THE STATUS OF SPIKEDACE IN THE VERDE RIVER, 1999: IMPLICATIONS FOR MANAGEMENT AND RESEARCH

John N. Rinne

The threatened spikedace, *Meda fulgida*, was once widespread and locally abundant in streams and rivers of the Gila River Basin. It is a federally listed threatened species, occurring in four isolated stream and river systems in Arizona and New Mexico. Based on 6 years of study of the Verde River population, the spikedace has declined dramatically in abundance, even to the point of non-detection in samples since 1997. Calculated probabilities suggest between 8 and 9 chances out of 10 that the species is extirpated from the upper Verde River. Based on current data, river hydrograph and nonnative fish play interactive roles in this decline. Complicating determination of relationships and causal factors has been removal of livestock grazing from the Verde River riparian stream corridor and the resulting changes in riparian stream habitat.

From an intrastream perspective, monitoring for spikedace on the upper Verde River should be intensified. In the event of reappearance, local experimental suppression or reduction of nonnative fishes in these reaches should be considered to observe the spikedace and native fish community response. Also, refugia streams should be identified and evaluated, culture techniques should be developed, and priorities for research established. One suggested research opportunity is comparative studies with the upper Gila River, New Mexico, to refine our understanding of the relationships and interactions of flow regimes, native-nonnative fish abundance, and land-use activities.

Verde River Spikedace Population

The upper Verde River (upstream of Sycamore Creek) is a free-flowing stream with low baseflows (0.57 m^3/sec), only one perennial tributary (Granite Creek), and periodic extreme flood events (Stefferud and Rinne 1995). Although adapted to the vagaries of southwestern stream dynamics, over the past 6 years spikedace populations have appeared to be affected dramatically by natural variations in the Verde River hydrograph (i.e. alternating floods and drought; Stefferud and Rinne 1995; Rinne and Stefferud 1997). In addition, introduced nonnative fishes such as red shiner (*Cyprinella lutrensis*; Rinne 1991; Douglas et al. 1994) and larger predatory species such as smallmouth bass (*Micropterus dolomieui*), green sunfish (*Lepomis cyanellus*), and yellow bullhead (*Ictalurus natalis*) appear to have negatively affected the species (Rinne 1991; Stefferud and Rinne 1995) through a proportional increase in the total fish community.

In addition, livestock grazing has been suggested to negatively impact spikedace habitats and abundance. Notwithstanding, no reports or published accounts are available that document the nature and extent of this impact in the upper Verde River or elsewhere in southwestern riparian stream systems. The only information implicating this land-use activity as negatively affecting spikedace habitat and populations was a draft biological opinion (administratively withdrawn) on one grazing allotment on the upper Verde River. In general, information is lacking on the relationships between native southwestern cypriniform fishes and livestock grazing (Rinne 1999).

The primary objectives of this paper are threefold: (a) Examine the current status of the spikedace based on temporal-spatial distribution and abundance in the upper Verde River. (b) Evaluate and discuss factors that may have affected the current status of the species in the upper Verde River. (c) Make short- and long-term recommendations for management and research that may aid in both sustaining and enhancing this threatened species of native minnow in the upper Verde River.

USDA Forest Service Rocky Mountain Research Station, Flagstaff, AZ 86001

Description and Biology

The spikedace is a slender, laterally compressed cyprinid. The dorsal surface is typically olive gray to brown, often mottled, the sides are usually silvery, and the ventral region whitened. Males become golden on their dorsal and lateral surfaces during breeding. The basic life history of the species has been studied primarily in one stream in Arizona—Aravaipa Creek (Barber and Minckley 1966, 1983; Barber et al. 1970; Minckley 1981; Turner and Tafanelli 1983; Rinne and Kroeger 1988). In addition, Anderson (1978), Propst et al. (1986), and Propst and Bestgen (1986) have studied the biology of the species in the Gila-Cliff reach of the mainstream Gila River in New Mexico. However, most of the information collected on the species has been from survey and monitoring activities to assess the distribution and abundance of the species in time and space (LaBounty and Minckley 1973; Anderson and Turner 1977; Barrett et al. 1985; Propst et al. 1986) and to provide limited information on the biology of the species.

Spikedace spawn in the spring and early summer (April to June), and are principally dependent upon streamflow and attendant water temperature, normally varying in time and space. In early March, 1999, extreme coloration of males and gravid females were noted in the Gila-Cliff valley of New Mexico (personal field observations). Eggs are expelled in the water column and are adhesive when fertilized, adhering to the substrates where spawning occurs. Sand to gravel-pebble substrates have been reported where reproductively ready individuals (i.e. based on coloration and gravidity) have been collected in the upper Verde River (Neary et al. 1996), Aravaipa Creek (Barber et al. 1970), and the upper Gila River, New Mexico (Propst et al. 1986).

