SRP12341

SPIKEDACE (*Meda fulgida*) AND LOACH MINNOW (*Tiaroga cobitig*) RELATIVE TO INTRODUCED RED SHINER (*Cyprinella lutrensis*)

by

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FINAL REPORT

to

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31 August 1989

DESCRIPTION OF THE PROJECT

This final report is submitted in fulfillment of a 30-month contract between Arizona State University and Arizona Game and Fish Department (AZGF), New Mexico Department of Game and Fish (NMGF), and U.S. Fish and Wildlife Service (FWS) for investigation of ecological interactions between native and exotic fishes in Arizona and New Mexico ("spikedace and loach minnow study").

Research focused on selected aspects of potential interaction between two native species, spikedace and loach minnow, and introduced red shiner, in an attempt to determine the role, if any, such relationships might play in explaining declines or extirpations of the natives. The approach was comparative in searching for differences in resource use (habitat and food) of wild populations at different localities and in differing combinations of native and non-native fishes. Experimental studies under controlled artificial conditions were designed to complement comparative analyses of descriptive field data in attempt to examine the hypothesis that competition is a mechanism whereby red shiner might replace spikedace.

The report is presented in eight sections: 1) introductions to the spikedace, loach minnow, and red shiner; 2) field study sites, sampling protocols, and analytical procedures; 3) physical characteristics of study streams; 4) studies of loach minnow; 5) habitat interrelations between wild populations of spikedace and red shiner; 6) comparative analysis of food use among wild populations of spikedace and red shiner; 7) habitat relations of spikedace and red shiner in an artificial system; and 8) summary and conclusions. Section 1 is derived in part from FWS (1988a and 1988b), Sections 2 to 5 include and expand on results of the first year of field research (Douglas et al. 1988), Sections 6 and 7 report results of laboratory and experimental studies conducted during the second and final year of the project, and Section 8 integrates findings for all aspects of the study. Comprehensive treatment of spikedace and red shiner food habits, including analyses of benthic and drifting macroinvertebrates, is being performed by F. J. Abarca as part of requirements for a Master of Science Degree at Arizona State University (ASU); that component of the study will be available after finalization of the thesis.

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1. INTRODUCTIONS TO SPIKEDACE, LOACH MINNOW, AND RED SHINER

Spikedace

The spikedace (Meda fulgida) is a small, stream-dwelling fish endemic to the Gila River system of AZ and NM, USA (Miller and Hubbs 1960, Minckley 1973); the species also likely occurred in the past in the San Pedro River in Sonora, Mexico (Miller and Winn 1951). Although among Southwestern stream fishes the biology of this unique, monotypic genus is relatively well known (Barber et al. 1970, Anderson 1978, Schreiber and Minckley 1981, Barber and Minckley 1983, Propst et al. 1986), substantial gaps in knowledge still exist, and its basic ecology needs further study. Once widely distributed among moderate-sized, intermediate-elevation streams in much of the Gila River system, at least upstream of Phoenix, AZ, the species is now restricted to scattered populations In relatively short stream reaches. The spikedace was apparently not considered imperiled by Miller (1961), although it had by 1937 been locally extirpated from much of the Salt River, AZ, and elsewhere. Marked reduction in its over-all range was noted by Barber and Minckley (1966), and widespread depletions were reported by Minckley (1973). Minckley (1985), Propst et al. (1986) and Rhode (1980) mapped its historic and recent distributions.

The spikedace was proposed (FWS 1985a) and subsequently listed (FWS 1986a) as a threatened species under authority of the Endangered Species Act (ESA) of 1973, as amended. Listing was justified on the basis of reductions in habitat and range due to damming, channel alteration, riparian destruction, channel downcutting, water diversion, groundwater pumping, and continued threats to its survival posed by ongoing habitat losses and non-native, predatory and competitive species (FWS 1985a). Critical habitat was initially proposed (FWS 1985a), but a subsequent rule (FWS 1986a) deferred its designation until 18 June 1987. Although that date has passed, proposed critical habitat is still in force, providing limited protection. Final designation of critical habitat is under administrative review.

The spikedace is classified by the State of AZ as a threatened species, which are those "... whose continued presence in Arizona could be in jeopardy in the near future" (AZGF 1988) and by the State of NM as a group 2 endangered species, defined as those "... whose prospects or survival and recruitment within the State are likely to be in jeopardy within the foreseeable future" (NM State Game Commission 1985). The latter listing provides protection under the NM Wildlife Conservation Act. The species is protected from take except by angling in AZ, or by specific collecting permit in both States. Neither state listing otherwise protects the fish or its the habitat. Deacon et al. (1979), Williams et al. (1985, 1989), and Johnson (1987), also recognized the spikedace as imperiled.

Description.--The spikedace is a small, sleek, stream-dwelling member of the minnow family (Cyprinidae). It's following description is summarized from Girard (1857), Miller and Hubbs (1960), and Minckley (1973):

> The body is slender, almost spindle-shaped, and slightly compressed laterally. Scales are present only as

small plates deeply embedded in the skin. There are two spinose rays at the leading edge of the dorsal fin, the first being obviously the strongest, sharp-pointed, and nearly as long as the second. The eyes and mouth both are large. Barbels are absent. There are seven rays in the dorsal fin, and the anal fin usually has nine. Pharyngeal teeth are in two rows, with the formula 1,4-4,1.

Coloration is bright silvery on the sides of the body, with vertically-elongated, black specks. The back is olive-gray to brownish, and usually is mottled with darker pigment. The underside is white. Males in breeding condition become brightly golden or brassy, especially on the head and at the fin bases.

Distribution and Abundance, Historical.--The spikedace is endemic to the upper Gila River basin of AZ and NM, USA. It was abundant in the San Pedro River, AZ, and although never collected in that stream in Sonora, Mexico, probably occurred there also (Miller and Winn 1951). Distribution in AZ was widespread in large and moderate-sized rivers and streams, including the Gila, Salt, and Verde rivers and their major tributaries upstream of the present Phoenix Metropolitan area, and the Agua Fria, San Pedro, and San Francisco rivers systems (Minckley 1973, Rhode 1980). Populations transplanted from Aravalpa Creek into Sonolta Creek, Santa Cruz County, in 1968, and 7-Springs Wash, Maricopa County, in 1970 were extirpated (Minckley and Brooks 1985). Original distribution in NM was in both the San Francisco and Gila rivers (Koster 1957, Propst et al. 1986), including the East, Middle and West forks of the latter. There are no records of spikedace transplants in NM.

There are substantial spatial and/or temporal gaps in quantitative data from which to assess historical abundance of the spikedace. Generally, it must have been common and even locally abundant in its preferred habitats. Although suitable habitat was probably not continuous, it was widespread throughout the species' range. Like most western cyprinids, population abundances and distributions probably fluctuated in natural response to local and regional environmental conditions. Recent examples of such variations have been recorded in Aravaipa Creek, AZ (Minckley and Meffe 1987), and in the Red Rock reach of the Gila River, NM (Marsh and Propst, unpubl. data).

Present distribution.--The spikedace now occurs in AZ only in Aravaipa Creek, tributary to San Pedro River, Graham and Pinal counties, Eagle Creek, tributary to Gila River, Graham and Greenlee counties, and the upper Verde River, Yavapai County. All three streams support at least moderate-sized, self-sustaining populations in their less-disturbed reaches. The Eagle Creek population, considered 'quite small" by FWS (1986) has since been found to be substantial (Marsh et al. in press). In NM, spikedace are restricted to the mainstem Gila and its East, Middle, and West forks; a few may be encountered in lowermost reaches of perennial tributaries. Propst et al. (1986) considered only the population occupying the Cliff-Gila Valley, NM, comparable in abundance to that of earlier years; others having been substantially reduced in numbers. Undiscovered populations of spikedace may occur in places which have not been surveyed or completely inventoried, especially within the expansive, remote San Carlos Apache and Fort

Apache Indian reservations, on U.S. Forest Service lands, or in Sonora where the Gila drainage is inadequately studied.

Both distribution and abundance of spikedace have been dramatically reduced in the past century, with major changes occurring in recent decades (Minckley 1973, Propst et al. 1986). Major rivers and streams, such as lower reaches of the Gila, Salt, and Verde rivers that once supported substantial populations, are no longer occupied, and remaining populations in tributaries have been depleted. Past changes in range and density must have been in response to natural spatial and temporal variations in the environment, but the current threatened status appears a direct or indirect result of man's activities.

Life History Information.--Biology of the spikedace has been studied intensively in only a few places, but those investigations provide a relatively broad base of information, summarized below. In AZ, only the population in Aravaipa Creek has received substantial attention (Barber and Minckley 1966, 1983; Barber et al. 1970, Minckley 1981, Schreiber and Minckley 1981, Turner and Tafanelli 1983, Rinne and Kroeger, in press), in part because that stream retains a largely-intact native fauna in relatively pristine habitat. In NM, Anderson (1978) examined populations primarily in the reach of Gila River downstream from the community of Cliff and in the lowermost East Fork of the Gila. Investigations by Propst et al. (1986) and Propst and Bestgen (1986) concentrated on the mainstem Gila River In the Cliff-Gila Valley, in part because that was one of few places in NM where the species was abundant enough to provide necessary information; they also collected ecological data from several other localities in the upper Gila system. Most other work on spikedace has been survey-type monitoring to assess distribution or status of local populations or fish communities (e.g., Jester et al. 1968, LaBounty and Minckley 1973, Anderson and Turner 1977, Ecology Audits 1979, Barrett et al. 1985, Bestgen 1985, Montgomery 1985, Propst et al. 1985), and does not contribute significant new information.

Habitat.--Spikedace occupy flowing waters, usually less than a meter deep, and as adults often aggregate In shear zones along gravel-sand bars, quiet eddies on the downstream edge of riffles, and broad, shallow areas above gravel-sand bars (Propst and Bestgen 1986, Rinne and Kroeger, in press). Smaller, younger fish are found in quiet water along pool margins over soft, fine-grained bottoms. In larger rivers (e.g., Salt River canyon), spikedace were in the vicinity of tributary mouths. The fish use shallow, strongly-flowing areas in springtime, often over sandy-gravelly substrates. Specific habitat associations vary seasonally, geographically, and ontogenetically (Anderson 1978, Rinne 1985, Propst et al. 1986, Propst and Bestgen 1986, Rinne and Kroeger in press).

Reproduction.--Spikedace breeding in spring (April-June) Is apparently initiated in response to a combination of declining stream discharge and increasing water temperatures; timing varies annually and geographically. Males patrol in shallow, sandy-gravelly riffles where current is moderate. There is no indication of territoriality, although males generally remain evenly spaced within an occupied area. Receptive females move into the area, often from up- or downstream pools, and are

approached at once by up to six males, two of which remain immediately alongside and slightly behind the female. Gametes are presumably deposited into the water column or on or near the substrate. No fertilized ova have been recovered; however, because they are adhesive and demersal based on eggs stripped and fertilized in the laboratory (P. Turner, pers. comm.), they likely adhere to substrates. Sex ratio among reproductive adults is not constant, varying from near unity among younger fish to a greater abundance of females among older individuals. Females may be fractional spawners, with elapsed periods of a few days to several weeks between spawnings. Fecundity of individual females based on gonad examination ranges from 90 to 250 ova, and is significantly correlated with both length and age. Ovum diameter at spawning is near 1.5 mm. No specific information on incubation times or size at hatching are available.

Growth.--Growth varies annually with water temperature (and thus geographic location), and among year classes. Generally, young grow rapidly during summer and autumn, attaining 35 to 40 mm in standard length (SL) by November. (Standard and total [TL] lengths of spikedace are convertable by the expression SL = 0.85TL - 0.12 [r2 = 0.99, n = 100] [Marsh, unpubl. data].) Winter growth is slow in some places, negligible in others. Fish average near 40 mm SL at the end of one year, and 50 to 63 mm SL at the end of the second year. Maximum size is near 65 mm in Aravaipa Creek, AZ, and 68 mm SL in the upper Gila River, NM. Longevity typically is one to two years; a few fish reach age three and exceptional individuals appear to survive four years. Growth of males and females appears similar, although there may be differences within particular year classes (Propst et al. 1986).

