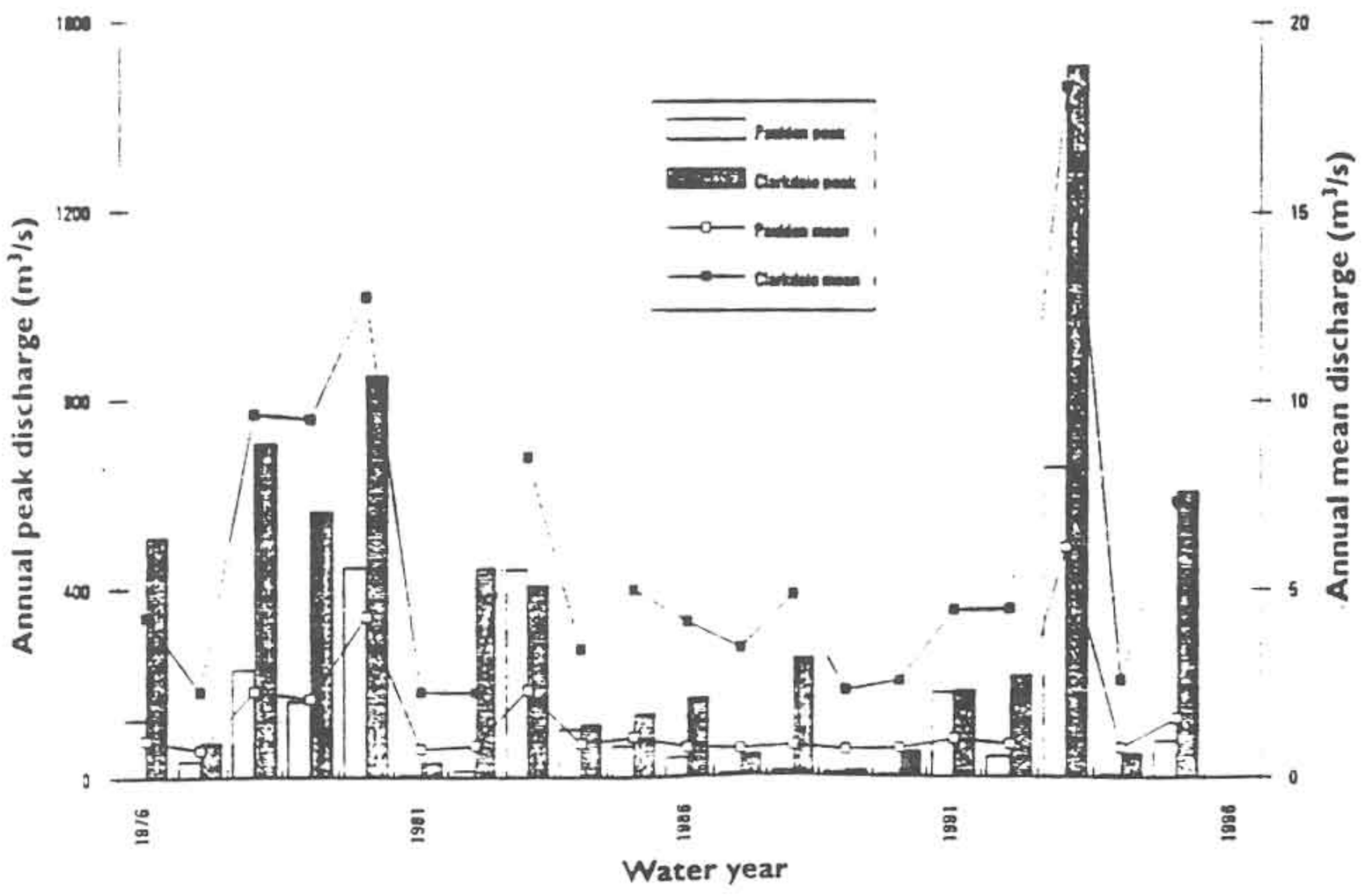

Fig. 3. Annual peak and mean annual discharge at Paulden and Clarkdale gauges during water years 1976 to 1995 (US Geological Survey records).

Table 3. Relative percentages of the fish community collected in the Verde River 1986–96. Species designation as in previous tables except for ICPU, channel catfish; species ratios (%) are indicated by season

Species	Spr 86	Spr 93	Aut 93	Spr 94	Aut 94	Spr 95	Aut 95	Spr 96
Native species								
CACL	18.7	26.2	20.9	30.4	10.8	25.7	14.7	21.3
CAIN	13.0	17.9	27.8	20.8	20.8	25.3	16.8	29.6
GIRO	11.0	1.8	1.6	8.9	5.8	26.8	4.3	11.7
AGCH	25.1	25.5	34.4	15.2	8.2	0.9	26.6	12.7
MEFU	19.1	3.7	2.5	4.9	8.1	5.7	20.1	6.3
RHOS	0.8	10.0	8.6	2.0	0.1	2.0	4.7	3.0
%	88.0	85.0	96.0	82.0	54.0	85.0	88.0	85.0
Non-native Species								
CYLU	6.6	7.4	2.9	16.9	38.8	7.6	10.6	12.4
CYCA	0.1	1.3	0.4	0.3	5.9	0.5	0.2	0.6
MIDO	0.6	1.5	0.0	0.0	0.0	2.3	0.5	0.3
AMNA	3.3	1.1	0.6	0.4	0.6	2.3	1.0	0.3
ICPU	0.4	0.4	0.0	0.1	0.0	0.2	0.0	0.0
PIPR	0.0	3.1	0.1	0.1	0.4	0.0	0.0	0.0
%	12.0	15.0	4.0	18.0	46.0	15.0	12.0	15.0