Historic Distribution and Current Status of Spikedace

The spikedace, *Meda fulgida*, is a diminutive, short-lived, stream-dwelling minnow endemic to the Gila River Basin of Arizona and New Mexico (Minckley 1973; Miller and Hubbs 1960). Although once widespread in the Gila River Basin (Rhode 1980; Propst et al. 1986), the spikedace is currently federally listed as a threatened species (U.S. Fish and Wildlife Service 1986) and presently occurs only at intermediate elevations (1070–1830 m) of the upper Gila River in southwestern New Mexico (Propst et al. 1986; U.S. Fish and Wildlife Service 1990), Aravaipa Creek (Barber and Minckley 1966; Bettasco et al. 1995), Eagle Creek (W. L. Minckley, unpublished data), and the upper Verde River (Stefferud and Rinne 1995).

Historically, the spikedace was probably widespread and locally abundant in the Gila River Basin from low to mid-elevation reaches of the San Pedro (type locality, Miller and Hubbs 1960), Salt, Verde, Agua Fria, San Francisco, and Gila rivers. Although present at upper elevations (1525–1830 m) of these same mainstream rivers, population numbers were likely lower. Gaps in quantified temporal-spatial information such as museum collections do not permit unequivocal assessment and delineation of historic distribution. Generally, the species was common throughout the basin and likely locally abundant in preferred habitats. As with many western native cyprinids, fluctuations in both range and numbers of spikedace in response to regional environmental and climatic conditions are the norm (Minckley 1973). Another related, rare native cyprinid, the Little Colorado spinedace (*Lepidomeda vitatta*), ranges from abundant to rare in habitats of its native range and is extirpated from certain local stream systems (Minckley and Carufel 1967). For both species, extrinsic and intrinsic factors may likely be delimiting variations in range and abundance; however, specific factors have not been adequately defined.

Recent Distribution and Abundance in the Upper Verde River

Although historically present in the Verde River, the spikedace was not re-discovered in samples until the early 1970s from the mouth of Sycamore Creek (Anonymous 1974). Large numbers of spikedace were collected by the U.S. Bureau of Reclamation in the mid 1980s in the upper Verde while examining instream flow needs of native fishes (U.S. Fish and Wildlife Service 1989). Spikedace were common in samples and comprised up to 11 percent of the native fish fauna.

The Rocky Mountain Research Station, Flagstaff Arizona, commenced study of fish populations in the upper Verde in 1994 following major flooding (75-year recurrence event) in the winter of 1992–93 (Stefferud and Rinne 1995). Spikedace were most abundant in the most upstream reaches of the upper Verde in 1994 (Table 1; Stefferud and Rinne 1995). Fewer were collected downstream at the Perkinsville and Black Bridge sites and at the mouth of Sycamore Creek. A reduced level of flooding (10-year recurrence event) occurred again in March 1995. Spikedace populations pulsed once

Table 1. Fish community composition at seven sampling sites in the upper Verde River, 1994–1999.

	1994	1995	1996	1997	1998	1999
NATIVE SPECIES						
Longfin dace	1319	12	282	21	13	2
Desert sucker	2644	328	471	231	126	167
Sonora sucker	1810	322	654	240	125	118
Roundtail chub	776	341	259	50	64	25
Spikedace	428	72	140	0	0	0
Speckled dace	171	25	68	1	12	2
NONNATIVE SPECIES						
Yellow bullhead	31	29	9	40	33	15
Common carp	23	6	13	19	9	4
Red shiner	1473	97	275	2238	1047	545
Channel catfish	5	2	0	1	0	0
Mosquito fish	0	0	0	3	6	59
Flathead catfish	0	1	1	1	1	0
Green sunfish	4	29	6	8	21	49
Smallmouth bass	14	10	32	35	66	104
Fathead minnow	7	0	0	0	0	0
Total fishes	8750	1274	2210	2288	1523	1090
Percent native	82	86	85	19	22	29

more in 1996 (Rinne and Stefferud 1997), only to decline in subsequent sampling to complete absence from samples at the seven established sites by spring 1997 (Rinne 1998). Additional sampling along the entire course of the upper Verde in 1997 and 1998 also indicated that the spikedace population had declined markedly. In the spring of 1999, sampling in the most upstream reaches of the Verde (Bear Siding upstream) again indicated no spikedace (unpublished data). Based on these data, the species presently is very rare in the upper Verde.