Foods.--Spikedace are carnivores that feed mostly upon aquatic and terrestrial insects entrained in stream drift. Kinds and quantities consumed vary with spatial and temporal availability of foods. Among aquatic forms, larval ephemeropterans, hydropsychid trichopterans, and chironomid dipterans are most important. Prey body sizes are small, typically ranging from two to five mm long. At times of emergence, pupal, imagine or adult stages of benthic insects, especially ephemeropterans, are consumed in large quantities. Other foods, including larval fishes, are occasionally eaten, but these constitute a minor component of the diet. Diversity of diet is greatest among smaller (post-larval) spikedace, which consume a variety of small, soft-bodied animals, while adults specialize on larger, drifting nymphal and adult ephemeropterans.

Co-occurring fishes.--Among native fishes, loach minnow (*Tiaroga cobitis*), speckled dace (*Rhinichthys osculus*), Sonora sucker (*Catostomus insignis*) and desert sucker (*Fantosteus clarki*) are commonly in the same habitats occupied by adult spikedace. Longfin dace (*Agosia chrysogaster*) may also co-occur in shallow, sandy, reaches with more laminar flow. Larval and juvenile spikedace in quiet habitats along stream margins may encounter small desert and Sonoran suckers, small loach minnow, larval and adult longfin dace, and perhaps small roundtail chub (*Gila robusta*).

Introduced red shiner (*Cyprinella lutrensis*) lives In similar habitats, and may often be taken in the same seine haul as spikedace.

The shiner now occurs at all places known to be formerly occupied by spikedace, with the exception of the San Francisco River above Frisco Hot Springs, and the two species overlap spatially (the native upstream, the exotic downstream, with a zone of contact between) in upper reaches of both Gila and Verde rivers. In the former, continuing contraction in range of spikedace has been attributed to a combination of habitat alteration and upstream expansion of shiner populations (Propst et al. 1986), while in the latter the two species have remained relatively stable in a region of sympatry, and appear to be co-existing (Minckley 1973, Marsh and Minckley, unpubl. data).

Although the mechanisms of interaction remain unclear, the red shiner has been repeatedly implicated in declines of spikedace and other native fishes, with direct predation, as well as displacement, suggested as potential impacts (FWS 1985, 1986; Minckley 1973, Minckley and Carufel 1967, Minckley and Deacon 1968, Propst et al. 1986).

Among other non-native fishes, channel catfish (Ictalurus punctatus) of all sizes, and small flathead catfish (Pylodictis olivaris) frequent riffles occupied by spikedace, especially at night when catfishes move onto riffles to feed. Largemouth (Micropterus salmoides) and smallmouth (M. dolomieui) bass in some habitats, and introduced trouts (Salmonidae) at higher elevations, may also co-occur. Interaction between the native and these non-native fishes is likely as prey and predators; however, importance of such relationships are yet to be established.

Reasons for Decline.--Habitat destruction or alteration and interaction(s) with non-native fishes have acted both independently and in concert to extirpate or deplete spikedace populations. In the San Pedro and Aqua Fria, plus major reaches of the Salt and Gila rivers, dewatering and other such drastic modifications resulted in demise of not only spikedace, but most native fishes. Downstream reaches of the Verde, Salt, and mainstem Gila rivers have been affected by impoundments and highly-altered flow regimes. Spikedace are unknown in reservoirs, and populations in tailwaters are subjected to impacts ranging from dewatering to altered chemical and thermal conditions. Channelization, bank stabilization, or other instream management for flood control or water diversion, have also directly destroyed their habitats.

Natural flooding of desert streams and rivers may play a significant role in lives of native fishes because they rejuvenate habitats (Propst et al. 1986), but perhaps more importantly because desert fishes effectively withstand such disturbances while non-native forms apparently do not (Meffe and Minckley 1987, Minckley and Meffe 1987). Activities that alter natural flow regimes may thus have negative impacts on native species.

Both historic and present landscapes surrounding spikedace habitats have been impacted to varying degrees by domestic livestock grazing, mining, agriculture, timber harvest, or other development (Hastings and Turner 1965, Hendrickson and Minckley 1985). These activities contribute to habitat degradation by altering flow regimes, increasing watershed and channel erosion and thus sedimentation, and adding contaminants such as acutely- or chronically-toxic materials, or nutrient-rich fertilizers to streams and rivers. Such perturbations may affect fishes in a variety of ways, such as direct mortality, interference with reproduction, and reduction in requisite resources

sucn as invertebrate foods. In one example, a wastewater spill at the Cananea open-pit copper mine, Sonora, Mexico, killed aquatic life Including all fishes throughout a 100-km reach downstream, well into the United States (Eberhardt 1981).

Non-native fishes introduced for sport, forage, bait, or accidentally also impact native fishes. Ictalurid catfishes, and centrarchids including largemouth and smallmouth bass and green sunfish (Lepomis cyanellus), prey upon them. At higher elevations, introduced salmonids (brown and rainbow trouts, Salmo truttA, Oncorhynchus mykiss) may similarly influence spikedace populations. Red shiner is particularly important as regards spikedace, because the two species where allopatric occupy essentially the same habitats, and where sympatric there is apparent displacement of the native to habitats which otherwise would scarcely be used (this report). Moreover, the concomittant reduction of spikedace and expansion of the shiner is powerful circumstantial evidence that red shiner has displaced spikedace in suitable habitats throughout much of its former range.

Loach minnow

The loach minnow (Tiaroga cobitis) is a small, secretive fish endemic to the Gila River basin of AZ and NM, USA, and Sonora, Mexico. Although this unique, monotypic genus has been known to science for more than a century, relatively little has been published on its basic ecology. It was apparently not considered imperiled by Miller (1961), but an increasing rarity was noted by Barber and Minckley (1966) and later by Minckley (1973). It once was locally abundant in suitable habitats in the Gila River system upstream of Phoenix, but today is restricted to scattered tributary populations in AZ and NM. Present and historic distributions were mapped for AZ by Minckley (1973, 1985) and for NM by Propst et al. (1988).

This species was proposed (FWS 1985b) and subsequently listed (FWS 1986b) as threatened under authority of the ESA. Listing was Justified on the bases of diminution of range and numbers due to habitat destruction, impoundment, channel downcutting, substrate sedimentation, water diversion, ground water pumping, and the spread of exotic predatory and competitive fishes, and because of continued threats posed by proposed dam construction, water loss, habitat perturbations, and exotic species (FWS 1985b). Critical habitat was initially proposed (FWS 1985b), but legal designation was deferred until 18 June 1987 (FWS 1986b). Although that date expired with no action, proposed critical habitat is still in force, providing limited habitat protection. Final designation of critical habitat is currently under review.

The loach minnow is recognized by numerous scientists as biologically imperiled (e.g., Deacon et al. 1979, Williams et al. 1985, 1989; Johnson 1987). Like spikedace, the species is classified by the State of NM as a Group 2 endangered species (NM State Game Commission 1985), which affords protection under the NM Wildlife Conservation Act, and by the State of AZ as a threatened species (AZGF 1988). The species can be taken in NM only by scientific collectors, and in AZ only by angling or special permit. Neither state specifically protects habitats occupied by loach minnow.

Description.-- The loach minnow is a small, stream-dwelling member of the minnow family (Cyprinidae); it's description below is summarized from Girard (1857) and Minckley (1973):

> The body is elongated, little compressed, and flattened ventrally. There are eight rays In the dorsal fin and seven in the anal fin. The lateral line has about 65 scales. The mouth is small, terminal, and highly oblique; there are no barbels. The upper lip is non-protractile, attached to the snout by a broad fold of tissue (the frenum). Openings to the gills are restricted. Pharyngeal teeth are in two rows, with formula 1,4-4,1.
>
> Coloration of the body is an olivaceous background, highly blotched with darker pigment. Whitish (depigmented) spots are present at origin and insertion of the dorsal fin and dorsal and ventral portions of the caudal fin base. A black, basicaudal spot usually is present. Breeding males have bright red-orange coloration at the bases of the paired fins and on the adjacent body, on the base of the caudal lobe, about the mouth, near the upper portion of the gill opening, and often on the abdomen. Females In breeding become yellowish on the fins and lower body.

Distribution and Abundance. Historical.--The loach minnow is endemic to the Gila River basin, AZ and NM, USA, and Sonora, Mexico. It was recorded In Mexico only in Rio San Pedro, in extreme northern Sonora (Miller and Winn 1951). Distribution in AZ included the Salt River mainstream near and above Phoenix, White River, East Fork White River, Verde River, Gila River, San Pedro River, Aravaipa Creek, San Francisco River, Blue River and Eagle Creek, plus major tributaries of larger streams (Minckley 1973, 1980; Marsh et al., in press). Populations transplanted from Aravaipa Creek into Sonoita Creek (Santa Cruz County, AZ) in 1968 and 7-Springs Wash (Maricopa County, AZ) in 1970 have since been extirpated (Minckley and Brooks 1985). Distribution in NM was in the Gila River (including East, Middle, and West forks), San Francisco River, Tularosa River, and Dry Blue Creek; there have been no recorded transplants of loach minnow in NM or Sonora.

There are substantial gaps in time and space among data upon which to base estimates of historical abundance of this species, but it is unlikely (because of its highly specialized nature) that it was ever abundant other than locally. However, the historical record indicates that suitable, presumably-occupied habitat was widespread throughout the region. Like most western cyprinids, distribution and abundance of loach minnow undoubtedly varied greatly in response to natural changes in environmental conditions (Minckley and Meffe 1987).

Present distribution.--Loach minnow is believed extirpated from Mexico, although the Gila River drainage in that Country still lacks adequate surveys. The species persists in AZ only in limited reaches in White River (Gila County), North and East forks of the White River (Navajo County), Aravaipa Creek (Graham and Pinal counties), and San Francisco, Blue, and Campbell Blue rivers (Greenlee County); it may also exist in Eagle Creek (Graham and Greenlee counties), although it has not been collected there since 1950 (Marsh et al., in press). Loach minnow

is rare to uncommon in AZ, except in Aravaipa Creek ana the Blue River drainage (Propst et al. 1985); known populations once present in other rivers and streams of the state have been eliminated. Unknown populations of the species may still occur in places not surveyed or incompletely inventoried, especially in Mexico and within the expansive San Carlos Apache and Fort Apache Indian reservations, or on National Forest lands in the United States.

In NM, the species still may be found in the upper Gila River, Including the East, Middle, and West forks (Grant and Catron counties), San Francisco and Tularosa rivers (Catron County), lowermost Whitewater Creek (Catron County), and lowermost Dry Blue Creek (Catron County). In 1982-1985, it was locally abundant in scattered reaches of these streams; populations were small in whitewater and Dry Blue creeks (Propst et al. 1988). Existing populations of loach minnow are presumably reproducing and recruiting, but their potential for long-term persistence is unknown.

Both the distribution and abundance of loach minnow have become dramatically reduced in the last century (Minckley 1973, Propst et al. 1988). It is probably extirpated from Mexico. Major stream reaches in AZ, including downstream reaches of Gila, Salt and Verde rivers, that once supported populations are no longer occupied, and its distribution in NM is fragmented. Similar changes in abundance and range likely occurred in the past in response to temporal and spatial variations in the environment, but indications are that its current imperiled status is a direct or indirect result of man's activities.

Life History Information .--Loach minnow has been intensively studied at only a few locations, resulting in a less-than-complete understanding of the species' ecology throughout its range. Arizona populations have received attention only in Aravaipa Creek (Barber and Minckley 1966, Minckley 1965, 1973, 1981; Schreiber and Minckley 1981, Turner and Tafanelli 1983, Rinne 1985, 1989), largely because that stream contained the only sizeable population in the State. Britt (1982) examined populations in the Gila and San Francisco rivers in NM, and Propst et al. (1988) concentrated investigations on the mainstem Gila River In the Cliff-Gila Valley, and Tularosa River, NM. Results and observations presented In this literature are summarized below; detailed information on individual populations Is available in original source materials. Most other work on loan minnow has been survey-type monitoring to assess status of local populations or fish communities (e.g., Jester et al. 1968, Anderson and Turner 1977, Ecology Audits 1979, Montgomery 1985, Propst et al. 1985); these do not contribute significant new life history information.