DISCUSSION

Minckley and Meffe (1987) contrasted differences in flood hydrology between southwestern arid lands and those of lowland mesic regions of the central and eastern USA. They reported that most of the annual water yield in southwestern systems was produced during high discharges in brief periods of time, whereas low discharges produced a far greater proportion of total yield from mesic systems. They suggested the differential effects of these patterns on fishes was significant to the native : non-native mix of species now present in the Southwest. Minckley and Meffe (1987) concluded that native southwestern fishes were better adapted to withstand the effects of large floods than non-native fishes. During severe floods, non-native species were either displaced or killed, whereas native species maintained position in or adjacent to channel habitats, persisted in micro-refuges, or rapidly recolonized if displaced. Based on our data from the Verde River following 50+ and 7-year flood events, it appears that floods of this magnitude negatively impact and dramatically reduce both native and non-native fish communities. The 7-year event in Winter (March) 1995 reduced the native fishes in the upper Verde by 86% and the non-native community by 89%. However, the native: non-native community composition ratio remained almost identical between years, respectively (82:18 and 85:15). Further, by Spring 1996 the native fish component had increased, on average, over 700%; non-natives, despite marked increases in red shiner and smallmouth bass, increased by an average of only 71%.

Data from work previous to our study indicated that following almost a decade (1984-92) of drought and low flows, non-natives only comprised 12% of the total fish community (Marty Jackle, US Bureau of Reclamation, pers. comm.; USFWS 1989). Following the massive flooding in 1993, non-natives were reduced to only 4% of the total fish community. Therefore, Minckley and Meffe's hypotheses on the mechanism of interactions and control of the native and non-native fish community in the Southwest may be partially correct. First, not only the non-natives are impacted by flooding, but the natives as well. Immediately post-flood, native fish rebound rapidly; non-natives also increase but more slowly, and some ratio of the two is established. The ratio appears, in part, to be dependent on the subsequent annual hydrographs, but has been consistently 85:15, native to non-native species. However, the fact that non-natives comprised only 12% of the total fish community in the late 1980s (see above) after a four-year period of low flow suggests other mechanisms may influence the native : non-native ratio in the Verde River.

Green sunfish was the only species to increase in absolute numbers in the Verde River fish community between 1994 and 1995 (5–29). We suggest it was a result of a differential magnitude of flooding over the entire study area. The flood in 1995, in contrast to that in 1993, affected mostly the reach of river downstream from Sycamore creek (i.e. the Clarkdale gauge). The majority (26–29 individuals) of the increase in green sunfish numbers occurred in the upper reaches of the river (sites 2–5). The peak discharge at these sites, as indicated by the Paulden gauge, suggests that flows were either below the threshold to negatively impact this species, or of the proper magnitude to overflow ponds on the watershed and introduce sunfish into the river, or a combination of both. Similarly, we suggest that the input of fathead minnow from watershed stock tanks may have been the reason for the appearance of this species immediately post-flood in the Spring 1993 sample at Burnt Ranch. By Autumn 1993, fatheads had disappeared and the native fish component reached 96% of the fish community.

Precipitation and stream hydrographs are stochastic and unpredictable in the Southwest and floods of significance (i.e. >400 m^3 sec^{-1}) in the upper Verde River appear to occur randomly. Cycles of flood and drought, however, are evident.

and ensuing years of low flow are now probable following the 1993 and 1995 floods. Accordingly, based on the historic hydrograph, the probability for a period of low flows from now to the year 2000 increases. Consequently, an excellent opportunity exists to study in detail native *versus* non-native fish interactions during reduced flooding and low flow conditions.

Typical of desert streams and rivers, flooding can be significant in the Verde River. Larger floods, estimated to have recurrence intervals of 50–60 years (US Geological Survey 1992), appear to 'reset' the biological and geomorphological reference baseline. That is, riparian vegetational succession was set back to a base level, channel morphology was modified, and stream-bed materials were sorted and rearranged. Flood events in 1993 (50+ year) and 1995 (7-year) altered channel morphology and aquatic habitats by eroding stream banks and restructuring and 'invigorating' substrate materials.