To assess and address more specifically the rarity and probability of extirpation of spikedace from the upper Verde, the approach of Grogan and Boreman (1998) was applied. This methodology uses years and last year of collection versus total years of surveys to arrive at a probability that a species, based on historic collection, is extirpated. A probability (P) of 0.873 that spikedace are gone from the Verde was calculated using U.S. Forest Service data since 1994 and a last date of collection of 1997. A more robust data set from Arizona State University that commences with collections in 1980 and has a last date of collection of 1997 resulted in a lower, but similar probability (P = 0.832) of extirpation of this species from the upper Verde River, above Sycamore Creek.

Habitat

Spikedace occupy lentic habitats of varying depths (<1 m) over gravel and pebble substrates. The species is often found in greater abundance in shear zones where two riffle areas converge to form eddying currents (Rinne 1985, 1991, 1992). In larger rivers, the species is most common in riffle areas of moderate velocities (30–50 cm/sec) and gradient (0.5–1.0%; Neary et al. 1996; Rinne unpublished data) over pebble-cobble and boulder substrates. The latter substrate frequently provides alteration or reduction of current velocity and creates eddying currents that appear to be one of the species' preferred habitats. Habitat associations may vary in both time and space as well as ontogenically (Anderson 1978; Rinne 1985; Propst et al. 1986; Propst and Bestgen 1986; Rinne and Kroeger 1988; Rinne 1991).

River Hydrograph

A study of the fish community of the upper Verde River relative to abiotic and biotic factors was conducted in 1997–98 by the U.S. Forest Service, Rocky Mountain Station with Arizona Heritage funding (Rinne 1998). The primary objective of the study was to determine the relative influence of the hydrograph and introduced fishes in delimiting the relative native to nonnative composition of the total fish community. The results of the 3 years of study (Rinne and Stefferud 1997) show that native fishes respond positively to flooding. Further, Rinne (1998) reported that the hydrograph and the lack of flooding over the entire Verde River have enhanced nonnative over native fishes. By spring 1998, after 3 years (1996–98) of no significant (i.e. greater than bankfull) flow events, the relative abundance of native fishes (>70%) was reduced to the extent that nonnative fishes comprised this same relative percentage of the total fish community. Rinne (1998) concluded that flooding was essential for sustaining a native fish fauna in a river system such as the upper Verde with nonnative fishes present.

Spikedace populations paralleled the overall population trend of native fishes in the upper Verde River (Rinne et al. 1998). The species was common in samples at four of the seven established sampling sites in the spring of 1994, rare by the spring of 1996, and absent from samples in spring of 1997 (Table 1). Therefore, flow regimes appear to be important to essential for sustaining populations of spikedace and other native species, especially in the presence of nonnative fishes.

Nonnative Fishes

Although Rinne and Stefferud (1997) concluded after 3 years of sampling that the river hydrograph was more influential than nonnative fishes for sustaining a native fish component in the upper Verde, it appears that the interaction of the two factors combine to legislate the relative native to nonnative composition of the overall fish community. That is, the lack of any significant flooding and sustained base flow since 1996 has resulted in nonnative fishes increasing significantly to comprise the majority (>70%) of the fish community (Table 1). Accordingly, in the absence of significant flow events, nonnative fish species have become dominant. Only with the advent of flooding of at least the 1995 level (5+ year recurrence) can this hypothesized relationship of hydrograph and nonnative fish abundance be more completely defined.

In summary, if our studies had been conducted only during 1994–1996, flooding could be readily defended as the controlling factor in delimiting spikedace populations in the upper Verde. By contrast, studies during only 1997–1999 could lead to the conclusion that nonnative fishes are the controlling factor in delimiting spikedace numbers in the upper Verde. These data emphasize the importance of continual monitoring up to and following the next flood event (10-year recurrence or greater).

Grazing Management Changes, Verde River Corridor

Changes in grazing management on the river corridor are confounding the question of which factor (i.e. flooding or nonnative fishes) is most influential in determining the status of all native fishes, and specifically spikedace. Since the spring of 1997, and following continuous reductions in animal unit months (AUMs) over the previous decade, livestock grazing has been totally eliminated from the Verde River corridor. As a result, riparian vegetation diversity, density, and biomass have increased dramatically on the river corridor (Al Medina, unpublished data; Figure 1). Neither native fishes nor spikedace have so far responded positively to this change in management (Figure 1), although nonnative fishes have paralleled the increases in vegetation both on streambanks and within aquatic habitats. These relationships or correlations need additional study.

Conversely, there has been an inverse relationship between decreases in native fish populations, livestock numbers, and flooding, and corresponding increases in nonnative fishes (Figure 1). There are clearly several factors interacting here (i.e. fishes, livestock, flooding, and vegetation). Lack of flooding has apparently been favorable to vegetation and nonnative fishes and unfavorable to native fishes, including the spikedace. The dramatic increase in vegetation since 1997 due to the removal of grazing parallels an increase in nonnative fish abundance. The marked increase in two predatory nonnatives, smallmouth bass and green sunfish (Table 1), may be a response, in part, to greater instream cover associated with increased nearstream and streambank vegetation density. These correlations and relationships could be coincidental; they have not yet been adequately studied or statistically tested.