Babitat.--The loach minnow inhabits turbulent, rocky riffles of mainstream rivers and tributaries up to about 2200 m elevation. Because of a reduced gas bladder, it is restricted almost exclusively to a bottom-dwelling habit; swimming above the substrate is only for brief moments as the fish darts from place to place. Most habitat occupied by loach minnow is relatively shallow, has moderate to swift current velocity and gravel- or cobble-dominated substrate (Barber and Minckley 1966, Minckley 1973, Propst et al. 1988, Rinne 1989). Loach minnow at some times and places (e.g., Aravaipa Creek, AZ) is associated with dense, filamentous green algae (Barber and Minckley 1966, Minckley

1973), while in other places this association has not been observed. In the upper Gila River, NM, depth, velocity, and substrate of occupied habitats vary ontogenetically, seasonally, and geographically (Propst et al. 1988); the same is to be expected elsewhere.

Reproduction.--Loach minnow first spawn at age I in late winter-early spring and autumn in Aravaipa Creek (Minckley 1973, Vives and Minckley, in press) and from late March into early June in NM (Britt 1982, Propst et al. 1988). Spawning is in the same riffles occupied by adults during the non-reproductive season, where sex ratios appear approximately equal. Adhesive eggs are deposited on the underside of flattened rocks; cavities usually are open on the downstream side while the upstream portion of the rock is embedded in the substrate. The male, and possibly the female as well, guards the nest cavity (Vives and Minckley, in press). Number of eggs per rock ranges from fewer than five to more than 250, with means among populations of 52 to 63. Fecundity of individual females ranges from about 150 to 250 mature ova, and generally increases with increasing size. Mature ova are about 1.5 mm in mean diameter, but greater (1.55-1.67 vs. 1.44-1.56 mm) among females more than 60 mm long (presumably age II), than in smaller, age I fish (Britt 1982). Embryos retrieved from beneath spawning rocks and incubated at 18 to 20C hatched yolk-sac larvae in five to six days.

Growth.--Loach minnow larvae are approximately five mm long at hatching. Growth rate varies with location and environmental conditions, and among year classes. Growth is most rapid during the first summer, with age 0 fish in NM usually attaining 30 to more than 40 mm SL by mid-summer and slightly more than 50 mm SL by end of the calendar year. (Standard and total lengths of loach minnow are convertible by the expression SL = 0.84TL + 0.56 [r^2 = 0.99, n = 100] [Marsh, unpubl. data].) Growth subsequently slows, with age-I fish averaging near 55 mm SL by end of their second growing season. Winter growth is negligible. Age II fish attain maxima of about 68 mm SL, although such size is infrequent. Longevity of most individuals is probably 15 to 24 months, although exceptional fish may survive 36 months. There is no evidence that male and female growth rates differ substantially, although males may have higher survivorship than females (Propst et al. 1988)

Foods.--Loach minnow are opportunistic, benthic insectivores, largely deriving their food supplies from among riffle-dwelling, larval ephemeropterans and simullid and chironomid dipterans; larvae of other aquatic insect groups, such as plecopterans, trichopterans, and occasionally pupae or emerging adults, may be seasonally important. Chironomids are relatively more important among the few food items utilized by larval and juvenile fishes; diversity of food types increases as fish become larger, but the array of foods eaten is usually small compared with other stream fishes (Schreiber and Minckley 1981, but see Abarca 1987). Because loach minnow are not known to swim In turbulent riffles other than for brief periods, it appears that they actively seek their food among bottom substrates, rather than pursuing animals entrained in the drift. Feeding habits therefore must parallel seasonal changes in size and relative abundance, and thus availability, of riffle-inhabiting invertebrates.

Co-occurring fishes.--Riffles that characterize habitats occupied by adult loach minnow are shared with few other species. Native speckled dace often occupies riffles with loach minnow, but the dace is a strong-swimming fish that may have little interaction with the benthic loach minnow. Native suckers, especially desert sucker, frequent riffle habitats, where they graze on attached algae and its associated microfauna. Among non-native (introduced) fishes that co-occur in places with adult loach minnow, only ictalurid catfishes are likely to interact strongly with the native. Channel catfish of all sizes move onto riffles to feed, often on the same animals most Important in diets of loach minnow. Juvenile flathead catfish also feed in riffles in darkness. Channel catfish tend to be benthic omnivores, but flathead catfish are notoriously piscivorous, even when small. Thus, potential for direct interaction (i.e., predation) between loach minnow and non-native catfishes is enhanced by motive (acquisition of food) and spatial overlap in riffles.

Larval and juvenile loach minnow, which occupy shallower and slower habitats along riffle margins than adults (Propst et al. 1988), may encounter a suite of other fishes. However, when collected they often are the only species in samples. Among natives, larval suckers (both desert and Sonoran suckers) and larval and adult cyprinids (especially the ubiquitous longfin dace) are most likely to interact with small loach minnow. These species have co-occurred for millennia.

Red shiner is the non-native fish most likely to be found along stream margins in places occupied by small loach minnow. Red shiner now occurs in all places known to be formerly occupied by loach minnow, but is absent or rare in places where the native species persists. Although a mechanism(s) of interaction is unclear, red shiner has repeatedly been implicated in declines of loach minnow and other native fishes (Minckley and Carufel 1967, Minckley and Deacon 1968, FWS 1985, 1986), and stream reaches where loach minnow have declined or disappeared are suspiciously complementary with range expansions of the shiner. Exotic mosquitofish, Gambusia affinis, also occupies lateral habitats used by smaller loach minnow, and although potential mosquitofish/loach minnow interactions have yet to be examined, mosquitofish are detrimental to native topminnow, Poeciliopsis occidentalis, in both field and laboratory settings (Meffe 1983, 1985)

Reasons for Decline.--Changes in distribution and abundance of loach minnow are directly or indirectly tied to man's uses of rivers, streams, and landscapes, which have been variously modified by past and present activities (Hastings and Turner 1965, Hendrickson and Minckley 1985). Direct impacts have resulted from stream habitat alterations accompanying a suite of land- and water-use practices; most often cited are dewatering, impoundment, and livestock grazing. Certain introduced and established non-native fishes may interact negatively with native kinds, and, independently or in concert with habitat alteration, result in their extirpation.

Dewatering of stream reaches may accompany groundwater pumping, stream channel ization, water diversion, or damming. Absence of water obviously destroys fishes, and there can be no re-establishment of aquatic populations until flow is restored. Much historic loach minnow habitat is now dry (for example, reaches of the Gila, Salt, and San Pedro rivers in AZ).

Impoundment results in creation of lentic habitat, which eliminates and excludes loach minnow. Downstream effects of dams may include dewatering (above), alteration in flow regime, amelioration of natural flood events, changes In thermal and chemical character of the stream, elimination of organic drift typical of flowing waters, and other impacts, which may have a variety of sublethal effects on fishes. As noted before, natural flooding of desert streams may play a significant role in life history of native fishes because they rejuvenate habitats (Propst et al. 1988), but perhaps more importantly because desert fishes effectively withstand floods while non-native forms apparently do not (Meffe and Minckley 1987, Minckley and Meffe 1987). Major reaches of the Gila and Salt rivers are influenced by dams and their reservoirs and tailwaters; loach minnow no longer occur in these affected waters (e.g., Minckley 1973, unpubl. data).

Livestock grazing that results in removal of covering grasses and shrubs from the watershed, or denuding of riparian vegetation, may induce dramatic changes in precipitation runoff, suspended sediment, and bedload that increase stream turbidity, clog interstitial spaces of coarse substrates, and enhance erosion of stream channels and banks. Similar effects may be realized through poor timber harvest practices, mining operations (that may also contribute acute- or chronically-toxic levels of contaminants such as heavy metals), agriculture (that may also deliver toxic pesticides or herbicides, or enriching fertilizers), and development for industrial, commercial, or residential purposes. Factors which influence substrate, changing it from clean, unconsolidated gravels to close-spaced silts and sand would be especially disadvantageous for loach minnow. Fishes that require unperturbed, natural habitats free of environmental contaminants may not maintain viable populations when faced with such modifications, or, where impacts are tolerated, such perturbations may weaken populations of native fishes so that invading predatory and competing non-natives effectively displace them.

It is clear that habitats supplied with water of sufficient quality and quantity, and which conform with other, specific environmental characteristics, are necessary for survival of loach minnow and other native fishes. Maintenence of stream flows uninterrupted by impoundment may be especially important for loach minnow, whose populations are often naturally small and disjunct.

Habitat alteration and interaction with non-native fishes are both undoubtedly important in declines of loach minnow. However, it may not be possible to separate effects of these phenomena because in most places both occurred during approximately the same period of time. The scientific and management communities have not yet developed capabilities to examine an area from which a species has been extirpated, or in most cases of southwestern fishes, even a habitat from which natives are in active decline, and determine with certainty which factor(s) is responsible.

Habitats unimpacted by man's activities, which still support loach minnows, do not exist. Even Aravaipa Creek, which has established populations of only a few introduced fishes and supports a thriving community of seven native kinds including loach minnow, has been subjected to perturbations due to grazing and water management. Reaches of the Gila River and Its major tributaries in NM, altered only by grazing, irrigation diversions, and/or mining, also are occupied by

viable native populations, and support few or no exotic fishes. Similar conditions characterize most streams and rivers that are still occupied by loach minnow. On the other hand, an inescapable observation is that all places where suitable aquatic habitat still remains, but from which loach minnow has been extirpated, now are occupied by populations of non-native fishes. Thus, moderate habitat alteration alone does not appear sufficient to eliminate loach minnow, except In cases where dewatering or severe habitat destruction has occurred. It is only when populations of non-native forms invade and become established, which may be contingent upon specific habitat alteration such as that induced by damming or overgrazing, that the native is depleted or extirpated.

Red shiner

The red shiner (Cyprinella lutrensis) is a moderately small, stream-dwelling cyprinid fish native to central and south-central North America. The species has been introduced and become established throughout the Colorado River basin (Minckley 1973, USFWS 1980). The red shiner is remarkably tolerant of adverse conditions, including intermittency, high turbidity and temperature, and low dissolved oxygen (Minckley 1973, Matthews and Hill 1979).

Declines and extirpations of populations of spikedace, loach minnow, and other native fishes have been coincident with invasion and establishment of red shiner in the Gila River basin of AZ and NM. Red shiner has been implicated as one factor in these declines, with suggested mechanisms including spatial displacement, competition for food resources, and direct predation (FWS 1985a and b, 1986a and b; Minckley 1973, Minckley and Carufel 1967, Minckley and Deacon 1968, Propst et al. 1986, Greger and Deacon 1988). However, only circumstantial evidence is generally available, and a comprehensive, quantitative assessment of interactions between red shiner and native southwestern fishes has yet to be accomplished.

Description—The red shiner is a moderately-small, highly compressed member of the minnow family. Its description which follows was adapted from Cross (1967) and Minckley (1973):

> The body is highly compressed; snout blunt; mouth terminal and oblique, jaws equal or nearly so. Dorsal fin rounded, and with 9 rays. Pharyngeal teeth usually 0,4-4,0, sometimes with a single tooth in one or both minor rows.
>
> Color is tan to olivaceous dorsally, silver on the sides, and white on the belly; a distinct mid-dorsal stripe is present. Breeding males have distinctive coloration that becomes more varied and intense with maturation: orange-to-red caudal and lower fins, bright pale blue sides, a prominent purplish crescent behind the head, red on top of the head, which Is rosy to yellowish on the sides, dorsal fin darkened. Breeding males with tubercles on head, nape, caudal region, and fins.

Distribution and abundance. Historical.--Historic range of the red shiner Included the Mississippi and Gulf of Mexico coastal drainages from SD and IL through northern Mexico (Matthews 1980), It has expanded

its range to the northeast during the past century (Matthews 1980, Becker 1983). Within its native range, this shiner is often the most abundant cyprinid in a wide variety of low-gradient habitats, especially backwaters, creek mouths, and medium-sized streams with silt-sand substrates; it Is uncommon or absent in clear, high- gradient streams (Matthews 1980).