After each flood, total abundance of fish was reduced and the population structure of the various species altered. Based on data collected in Winter 1993 and 1995 flood events, both 50+ and 7-year return intervals reduced both native and non-native species. Nevertheless, natives still comprised 85% or more of the fish community. Following these events the natives rebound quickly in numbers in response to the restructuring or 'invigorating' of substrate materials (Mueller 1984). Spawning success and recruitment probably contribute to the quick re-establishment of native fish populations. Although non-native species begin to increase at the same time (Table 2.) their lowered numbers also would favour a rapid increase in native fish numbers because of the lack of competition and more probably predation (Minckley 1983; Rinne and Alexander 1995; Rinne 1995*b*). Further, recovery rates of non-native fish populations were variable. Red shiner were markedly reduced by the 7-year flood event, common carp were less reduced, and smallmouth bass sustained their numbers.

Long-term (>5 years) studies of native fish populations in low, desert rivers of similar or larger-size are non-existent. Several long-term studies in smaller streams are ongoing: Aravaipa Creek has a 25-year record of fish community dynamics (W L Minckley pers. comm.), and there are 10-year records of native fishes and habitat associations for several streams in the upper San Francisco and Gila River drainages in New Mexico (D L Propst pers. comm.). Whereas these existing data sets may be useful for comparing effects of floods and droughts on native species, none of the studies are in stream reaches that have a significant non-native fish component. Thus the Verde River project is unique in the Southwest and offers an excellent opportunity to test and refine current hypotheses relative to native : non-native fish interactions as influenced by drought and flooding over the long term.

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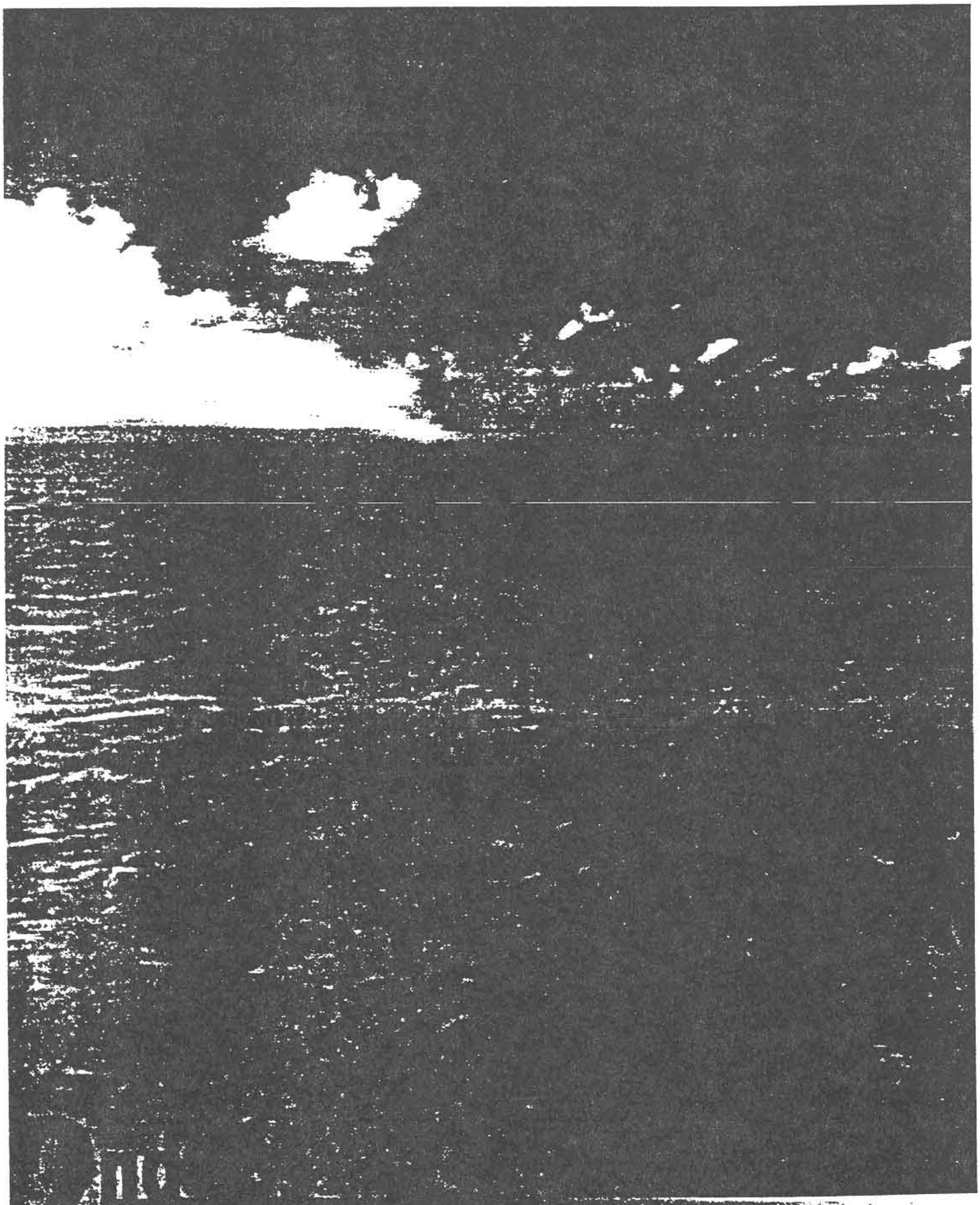

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