Discussion

Notwithstanding known cycles of abundance (Minckley 1981; Propst et al. 1986), the current status of the spikedace in the upper Verde River is perilous at best. They have declined in just a few years from 6 or 7 percent (1994 and 1996, respectively) of the native fish community to a level of non-detection. This decline coincided with an increase in base flow over the past 2 decades (Neary and Rinne 1997), but also with a period of no flooding. The combination of the predominance of nonnative fishes, the probability of entering a drought cycle, and the change in riverine habitat resulting from grazing management changes could lead to extirpation of one of only two large river populations of spikedace in the Southwest. Although statistically nonsignificant, the high probability that spikedace is extirpated from the upper Verde is cause for concern.

Of these three factors, flooding, nonnative fishes, and habitat change, only two can be addressed by management. Flood events are subject to the vagaries of the southwestern climate. Alternating cycles of drought and flood are the rule, not the exception. Data from the upper Verde River (Stefferud and Rinne 1995; Rinne and Stefferud 1997; Brouder in review) and the upper Gila River (Propst et al. 1986; Rinne et al. in press), and the conclusions of other documented effects of flooding on fishes (Minckley and Meffe 1987), show that native fish populations, including spikedace, appear to be positively correlated to flooding. In the upper Verde River, spikedace have gone from common to very rare to absent from samples in just a few years during a period with no flood events and a drought or base flow condition (Rinne and Stefferud 1997; Rinne et al. 1998).