Present distribution.--Red shiner was introduced to southwestern United States in the Colorado River during the early 1950s (Hubbs 1954, Miller 1961). It has since spread through a combination of natural colonization and Intentional and inadvertant stockings as baitfish to establish populations In lower-elevation streams throughout the system (Minckley 1973, USFWS 1980). It has become one of the most abundant fishes of the Gila basin in AZ and into NM, including the Gila, Salt, and Verde rivers and their tributaries (Minckley 1973, 1985, Bestgen and Propst 1987).

Life-History Information.--Biology of red shiner has been widely studied and reported in its native range (Saskena 1962, Hale 1963, Cross 1967, Laser and Carlander 1971, Cavin 1972, Harwood 1972, Farringer et al. 1979, Matthews and Hill 1977, 1979, Matthews and Maness 1979, Robison and Buchanan 1988). Numerous other publications Include distributional data, summary and anecdotal information, and discussions of local or regional aspects of its life history (e.g., Koster 1957; Metcalf 1966; Carlander 1969; Pflieger 1971, 1975; Douglas 1974; Cross and Collins 1975; Smith 1979). These reports provide the basis of information presented below.

Little has been published on biology of red shiner in streams and rivers of the arid southwest, despite its ever-increasing distribution, abundance, and importance in the region. Spawning behavior of a population in Burro Creek, AZ, was reported by Minckley (1972). Minckley (1973) reviewed Its status and biology in AZ, status of the species in CA was detailed by Moyle (1976), and studies of the lower Colorado River that included red shiner were reported by Minckley (1979, 1982) and Marsh and Minckley (1985, 1987). Studies of red shiner in the Virgin River, AZ-NV-UT, have concentrated on its potential interaction with endangered woundfin (*Plagopterus argentissimus*) and other native fishes in that system (Cross 1985, Deacon 1988, Greger 1983, Greger and Deacon 1988).

Habitat.--Red shiner is virtually ubiquitous throughout Its historic and introduced range, and occupies a wide variety of lotic and lentic habitats. It is most common in slower reaches of sand/silt-bottomed streams, and population abundances generally increase during periods of drought when populations of other fishes decline. It is not generally associated with high gradients or riffles, although these habitats may be occupied during high-water periods. Red shiner in the South Canadian River, OK, consistently selected water deeper than 20 cm with negligible current, and avoided turbulent flow, unsheltered locations, and clean, unstable sand substrate (Matthews and Hill 1979). The species was most abundant in backwaters and non-flowing pools. There appears little geographic variation in occupied habitats by red shiner across its natural range.

In the lower Colorado River, AZ-CA, red shiner was typically collected in areas with moderate current along sandy margins of main channel beaches and bars, shallow backwaters, and connecting channels (Marsh and Minckley 1985, 1987). It was uncommon in open waters of the main channel and deep backwaters. In the Gila River basin, red shiner is found in streams to about 1500 m elevation, where it occupies habiats similar to those of spikedace (Minckley 1973), i.e., shear zones along gravel-sand bars, quiet eddies on the downstream edge of riffles, and broad, shallow areas above gravel-sand bars (Propst et al. 1986). The shiner also is found in abundance along sandy shorelines and tributary mouths of larger rivers and reservoirs (Minckley 1973). Habitats of red shiner in the Colorado River basin are thus generally similar to those occupied by the species within its native range.

Reproduction.--The spawning season of red shiner in its historic range occurs over an extended period from April or late May to early September or October in KS, MO, and OK, and becomes shorter to the north (e.g., June to August in WI); most activity occurs in June and July at water temperatures in the mid 20s C. Fish first spawn at age I, typically over submerged aquatic vegetation or other objects, and sometimes over the nests of a host of sunfishes (Lepomis spp.). Breeding behavior in KS was described in detail by Minckley (1959). After spawning, usually in calm water and less often in riffles, fertilized eggs settle to the bottom where they adhere to the substrate. Fecundity during the breeding season in IA ranged from 485 to 684 eggs, and was not correlated with length or weight of the female (Laser and Carlander 1971).

Captive red shiner were fractional (more than one clutch per year) crevice spawners, the latter not known to occur among wild populations (Gale 1986). A single female subjected to a 24-hr photoperiod spawned a total of 113,510 eggs among 200 clutches in a 21-month test period. Red shiner thus has remarkable reproductive potential, and may spawn in or over a wide variety of substrates.

Red shiners in central AZ usually spawn from March through June, although ripe fish may be collected in some years almost anytime from February into October. Breeding habitats and behaviors in AZ do not appear distinctive compared with those exhibited in the native range.

Growth.--Red shiner in IA attained total lengths of 17-35 mm (age 0), 37-65 mm (age II) 69-75 mm (age III) In June and early July (Laser and Carlander 1971). In MO, fish at the end of the growing season averaged 23 mm (age 0), and 46 mm (age I). Few fish live beyond their third summer (age II). Growth is more rapid in new impoundments than in streams (Becker 1983), and presumably faster in southern than northern portions of the range.

Size frequency distributions of shiners in the lower Colorado River suggested red shiner spawned from mid- to late summer, grew to about 60 mm during the first year, and attained maximum length near 85 mm by the end of the second summer (Marsh and Minckley 1987). The species thus appears to have higher growth rates and attain larger size in the southwest than in most parts of its native range. Rates undoubtedly vary geographically within the Gila basin, but we are aware of no other published regional information on its growth.

Foods.--The red shiner Is an opportunistic omnivore throughout its native and introduced ranges. It feeds by sight, taking foods at all levels of the water column (Becker 1983). Primary foods vary temporally and spatially, presumably in accordance with availability. Red shiners collected in an IA stream consumed mostly algae and insects, with the proportion of the latter increasing during a high flow period (Laser and Carlander 1971). In MO ponds, red shiner <34 mm long ate mostly collembola in August, and vascular plant and algal material in September, while in another pond zooplankton was the primary food (Divine 1968). Insects were the predominant dietary constituent among fish >50 mm long. Filamentous algae composed a third of the diet of OK red shiners, and terrestrial insects made up the remainder (Hale 1963).

Red shiner in the lower Colorado River (Minckley 1982, Marsh and Minckley 1987) ate primarily detritus, zooplanktonic crustaceans, and benthic insects (mostly chironomids). Food habits varied seasonally, and there was no evidence of size-related differences in the diet of fish 19 to 56 mm long (Marsh and Minckley 1987). In AZ, lake-dwelling red shiner feed mostly upon aquatic insect larvae, while those Inhabiting streams consume algae, aquatic and terrestrial insects, and young of other fishes (Minckley 1973).

Co-occurrina fishes.--Habitats occupied by red shiner are so varied that a comprehensive checklist of co-occurring fishes would be meaningless since it would include dozens of species. Pflieger (1975) found it most often in association with sand (Notropis stramineus), redfin (N. umbratilis), bigmouth (N. dorsalis), Topeka (N. toPeka), and ghost (N. buchanani) shiners. The range of the red shiner Is complementary with that of the spotfin shiner (Cyprinella spilopterus), and ecological incompatability apparently exists between the two species because the range of the red shiner expands as that of the spotfin is reduced (Page and Smith 1970). This relationship may be simlar to that between red shiner and spikedace in some streams of the Gila River basin

Red shiner In the Gila River basin may be found in association with almost any native or introduced species that occupies lower elevation streams. Among native fishes, longfin dace, speckled dace, spikedace, chubs of the genus Gila, and Sonoran and desert suckers are most commonly collected with red shiner.

5tatus.--Red shiner has expanded its natural range northward in the Mississippi drainage in the past century (Matthews 1980, Becker 1983). Although the species becomes less common at the periphery of its range, it is elsewhere widespread and abundant, and thus secure.

In the Colorado River basin, including the Gila River drainage of AZ and NM, the red shiner enjoys a wide distribution and is the most common fish in many streams. It is commonly used for bait. Most non-game fishery biologists consider it a pest In the arid southwest.

2. FIELD STUDY SITES, SAMPLING PROTOCOLS, AND ANALYTICAL PROCEDURES

Preliminary sampling to test equipment, familiarize personnel with protocols, finalize standardized data sheets, and acquire selected specimens for examination was performed in May 1987 (Table 1). Intensive spring-summer (May-September 1987) field studies were then conducted in seven reaches of five streams (Table 1, Fig. 1):

1) upper (east) and lower (west) Aravaipa Creek, respectively in Graham and Pinal counties, AZ (spikedace plus loach minnow);

2) Blue River, Greenlee County, AZ (loach minnow);

3) Gila River at Gila (Gila-Gila) and Redrock (Gila-Redrock), Grant County, NM (respectively spikedace and loach minnow, and spikedace plus red shiner [hereafter shiner]);

4) Sycamore Creek, Maricopa County, AZ (shiner); and

5) Verde River, Yavapai County, AZ (spikedace plus shiner).

An eighth study reach was to be located on the Verde River near the mouth of Sycamore Creek (Yavapai County, AZ); however, a preliminary reconnaissance suggested this site would be inappropriate because, although fishes were present, none was collected after modest seining effort (shiner, and possibly spikedace were expected there). It was decided that acquisition of fishes would, because of size and complexity of the stream, require pursuit and entrapment, thus rendering meaningless any derived relationships between fish presence and habitat occupied. The reach was not further considered.

Reaches were selected on bases of resident fishes and representation of the suite of microhabitat types available in the area. One to three sites, each 0.1 to 4 km in length, were sampled in each reach so that local variations in habitat diversity and species composition could be evaluated on within-stream bases.

Fishes at each site were collected with a 2.0- X 1.2-m, 0.32-cm-mesh straight seine, deployed to consistently sample 10 m^2 of area. Seining for loach minnow was ineffective on riffles at east Aravaipa Creek, Blue River, and Gila-Gila, and fishes there were collected by bank electroshocker (115 VAC, 900 W gasoline generator, with stainless steel electrodes mounted on two, hand-held fiberglass probes). Electrofishing was conducted within five-m sections (ca. two-m wide, and comparable in surface area to seine samples) blocked downstream by 0.32-cm-mesh netting. Specific locations of sample areas within each site were determined at random for relatively homogeneous areas within available microhabitats, and distribution of samples among riffles, runs, flatwater, and pools was in estimated proportion to areal extent of available microhabitat types. Sample sizes (seine hauls or electrofishing units) varied from 89 to 239.

Identity, number, and size (larva, juvenile, adult; Table 2) of all fishes encountered were determined, and specimens were released alive or a subsample preserved in 10% formalin for later dietary analysis.

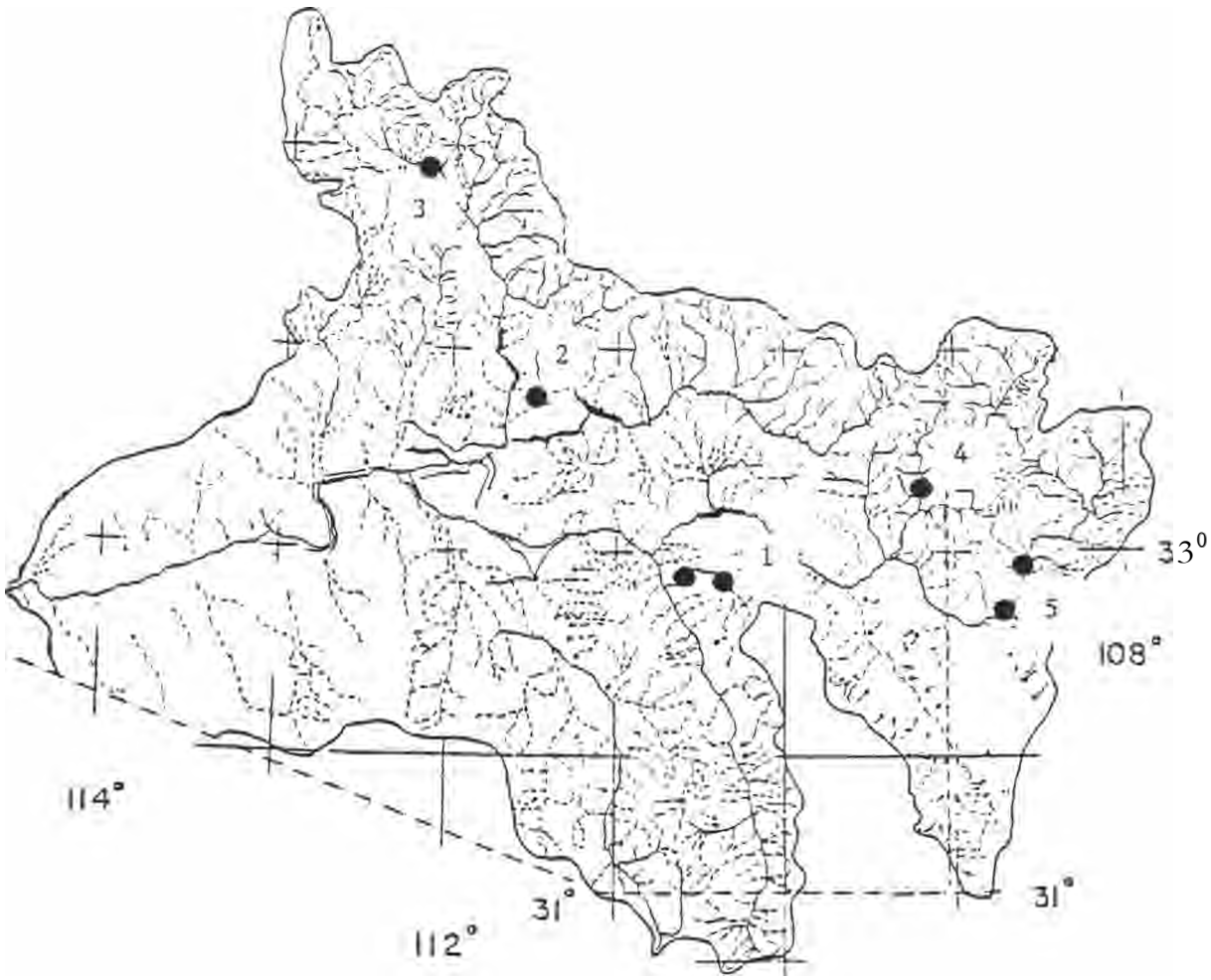

FIGURE 1. Study reaches of five streams in the Gila River basin, Arizona and New Mexico. (1) upper (east) and lower (west) Aravaipa Creek, Graham and Pinal counties, Arizona; (2) Sycamore Creek, Maricopa County, Arizona; (3) Verde River, Yavapai County, Arizona; (4) Blue River, Greenlee County, Arizona; and (5) Gila River at Gila and Redrock, Catron County, New Mexico.

TABLE 1. Field study areas, stream reaches, sampling dates, and sample inventories, spikedace and loach minnow study, 1987-1989. T = township, R = range, S = section, FSR = Forest Service Road, hwy = highway. Seine collections were in addition to those associated with physical habitat measurements, and were performed for other purposes. Preserved specimens includes fishes and/or invertebrates. Preliminary investigations are designated by asterisk (*).

*Sycamore Creek at Sugarloaf, Maricopa Co., AZ; T4N R8E S16
18 May 1987
Protocols: microhabitat Replications: 10
Specimens preserved.

*West Aravaipa Creek above Woods Ranch diversion, Final Co., AZ; T6S R17E S24
20 May 1987
Protocols: seine Replications: 5
drift 2 (noon)
Specimens preserved.

*West Aravaipa Creek at San Pedro confluence, Pinal Co., AZ; T7S R16E S9
20 May 1987
Protocols: seine Replications: 16
Specimens preserved.

*West Aravaipa Creek at Sycamore tree, Pinal Co., AZ; T7S R17E S9
20 May 1987
Protocols: seine Replications: 10
No specimens preserved.

West Aravaipa Creek above Wagoner Ranch, Pinal Co., AZ; T6S R17E S13-14 and T6S R18E S18
21 May 1987
Protocols: microhabitat Replications: 100
Larval fishes preserved.

West Aravaipa Creek above Woods Ranch diversion, Pinal Co., AZ; T6S R17E S24
22 May 1987
Protocols: seine Replications: 5
No specimens preserved.

Verde River at FSR 638, Yavapai Co., AZ; T17N R1W S4-5
26 May 1987
Protocols: microhabitat Replications: 30
drift 2 (noon)
seine 12
benthic kick 3
Specimens preserved.

(continued).

TABLE 1 (continued).

Verde River at Perkinsville, Yavapal Co., AZ; T18N R2E S31
27 May 1987
Protocols: microhabiat Replications: 30
drift 2 (noon)
drift 2 (midnight)
seine 13 (noon)
seine 13 (midnight)
benthic kick 3
Specimens preserved.

28 May 1987
Protocols: microhabitat 20
Specimens preserved.

17 August 1989
Protocols: seine 60
Specimens preserved.

Verde River at Sycamore Creek confluence, Yavapal Co., AZ; T17N R3E S7
28 May 1987
Protocols: microhabitat Replications: 10
No fishes collected.

Verde River at Perkinsville, Yavapal Co., AZ; T18N R2E S31
03 June 1987
Protocols: drift Replications: 8 (diel)
seine 8 (diel)
Specimens preserved.

Gila River at Gila (2.4 km S hwy 180 on FSR 809), Grant Co., NM; T6S R17W S16
17 June 1987
Protocols: drift Replications: 2 (noon)
microhabitat 40
benthic kick 3
drift 2 (midnight)
Specimens preserved; ontogenetic series.

18 June 1987
Protocols: microhabitat Replications: 40
No specimens preserved.

Gila River at Gila (5.6 km N on hwy 293), Grant Co., NM; T6S R17W S16
19 June 1987
Protocols: microhabitat Replications: 80
benthic kick 3
Specimens preserved.

(continued).

TABLE 1 (continued).

Gila River at Gila (7.2 km N on hwy 293), Grant Co., NM; T5S R17W S14
20 June 1987
Protocols: microhabitat Replications: 31
No specimens preserved.

21 June 1987
Protocols: microhabitat Replications: 49
benthic kick 3
Specimens preserved.

Blue River (3.2 km S FSR 475C), Greenlee Co., AZ; T2S R31E S6
22 June 1987
Protocols: microhabitat Replications: 40
No specimens preserved.

23 June 1987
Protocols: microhabitat Replications: 40
benthic kick 3
Specimens preserved.

Blue River (1.6 km S FSR 475C), Greenlee Co., AZ; T1S R31E S31
23 June 1987
Protocols: microhabitat Replications: 30
drift 12 (diel)
Specimens preserved.

24 June 1987
Protocols: microhabitat Replications: 50
benthic kick 3
Specimens preserved.

Blue River (0.8 km N FSR 475C), Greenlee Co., AZ; T1S R31E S19
25 June 1987
Protocols: microhabitat Replications: 80
benthic kick 3
Specimens preserved.

Sycamore Creek at Mesquite Wash, Maricopa Co., AZ; T5N R8E S34
03 August 1987
Protocols: microhabitat Replications: 40
drift 8 (diel)
Specimens preserved.

04 August 1987
Protocols: microhabitat 60
benthic kick 3
Specimens preserved.

(continued).

TABLE 1 (concluded).

East Aravaipa Creek below Juan Miller lower crossing, Graham Co., AZ; T6S R19E S21+28

10 August 1987
Protocols: microhabitat Replications: 10
drift 9 (diel)
Specimens preserved.

11 August 1987
Protocols: microhabitat Replications: 30
No specimens preserved.

12 August 1987
Protocols: microhabitat Replications: 60
benthic kick 3
Specimens preserved.

Gila River at Redrock (below bridge), Grant Co., NM; T18S R18W S31

12 September 1987
Protocols: microhabitat Replications: 30
No specimens preserved.

Gila River at Redrock (Nichols Canyon), Grant Co., NM; T18S R19W S18

13 September 1987
Protocols: microhabitat Replications: 40
No specimens preserved.

Gila River at Redrock (lower box), Grant Co., NM; T18S R19W S18

14 September 1987
Protocols: microhabitat Replications: 30
No specimens preserved.

TABLE 2. Numbers of larval, juvenile, and adult fishes collected from each of seven reaches of five streams in the Gila River basin, Arizona and New Mexico. Sample size (number of standard seine or electrofishing areas) in parentheses.

East (upper) Aravaipa Creek, Arizona, August 1987 (n = 99).

Taxa	larva	juvenile	adult
Gila robusta	0	1	4
Meda fulgida	14	198	141
Agosia chrysogaster	16	50	24
Rhinichthys osculus	2	13	20
Tiaroga cobitis	6	35	80
Catostomus insignis	6	5	13
Pantosteus clarki	34	72	85
Catostomidae	11		
undetermined	1		

West (lower) Aravaipa Creek, Arizona, May 1987 (n = 102).

Taxa	larva	juvenile	adult
Gila robusta	68	2	4
Meda fulgida	420	6	87
Agosia chrysogaster	488	0	47
Catostomus insignis	0	10	9
Pantosteus clarki	0	9	19
Catostomidae	199		
undetermined	5		

TABLE 2 (continued).

Blue River at lower Juan Miller Crossing, Arizona, June 1987 (n = 230).

Taxa	larva	juvenile	adult
Agosia chrysogaster	201	3	119
Phinichthys osculus	4	29	309
Tiarocra cobitis	48	85	119
Cyprinella lutrensis	0	1	3
Catostomus insignis	65	35	1
Pantosteus clarki	59	79	4
Catostomidae	2255	1	
undetermined	12		

Gila River at Gila, New Mexico, June 1987 (n = 239).

Taxa	larva	juvenile	adult
Gila robusta	72	0	0
Agosia chrysociaster	139	3	11
Tiaroga cobitis	227	109	31
Meda fulgida	1838	161	35
Cyprinella lutrensis	0	0	3
Catostomus insionis	125	25	0
Pantosteus clarki	96	8	0
Catostomidae	2841	--	--
Gambusia affinis	2	14	61
undetermined	12		

(continued).

TABLE 2 (continued).

Gila River at Redrock, New Mexico, September 1987 (n = 89).

Taxa	larva	juvenile	adult
Agosia chrysogaster	0	345	765
Meda fulgida	29	188	50
Cyprinella lutrensis	74	45	14
Catostomus insimis	3	12	0
Pantosteus clarki	1	4	0
Pylodictis olivaris	0	1	0
Ictalurus punctatus	0	4	2
Gambusia affinis	0	0	12

Sycamore Creek at Mesquite Wash, Arizona, August 1987 (n = 100).

Taxa	larva	juvenile	adult
Agosia chrysogaster	180	598	332
Cyprinella lutrensis	223	515	251
Pimephales promelas	0	1	2
Catostomus insignis	6	0	0
Pantosteus clarki	11	0	0
Catostomidae	7		

(continued).

TABLE 2 (concluded).

Verde River near Perkinsville, Arizona, May 1987 (n = 110).

Taxa	larva	Juvenile	adult
Gila robust	115	1	0
Meda fulgida	3	2	70
Agosia chrysociaster	38	7	77
Cyprinella lutrensis	13	49	32
Catostomus insignis	88	1	0
Pantosteus clarki	181	2	0
Catostomidae	362		
Gambusia affinis	4	3	9
Micropterus dolomieui	1	0	0
undetermined	4		

Numbers of fishes in preserved subsamples varied among sites due to differences in availability and constraints imposed for spikedace and loach minnow by State and Federal collecting permits.

Measurements of current velocity (nearest 1.0 cm/s, determined by Marsh McBirney model 201D meter) and stream depth (nearest 1.0 cm, direct measure with meter stick) were made at five points (center and each corner) within each seined or electrofished area, means were calculated for each. Cover (macrophytes, algae, rock, inorganic, etc.), shade (riparian vegetation, canyon walls, etc.), and substrate composition (silt, sand, gravel, cobble, boulder, bedrock, organic material) were scored as percentages for the sample area as a whole.