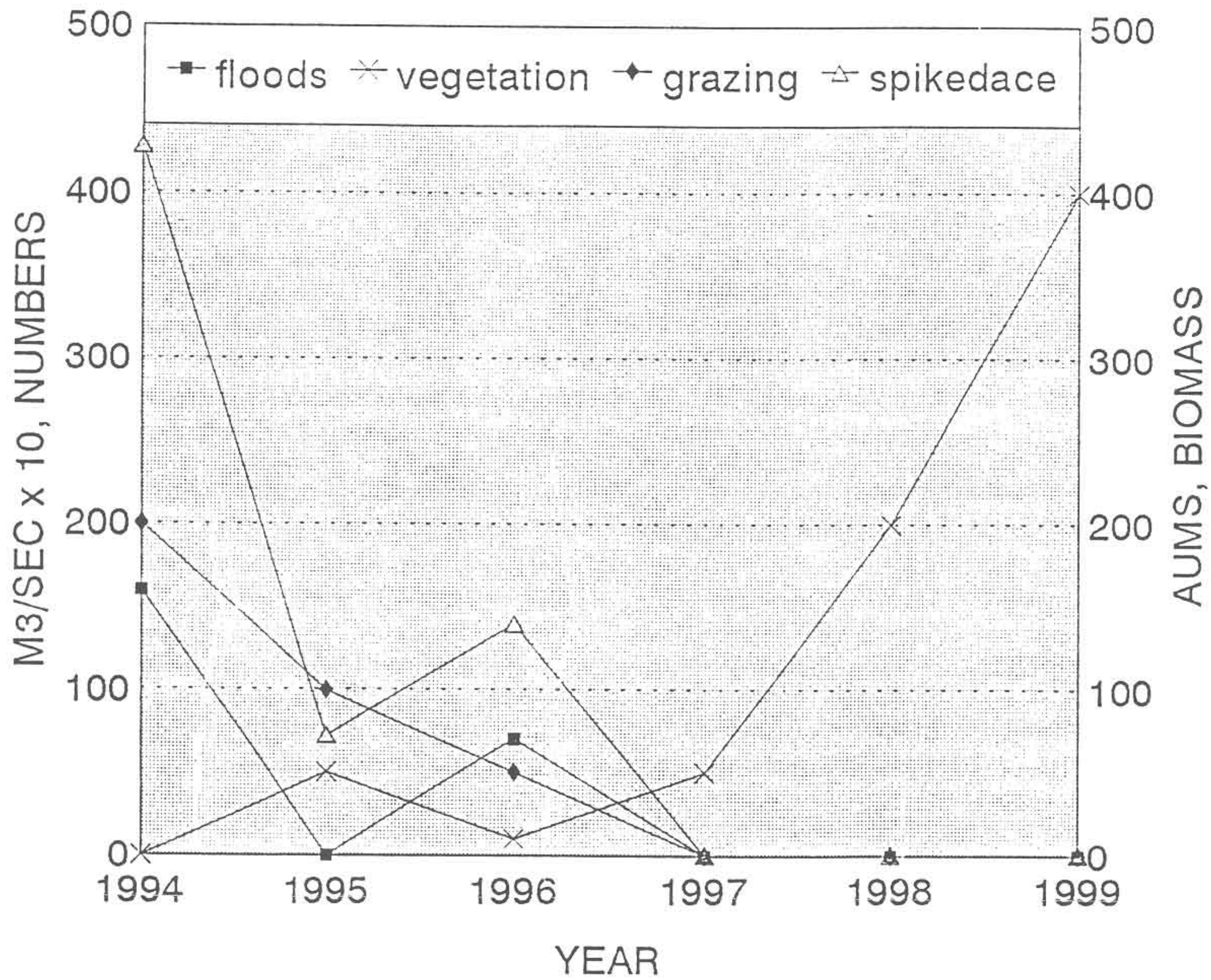

Figure 1. General trends in relationships of floods (m^3/sec x 10), grazing (AUM trend), riparian vegetation (biomass trend), and spikedace (numbers) in the upper Verde River, 1994–1999.

Of equal importance in the upper Verde, as elsewhere in the West (Minckley and Deacon 1991) and Southwest (Rinne 1994, 1997), is that nonnative fishes have consistently demonstrated a negative impact on native fishes. Whether by displacement or replacement (Douglas et al. 1994), nonnatives apparently out-compete and prey upon native species (Minckley 1983; Meffe 1985; Rinne 1995; Blinn et al. 1993). Predation may indeed be the primary factor of replacement of native fish species by nonnatives (Marsh in press). At present, more than 70 of every 100 individual fish inhabiting the upper Verde River are nonnative. Combined with the lack of collection of spikedace for the past 2 years, this is cause for both concern and focused management by state and federal agencies.

Finally, livestock grazing is a manageable land-use activity. Anecdotally and coincidentally, livestock removal from the river in 1997 has paralleled both the lack of flooding and the decline of spikedace in the upper river (Figure 1). The indirect impact of livestock grazing on the watershed of the upper Verde presents a possible threat to spikedace sustainability. Although not discountable, the relative impact of livestock grazing on the watershed, when compared to the predominance of a competitive and predatory nonnative fish fauna in the upper Verde River, becomes a moot point in the near term for management alternatives.

Complete removal of nonnative fishes from the upper Verde, which is also a highly improbable near-term management alternative, should

very likely be the highest priority for management at present. Although immediate, complete removal of nonnative fishes is not administratively or logistically feasible, efforts to suppress or reduce their abundance should be considered as a timely management alternative. Waiting for the next flood event to reduce nonnatives as a management alternative is not an appropriate management strategy because of the time factor, the current status of the spikedace, and the predominance of nonnative fishes in the upper Verde River. However, synchronizing future nonnative fish suppression with natural reduction in numbers by flooding (Rinne and Stefferud 1997) may have merit as a viable management alternative.

Flooding is a natural disturbance that may indeed be a prerequisite for native fish sustainability in the presence of nonnative fishes. Historically, floods and droughts have caused extreme fluctuations in the numbers and ranges of native fish, including the spikedace. After reduction of the entire fish community, recolonization from refugia reaches (Sedell et al. 1990) has been possible historically in the absence of nonnative fishes and without many of the current mainstream dams and their alteration of flow regimes (Rinne 1994, 1995) and removal of fluvial connectivity.

The upper Verde has no significant mainstream impoundments or diversions, only a nonnative fish assemblage. Further, with recent low drought flows and the removal of livestock, the riparian stream ecosystem of the upper Verde has become stabilized for the near term. Such stable aquatic conditions appear to be favorable to nonnative fishes in this river system. Without nonnatives, the stability characterized by adequate and perhaps enhanced baseflow (Neary and Rinne 1997) and the increase in instream and streambank vegetation, even in the absence of floods, would probably be favorable to native fishes. Nevertheless, until the next significant peak flow event occurs, nonnative fishes will continue to impact the spikedace—an impact that could result in extirpation of this threatened species from the Verde River system.

Conclusions and Management Recommendations

Currently, the spikedace is markedly reduced in population size in the upper Verde. Calculated probabilities suggest between 8 and 9 chances out of 10 that the species is gone from the upper Verde River. Even if a residual population exists, and even if spawning does occur annually, the probability of survival of young-of-year spikedace is low given the excessive numbers of nonnative, predatory species present in the river (Stefferud and Rinne 1995, Table 1). One appropriate management alternative might be to immediately begin suppression of nonnative fish populations in the most upstream reaches of the upper Verde. Such action could help sustain the spikedace locally (if present in future surveys) until the next flood event. Removal of grazing from the watershed or limits on sport fishes are commendable management strategies; however, both are cosmetic at best, and pale in significance to mechanical reduction in abundance of nonnative fishes, especially when coordinated with natural hydrologic reduction. Even mechanical, partial suppression of nonnative fishes is conceivably ineffective, unless instituted immediately following a significant flood event and a concomitant reduction in the total fish community (Rinne and Stefferud 1997).