Field data were entered into the ASU IBM-3090 mainframe computer for analyses using the Statistical Analysis System (SAS 1985). Initial comparisons were performed using Analysis of Variance (ANOVAs), with a posteriori t-tests. Seine and electrofishing samples were pooled, and data from the three sites within each stream reach were pooled for analysis.

The seven stream reaches (designated east and west Aravaipa, Blue, Gila-Gila, Gila-Redrock, Sycamore, and Verde) were compared and contrasted through use of unweighted ANOVAs performed over mean depth, mean velocity, and weighted substrate. The last variable was derived by taking the predominant recorded substrate category and converting it to mean particle size through multiplication by coefficients appropriate to that category (i.e., silt = 0.1 mm, sand = 1.0 mm, gravel = 10.0 mm, cobble = 100.0 mm, boulder 1000.0 mm, and bedrock >1000.0 mm; Hynes [1972)); weighted substrate for the reach was then computed as the sum of weighted values for each particle size from each sample. The three environmental variables were either found to be normally distributed, or were adjusted to normality (mean depth and weighted substrate were $\log_{10}$-transformed to achieve that status), and variance between streams was homoscedastic. Results of these analyses: 1) delineate the array of habitats available to fishes within each stream reach; and 2) contrast physical differences between individual reaches, which is a necessary assessment before differences in habitat occupied by target species can be evaluated (Sections 4 and 5, below).

Available habitat was defined by physical parameter estimates for all samples from a stream reach, whether or not fish were present. Occupied habitat was defined by physical parameters estimated only for those samples that included target species either alone (i.e., loach minnow, spikedace, or shiner) or in combination (spikedace plus shiner or loach minnow plus shiner). Comparisons were also made between parameters for occupied habitats (presence) and those where a species was not found (absence). Thus, habitat occupied by fishes in allotopy (i.e., native spikedace and/or loach minnow In absence of introduced shiner, and shiner in absence of either native) was considered preferred where it differed from that available or that where the species was absent. It was inferred that some level of interspecific interaction occurred where differences were found between preferred habitat of the native fish(es) and that occupied by the natives when syntopic with shiner, but habitat availability did not differ.

A second group of ANOVAs compared occupied habitats of the two native species or shiner in each stream reach by weighting simple presence of a species by numbers of individuals taken In each sample (i.e., seine haul). Preference was thus given to those sites at which a

particular species occurred. The more abundant a fish at a given sample point, the greater the weight attributed to environmental variables recorded there. Results from weighted analyses both define occupied habitat and suggest the "preferred" habitat of each species within each reach. Where spikedace or loach minnow and shiner both were recorded within a particular sample, the weight for environmental variables at that location was the total number of individuals of both species. The rationale for combining both species was that areas of stream which are effectively being integrated by the target fishes should be given greater weight than those where one or the other was absent.

Preserved fishes returned to the laboratory were measured (TL, plus SL, for a subsample of 100 each spikedace and loach minnow), weighed (nearest 0.1 g), and dissected to determine sex. Digestive tracts were excised (pharyngeal sphinctor to anus) and contained foods removed for microscopic examination. Percentage fullness was determined as estimated proportion of total tract volume occupied by ingested materials. After identification (invertebrates usually to family), food Items were enumerated and a visual estimate of volume obtained; the sum of volumes for Individual items was equal to total percentage fullness for that tract. Results for each food category were expressed as average volume percentage (V), percentage of total number (N), percentage frequency (F), and index of relative importance (IRI = F [V + N]; George and Hadley 1979). Food habits of loach minnow, spikedace, and shiner were analysed on a MacIntosh SE computer using Exstatix software.

Potential food-resource overlap between spikedace and shiner was estimated using indices developed by Horn (1966), Levins (1968), and Schoener (1970). Loach minnow and shiner did not co-occur in sufficient numbers to allow meaningful comparisons. Both volumetric and numerical percentage data were used in these analyses because results and their interpretations may vary as a function of input data. Spikedace and shiner co-occrred in sufficient numbers for reliable estimates of overlap only In Verde River. However, data from specimens taken from other stream reaches where each species was found to exclusion of the other (i.e., Aravaipa and Sycamore creeks, Gila River) were compared to derived hypothetical estimates of food overlap. This level of analysis clearly provides insight about site-specific food habits, and could prove useful in interpretation of possible interaction between spikedace and shiner, but strict extrapolations must be avoided because available resources may differ among streams.

Benthic and drifting macroinvertebrates were collected concurrently with fishes. Analyses of these collections will be reported later by Francisco J. Abarca; however, protocols are included here for sake of completeness. Availability of these samples provided opportunity to investigate potential food preferenda of spikedace and shiner. Riffle-dwelling benthic invertebrate samples comprised triplicate, 1.0 m2 kicks washed into a downstream net of 0.50-mm mesh, which then was then cleared of all entrained animals. Specimens were preserved in 70% ethanol, and later examined, sorted, identified, and enumerated in the laboratory. Kick samples of this type have been demonstrated to be reliable in determining both diversity and relative abundance of benthic macroinvertebrates (Elliott 1977, Resh 1979); however, they are generally unsuitable for estimation of total (absolute) abundances.

Aquatic drift was collected in duplicate nets (0.15 m wide x 0.30 cm high x 1.00 m long; 0.50-mm mesh) set for 24-hours in mid-channel of uniform riffle reaches. Nets were emptied and replaced at 4-hour intervals, and captured organisms preserved and processed as above. Because stream discharges and volumes of flow through nets were not measured, no estimates of total aquatic drift was possible.

Methodologies specific to investigation of interactions between spikedace and shiner in an artificial stream system are detailed in Section 7, below.

3. PHYSICAL CHARACTERISTICS OF STUDY REACHES

Descriptive statistics

Descriptive statistics for physical characteristics of the seven study reaches are summarized in Table 3, and frequency distributions for depth, current velocity, and weighted substrate are provided in Figs. 2-8. These data encompass all samples and thus represent the habitats available to fishes occupying the respective waters.

Among streams, mean depths varied from 19.0 cm at Blue River to 28.1 cm at Verde River; mean current velocities varied from 15.3 cm/s at Sycamore Creek to 62.2 cm/s at east Aravaipa; and mean weighted substrate was from 56.3 at west Aravaipa Creek to 142.3 at Verde River (Table 3).

Selected Statistical Comparisons

Statistical comparisons of available habitat were performed for selected study reaches where target species, alone or in combination, were found. Because loach minnow was in isolation from shiner in all samples from east Aravaipa and Gila-Gila, and the two species co-occurred in only two seine hauls from Blue River, habitat comparisons specifically in behalf of loach minnow were not performed.

Spikedace was found to the exclusion of shiner at east and west Aravaipa and Gila-Gila. Physical differences in available habitat among these three stream reaches are summarized in Table 4, and contrasted as follows:

1) west Aravaipa (n = 102) on average was significantly ($F = 44.97$; $p < 0.0001$; n = 439) shallower (mean depth 20.6+11.5 cm) than east Aravalpa (mean 23.3+6.6 cm, n = 99) and Gila-Gila (mean 23.4+13.2 cm, n = 239);

2) east Aravaipa had significantly ($F = 5.77$; $p < 0.003$; n = 439) greater mean current velocity (62.2+27.4 cm/s) than west Aravaipa (37.6+18.0 cm/s) and Gila-Gila (38.5+21.3 cm/s); and

3) there were no significant differences ($p > 0.05$) In mean weighted substrate particle size among stream reaches, which were 70.0+124.1 (n = 99) at east Aravaipa, 56.3 +44.7 (n = 102) at west Araviapa, and 98.4+170.1 at Gila-Gila.

TABLE 3. Mean, standard deviation (SD), and sample size (n = number of standard seine or electrofishing areas) depth (cm), current velocity (cm/s), and weighted substrate (WSubs) available in seven reaches of five streams, Arizona and New Mexico.

Stream reach	N	Depth	SD	Velocity	SD	WSubs	SD
East Aravaipa	99	23.3	6.6	62.2	27.4	70.0	124.1
West Araviapa	102	20.6	11.5	37.6	18.0	56.3	44.4
Blue	230	19.0	12.6	32.9	16.7	61.1	113.6
Gila-Gila	239	23.4	13.2	38.5	21.3	98.4	170.1
Gila-Redrock	89	26.7	11.8	34.9	19.0	140.7	118.8
Sycamore	100	19.5	15.1	15.3	11.9	41.9	36.0
Verde	110	28.1	11.7	38.1	20.7	142.3	234.8

TABLE 4. Results of an Analysis of Variance (ANOVA) contrasting differences in available habitat for three selected stream reaches, Arizona and New Mexico. Spikedace was captured in all three streams and loach minnow was at east Aravaipa and Gila-Gila; red shiner was not found in these stream reaches. Values are log-depth, velocity (cm/s), log-substrate, and sample size (n).

Stream reach	L-depth	Velocity	L-substrate	
East Aravaipa	1.370	62.2*	1.645	99
West Aravaipa	1.274**	37.6	1.536	102
Gila-Gila	1.335	38.6	1.603	239

F = 5.77; p < 0.0030; n = 439
** F = 44.97; p < 0.0001; n = 439

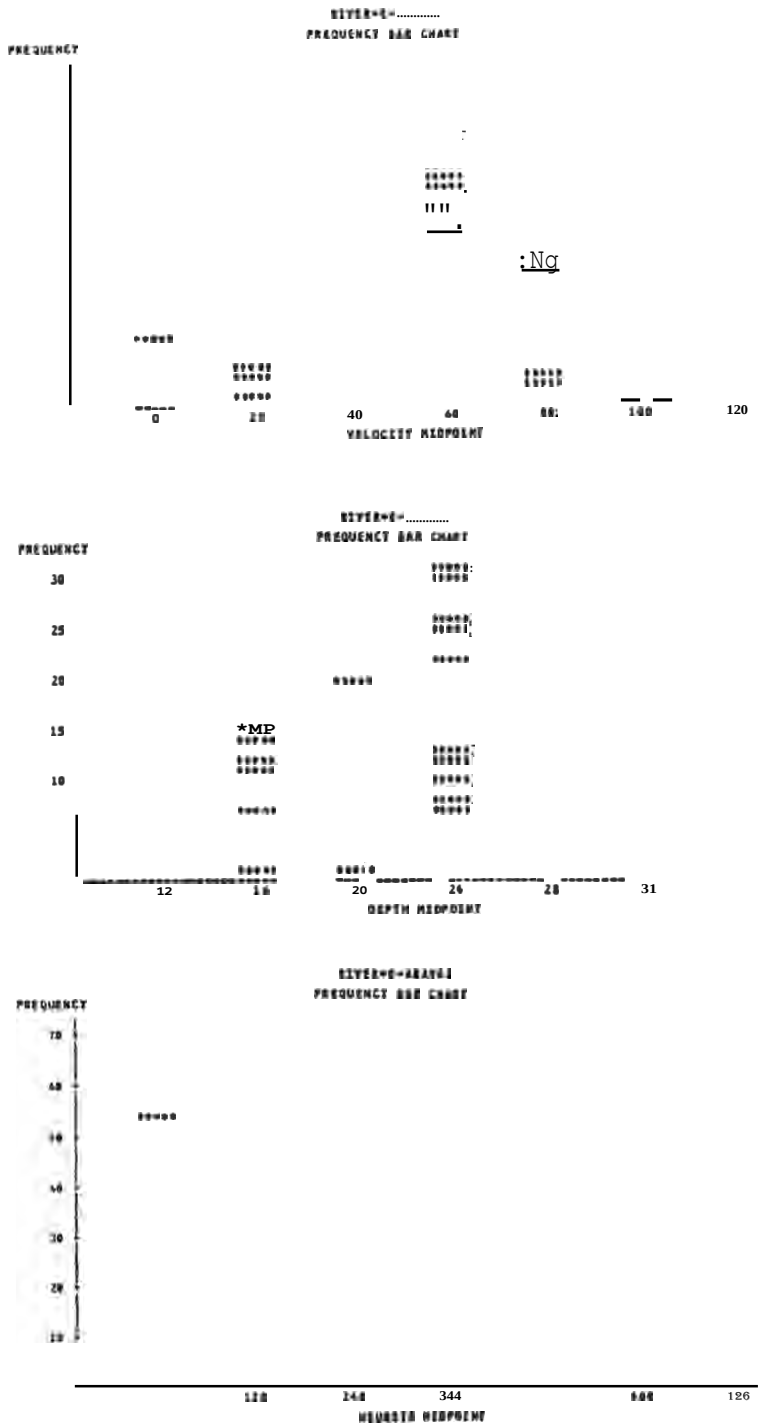

FIGURE 2. Frequency distributions of available current velocity (cm/s), depth (cm), and weighted substrate particle size, east (upper) Aravalpa Creek, Graham County, Arizona.