Because of genetic considerations, the introduction of spikedace from other river systems cannot currently be considered a viable management alternative (Tibbets and Dowling 1996). Isolation of the spikedace in the upper Verde River from those of the Gila River and Aravaipa Creek dates at least to completion of the Horseshoe and Bartlett dams on the Verde in the 1930s. Analyses of spikedace populations in the Gila River system (Tibbets and Dowling 1996) suggest that the population of spikedace in the upper Verde is genetically distinct. Accordingly, no translocation of spikedace should occur unless there is unequivocal evidence that the spikedace has been extirpated from the upper Verde River drainage. At what point do we reach an unequivocal conclusion—at extirpation? Despite extensive sampling in Eagle Creek, Arizona, spikedace were not collected for more than 2 decades, but the species was recently confirmed with great effort at a disturbed road-crossing site in this stream. However, none of these situations justify adopting a no-action, non-progressive, or pro-active approach to management.

Three major additional management strategies should be strongly considered and instituted immediately. The first is intensification of survey and monitoring activity to search for spikedace. Second is locating and evaluating possible refugia streams in the Verde Basin. Last, culture techniques must be developed immediately for the species. These last two items should be in place when the next flood event occurs, which is presumably when spikedace will reappear in samples

and become abundant enough to facilitate transfer to a hatchery for propagation or stocking into identified refugia streams.

A study of the role of disturbances in native fish ecology, and spikedace specifically, also should be initiated. Comparisons should be made of successional responses of spikedace in the upper Verde with other spikedace (and native fish) populations. Following significant flooding of the Gila River resulting from Hurricane Linda in September of 1997, spikedace are currently (spring of 1999) one of the most common species of fish in the upper Gila River system (37% of the native fish community; Rinne et al. in press). A few spikedace were collected in spring-summer of 1998 in this same river. Further, nonnative fish are scarce in the upper Gila. Of more than 6000 individual fish collected between March and July of 1999 in this river system, only 10 percent were nonnatives (Rinne et al. in press).

The opportunity therefore exists to examine the population dynamics of spikedace and several other Gila River native species, such as longfin dace (*Agosia chrysogaster*), desert sucker (*Catostomus clarki*), Sonora sucker (*Catostomus insignis*), roundtail chub (*Gila robusta*), and loach minnow (*Rhinichthys* [*Tiaroga*] *cobitis*), relative to the hydrograph and in the absence of or reduction in nonnative fishes. A parallel study on the upper Verde could be conducted that examines the response of native fishes relative to mechanical reduction or suppression of nonnative fish abundance. There is a window of opportunity to examine flooding disturbance and fish community structure and succession from two extant scenarios: the abundance of natives and especially spikedace combined with a few nonnatives in the Gila River and Aravaipa Creek; and the abundance of nonnatives, the presence of a few natives, and an apparent lack of spikedace in the Verde River.

Finally, the study effort should be a coordinated regional approach to understanding the problem of floods and fish community composition, not that of a single river system or jurisdiction. There is an excellent opportunity for collaboration among Forest Service management and researchers and state agencies to understand the interrelationships of flooding, disturbance, and native-nonnative fish community structure and succession in the Southwest. The rarity of spikedace in the upper Verde River, its abundance in the upper Gila River, the abundance of nonnative fishes in the former river and scarcity in the latter, and the short-lived nature of the spikedace, are all urgent reasons for a coordinated regional management-research approach to address sustaining the spikedace in southwestern streams and rivers.

Literature Cited

Anderson, R. M. 1978. The distribution and aspects of the life history of *Meda fulgida* in New Mexico. Master's thesis, New Mexico State University, Las Cruces. 62 pp.

Anderson, R. M., and P. R. Turner. 1977. Stream survey of the San Francisco River. Final report, contract number 516-65-24. New Mexico Department of Game and Fish, Santa Fe. 20 pp.

Anonymous, 1974. Cyprinidae, *Meda fulgida* Girard, spikedace. Arizona Game and Fish Department, Phoenix. 4 pp, map.

Barber, W. E., and W. L. Minckley. 1966. Fishes of Aravaipa Creek, Graham and Pinal counties, Arizona. Southwestern Nat. 11(3):313–324.

Barber, W. E., and W. L. Minckley. 1983. Feeding ecology of a southwestern cyprinid fish, the spikedace, *Meda fulgida* Girard. Southwestern Nat. 28(1):33–40.

Barber, W. E., D. C. Williams, and W. L. Minckley. 1970. Biology of the Gila spikedace, *Meda fulgida*, in Arizona. Copeia 1970 (1):9–18.

Barrett, P. J., W. G. Kepner, J. E. Burton, and M. D. Jakle. 1985. Upper Verde River aquatic study. Draft report, U.S. Fish and Wildlife Service, Phoenix, AZ. 17 pp.

Bettasco, R. H., D. B. Dorum, and K. L. Young. 1995. Results of the 1992–1994 Aravaipa Creek monitoring program. Technical Report 73, Arizona Game and Fish Department, Phoenix. 84 pp.

Blinn, D. W., C. Runck, A. Clark, and J. N. Rinne. 1993. Effects of rainbow trout predation on Little Colorado River spinedace. Trans. Amer. Fish. Soc. 122(1): 139–143.

Brouder, M. J. In review. Flooding and recruitment of *Gila robusta* in a southwestern river.

Douglas, M. E., P. C. Marsh, and W. L. Minckley. 1994. Indigenous fishes of western North America and the hypothesis of competitive displacement: *Meda fulgida* (Cyprinidae) as a case study. Copeia 1994 (1):9–19.

Grogan, C. S., and J. Boreman. 1998. Estimating the probability that historic populations of fish species are extirpated. North Amer. J. Fish. Management 18:522–529.

LaBounty, J. F., and W. L. Minckley. 1973. Native fishes of the upper Gila River system, New Mexico. In A Symposium on Rare and Endangered Wildlife of the Southwestern United Sates, pp. 134–146. New Mexico Department of Game and Fish, Santa Fe.

Marsh, P. C. In press. Immiscibility of native and nonnative fishes. In A Symposium and Workshop on Restoring Native Fish to the Lower Colorado River: Interactions of Native and Nonnative Fishes, edited by S. Leon, P. Stine, and C. Springer. July 13–14, 1999, Las Vegas, Nevada.

Meffe, G. K. 1985. Predation and species replacement in American southwestern fishes: A case study. Southwestern Nat. 30(2):173–187.

Miller, R. R., and C. L. Hubbs. 1960. The spiny-rayed cyprinid fishes (Plagopterini) of the Colorado River system in western North America. Misc. Publ. Mus. Zool. Univ. of Michigan 115:1–5.

Minckley, W. L. 1973. Fishes of Arizona. Arizona Game and Fish Department, Phoenix. 293 pp.

Minckley, W. L. 1981. Ecological studies of Aravaipa Creek, central Arizona, relative to past, present and future uses. Final report, U.S. Bureau of Land Management, YA-512-CT6-98. Safford, Arizona. 362 pp.

Minckley, W. L. 1983. Status of the razorback sucker, *Xyrauchen texanus* (Abbott), in the lower Colorado River basin. Southwestern Nat. 28:165–187.

Minckley, W. L., and L. H. Carufel. 1967. The Little Colorado spinedace, *Lepidomeda vitatta*, in Arizona. Southwestern Naturalist 13(3):291–302.

Minckley, W. L., and G. K. Meffe. 1987. Differential selection by flood in stream-fish communities of the arid American Southwest. In Evolutionary and Community Ecology of North American Stream Fishes, edited by W. J. Matthews and D. E. Heins, pp. 93–104. University of Oklahoma Press, Norman.

Minckley, W. L., and J. E. Deacon. 1991. Battle against extinction: Native fish management in the American West. University of Arizona Press, Tucson. 517 pp.

Neary, D. G., and J. N. Rinne. 1997. Baseflow trends in the upper Verde River relative to fish habitat requirements. Hydrology and Water Resources in Arizona 27:57–63.

Neary, A. P., J. N. Rinne, and D. G. Neary. 1996. Physical habitat use by spikedace in the upper Verde River, Arizona. Hydrology and Water Resources in Arizona and the Southwest 26:23–28.

Propst, D. L., and K. R. Bestgen. 1986. Microhabitat utilization patterns of spikedace in New Mexico. Proc. Desert Fishes Council 18 (1986):242–243.

Propst, D. L., K. R. Bestgen, and C. W. Painter. 1986. Distribution, status, and biology of the spikedace (*Meda fulgida*) in New Mexico. Endangered Species Report 15, pp. 1–93. U.S. Fish and Wildlife Service, Albuquerque, New Mexico.

Rhode, F. C. 1980. *Meda fulgida* Girard, spikedace. In Atlas of North American Freshwater Fishes, edited by D. S. Lee, C. R. Gilbert, C. H. Hocutt, R. E. Jenkins, D. E. McAllister, and J. R. Stauffer, Jr., p. 206. North Carolina State Museum of Natural History, Raleigh.