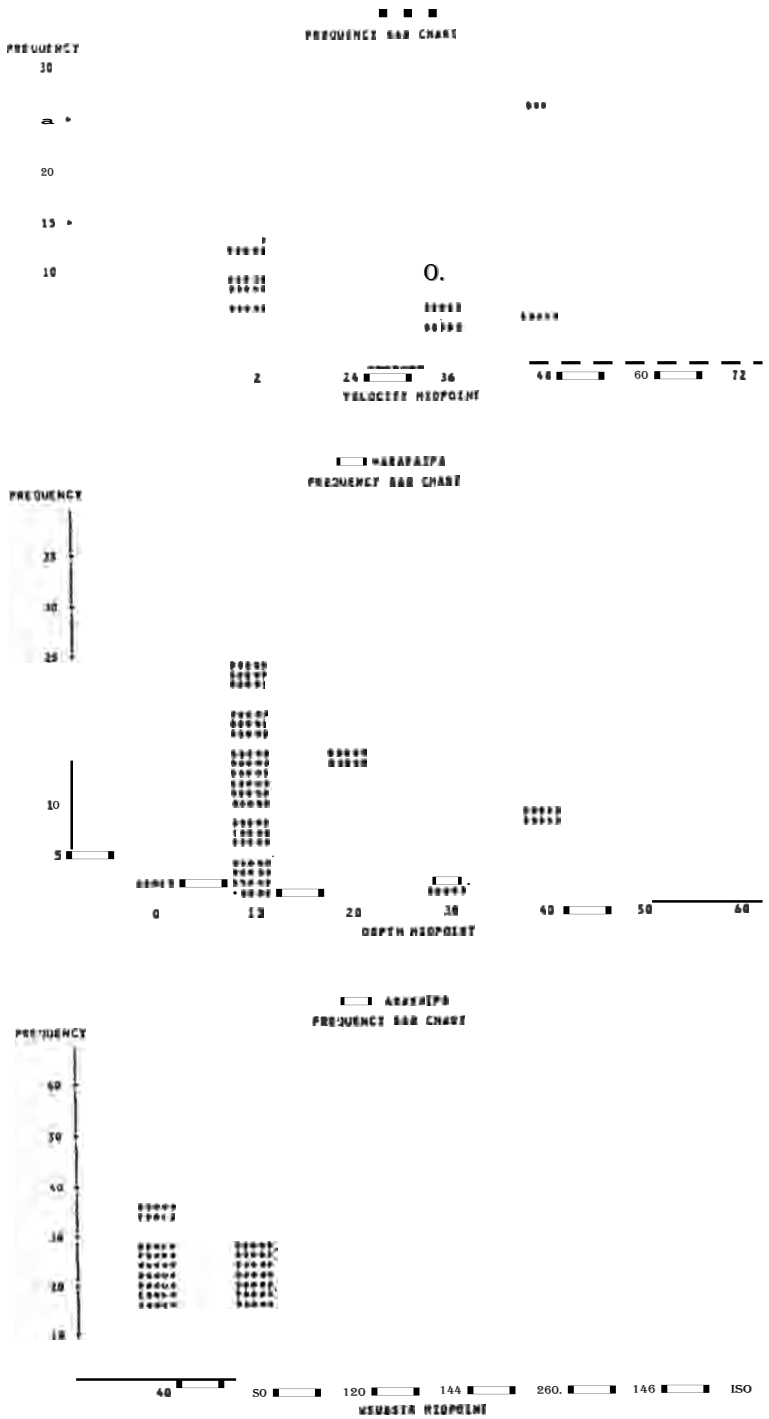

FIGURE 3. Frequency distributions of available current velocity (cm/s), depth (cm), and weighted substrate particle size, west (lower) Aravaipa Creek, Pinal County, Arizona.

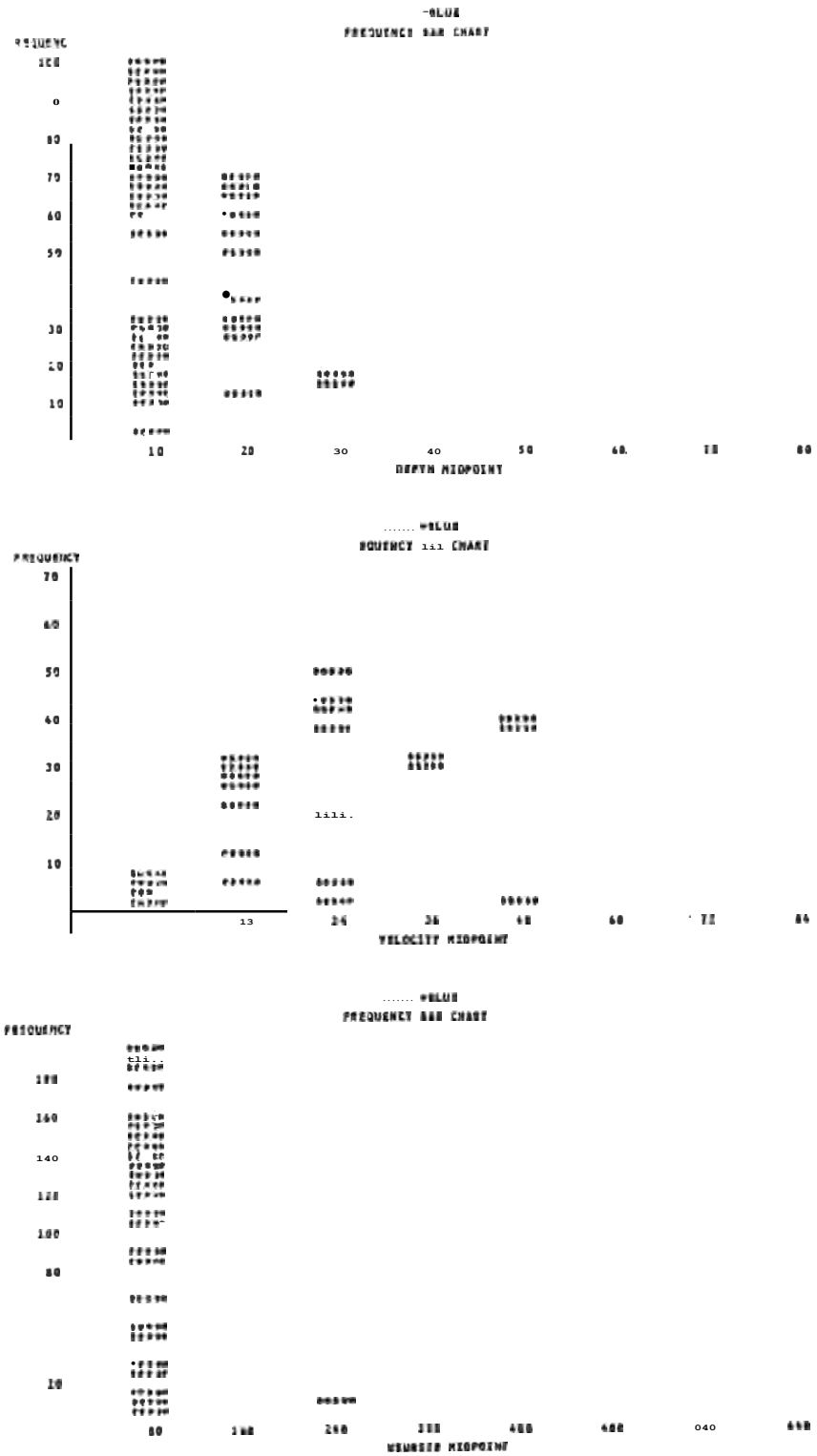

FIGURE 4. Frequency distributions of available current velocity (cm/s), depth (cm), and weighted substrate particle size, Blue River, Greenlee County, Arizona.

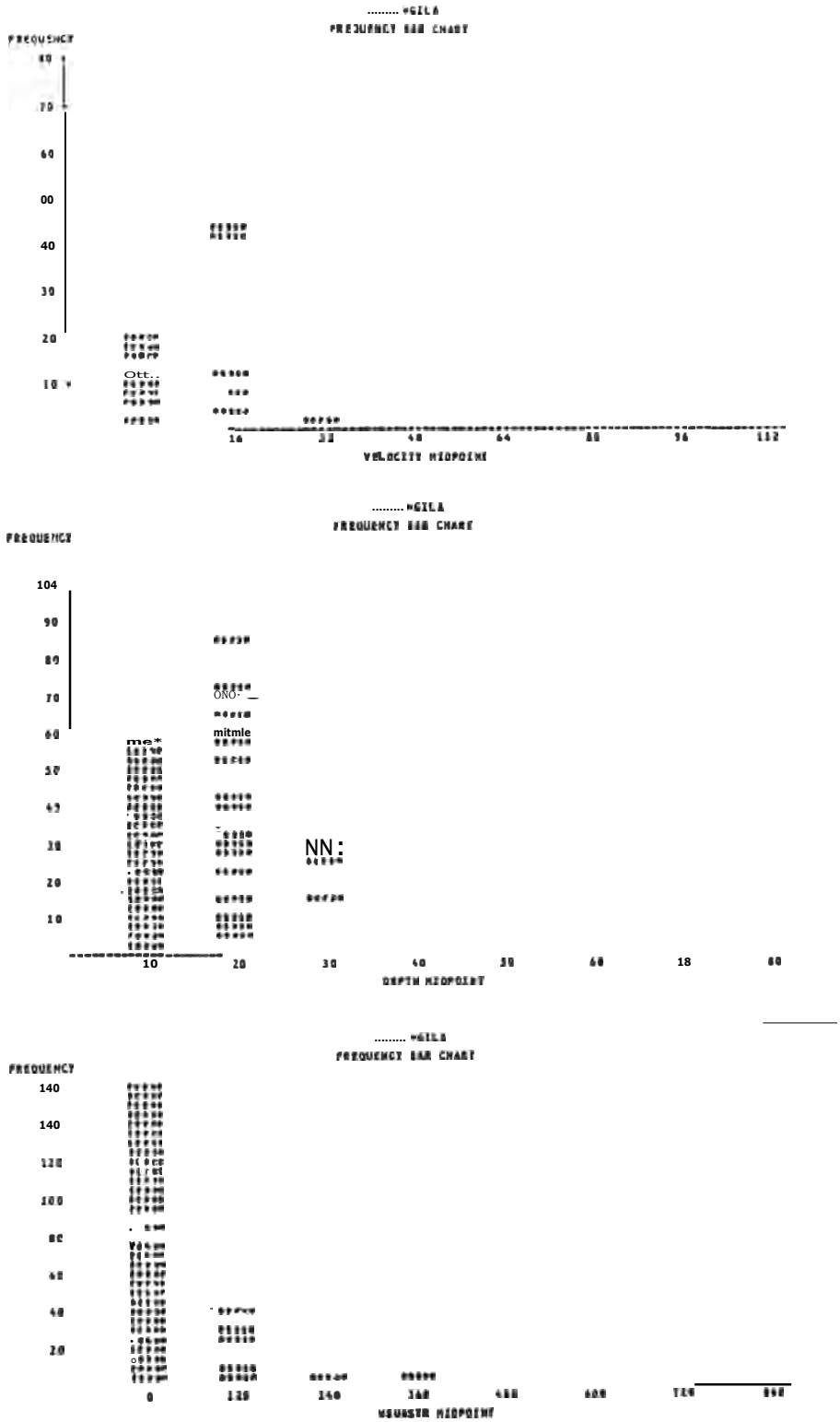

FIGURE 5. Frequency distributions of available current velocity (cm/s), depth (cm), and weighted substrate particle size, Gila River at Gila, Catron County, New Mexico.