Rinne, J. N. 1985. Physical habitat evaluation of small stream fishes: Point or transect, observation or capture methodologies. J. Freshwater Ecol. 3(1):121–131.

Rinne, J. N. 1991. Physical habitat use by spikedace, *Meda fulgida*, in southwestern desert streams with probable habitat competition by red shiner, *Notropis lutrensis* (Pisces: Cyprinidae). Southwest Nat. 36(1): 7–13.

Rinne, J. N. 1992. Physical habitat utilization of fish in a Sonoran Desert stream, Arizona, southwestern United States. Ecol. Freshwater Fishes 1:1–8.

Rinne, J. N. 1994. Declining southwestern aquatic habitats and fishes: Are they sustainable? Sustainability Symposium, USDA Forest Service General Technical Report RM-247, pp. 256–265. Flagstaff, AZ.

Rinne, J. N. 1995. Interactions of predation and hydrology on native southwestern fishes: Little Colorado spinedace in Nutrioso Creek, Arizona. Hydrology and Water Resources in Arizona and the Southwest 22–25:33–38.

Rinne, J. N. 1997. The effects of introduced fishes on native fishes: Arizona, southwestern United States. In Protection of Aquatic Diversity, Proceedings of the World Fisheries Conference, Theme 3, edited by D. P. Philipp, J. M. Epifanio, J. E. Marsten, J. E. Claussen, and R. J. Wolotira, pp. 149–159. Oxford & IBH, New Delhi.

Rinne, J. N. 1998. Verde River native fishes: The impacts of abiotic and biotic factors. Final report to Heritage Project I96002. Arizona Game and Fish Department, Phoenix. 22 pp., appendices.

Rinne, J. N. 1999. Fish and grazing relationships: The facts and some pleas. Fisheries 24(8):12–21.

Rinne, J. N., and E. Kroeger. 1988. Physical habitat used by spikedace, *Meda fulgida*, in Aravaipa Creek, Arizona. Proc. West. Assoc. Fish Wildl. Agen. 68:282–290.

Rinne, J. N., and J. A. Stefferud. 1997. Factors contributing to collapse yet maintenance of a native fish community in the desert Southwest (USA). In Developing and Sustaining World Fisheries Resources: The State of Science and Management, edited by D. A Hancock, D. C. Smith, A. Grant, and J. P. Beaumer, pp. 157–162. Second World Fish Congress, Brisbane, Australia, July 28–August 2, 1996.

Rinne, J. N, J. A. Stefferud, A. Clark, and P. Sponholtz. 1998. Fish community structure in the Verde River, Arizona, 1975–1997. Hydrology and Water Resources in Arizona and the Southwest 28:75–80.

Rinne, J. N, P. Boucher, D. Miller, R. Pope, A. Telles, T. Myers, B. Deason, and W. Merhage. In press (1999). Comparative fish community structure in two southwestern desert rivers. In A Symposium and Workshop on Restoring Native Fish to the Lower Colorado River: Interactions of Native and Nonnative Fishes, edited by S. Leon, P. Stine, and C. Springer. July 13–14, 1999, Las Vegas, Nevada.

Sedell, J. R., G. H. Reeves, F. R. Hauer, J. A. Stanford, and C. P. Hawkins. 1990. Role of refugia in recovery from disturbances: Modern fragmented and disconnected river systems. Environ. Manag. 14:711–724.

Stefferud J. A., and J. N. Rinne. 1995. Preliminary observations on the sustainability of fishes in a desert river: The roles of streamflow and introduced fishes. Hydrology and Water Resources in Arizona and the Southwest 22–25:26–32.

Tibbets, C. A., and T. E. Dowling. 1996. Effects of intrinsic and extrinsic factors on population fragmentation in three species of North American minnows (Teleostei: Cyprinidae). Evolution 50(3):1280–1292.

Turner, P. R., and R. J. Tafanelli. 1983. Evaluation of the instream flow requirements of the native fishes of Aravaipa Creek, Arizona by the incremental methodology. Final report, U.S. Fish and Wildlife Service, Albuquerque, New Mexico. 118 pp.

U.S. Fish and Wildlife Service. 1986. Endangered and threatened wildlife and plants; determination of threatened status for the spikedace. Federal Register 51 (126):3237679–243781. July 1, 1986.

U.S. Fish and Wildlife Service. 1989. Instream flow requirements of fishes of the Verde River system. U.S. Fish and Wildlife Service, Phoenix, AZ. 131 pp.

U.S. Fish and Wildlife Service. 1990. Spikedace Recovery Plan. Albuquerque, New Mexico. 38 pp.