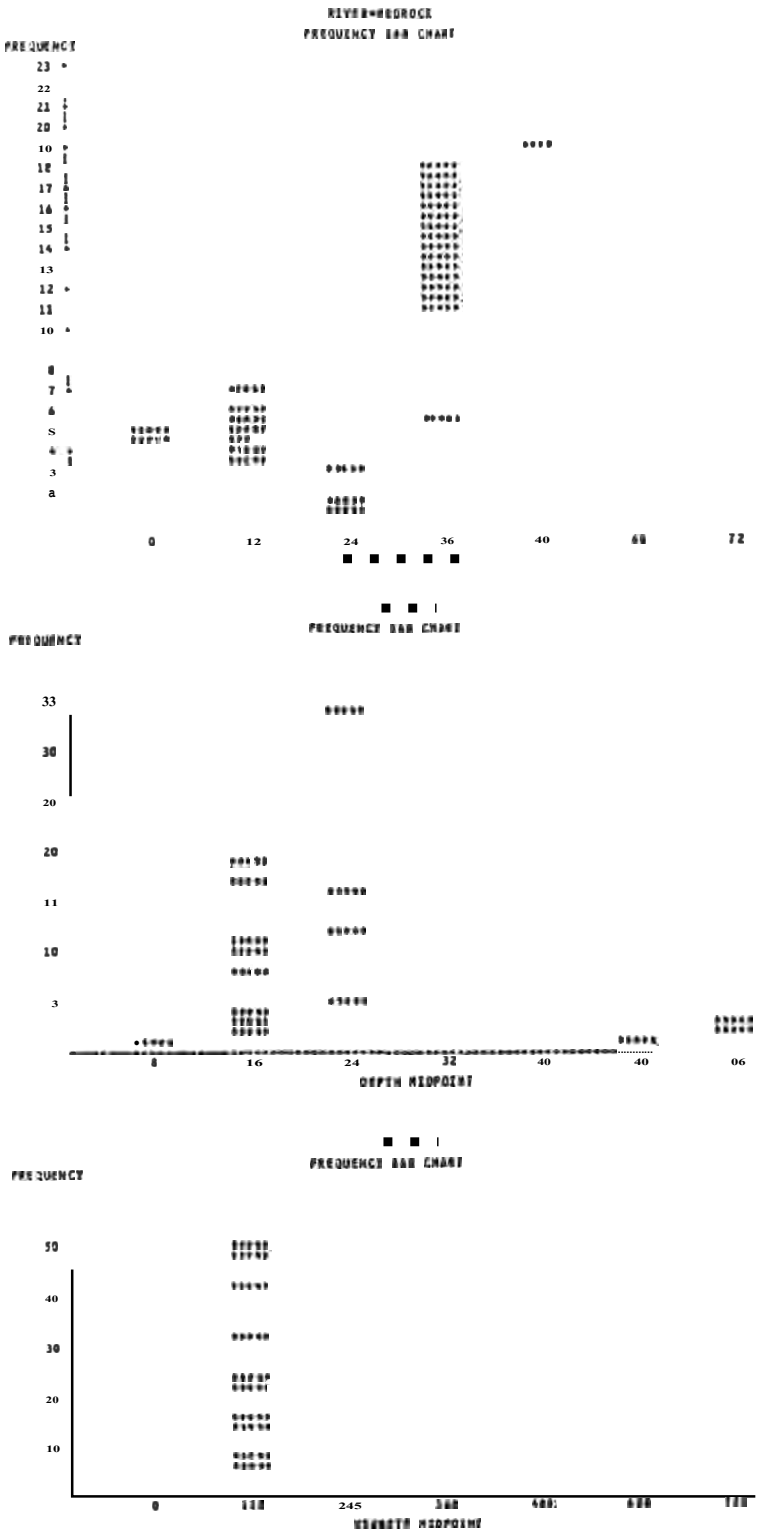

FIGURE 6. Frequency distributions of available current velocity (cm/s), depth (cm), and weighted substrate particle size, Gila River at Redrock, Catron County, New Mexico.

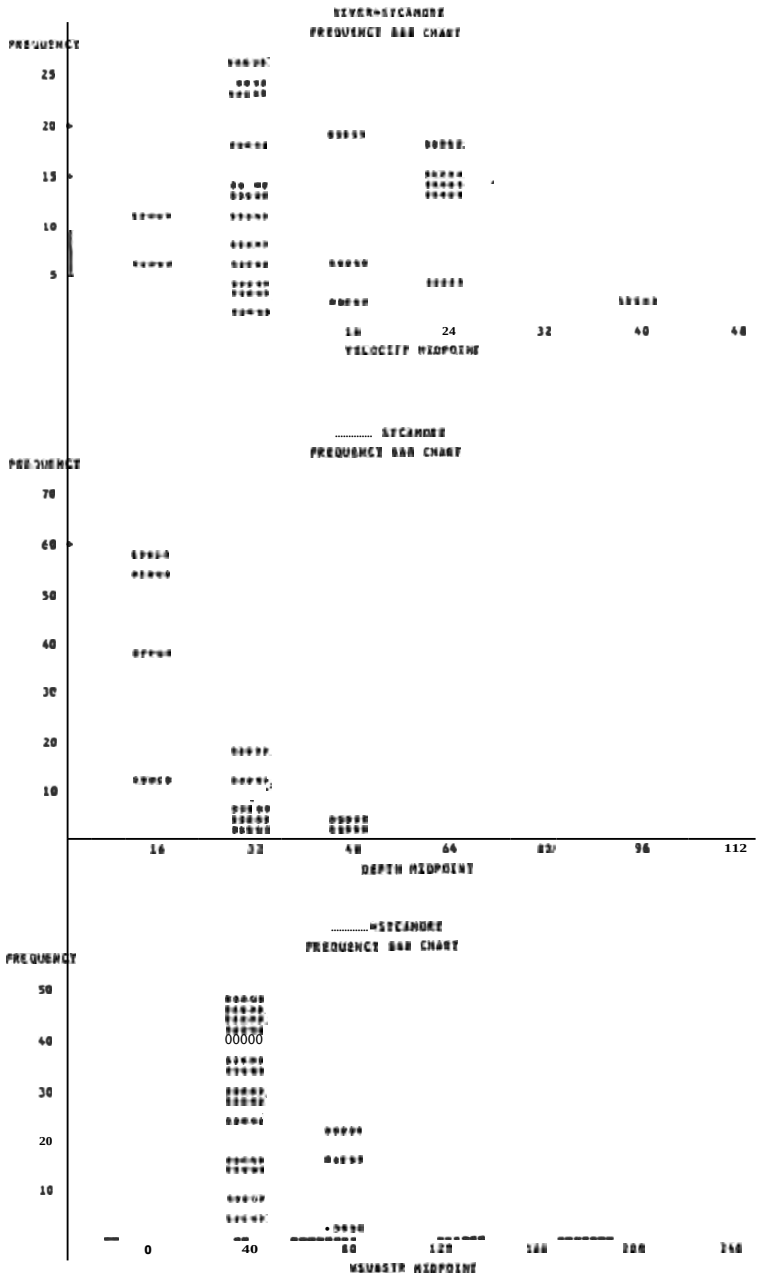

FIGURE 7. Frequency distributions of available current velocity (cm/s), depth (cm), and weighted substrate particle size, Sycamore Creek, Maricopa County, Arizona.

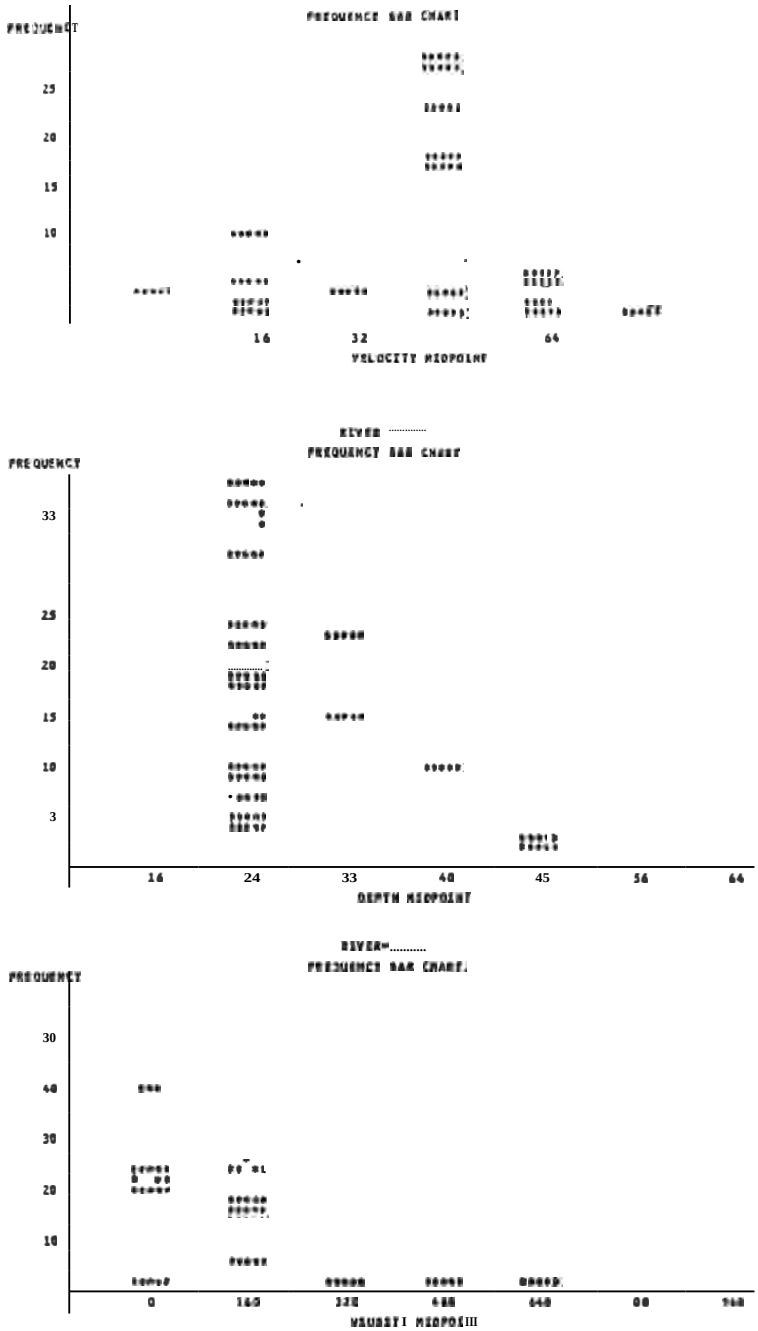

FIGURE 8. Frequency distributions of available current velocity (cm/s), depth (cm), and weighted substrate particle size, Verde River, Yavapai County, Arizona.

Spikedace was found, either isolated from or syntopic with shiner in four streams, i.e., alone at west Aravaipa and Gila-Gila, with shiner at Gila-Redrock and Verde. These streams are compared as follows:

1) Available habitat did not differ significantly ($p > 0.05$; $n = 540$) among these reaches as regards mean current velocities, (means at Gila Redrock and Verde were respectively 34.9+19.0 cm/s, $n = 8$; and 38.1+20.7 cm/s, $n = 110$; values for west Aravaipa and Gila-Gila are given above) (Tables 3 and 5).

2) West Aravaipa and Gila-Gila were significantly ($F = 13.61$; $p < 0.001$; $n = 540$) shallower (mean depths above) than Gila-Redrock (mean 26.7+11.8 cm, $n = 89$) and Verde (mean 28.1±11.7, $n = 110$) (Table 5).

3) Both Gila-Redrock and Verde had significantly ($F = 24.14$; $p < 0.0001$; $n = 540$) larger mean weighted substrate particle sizes (respectively 140.7±118.8, $n = 89$; and 142.3±234.8, $n = 110$) than west Aravaipa and Gila-Gila (respectively 56.3±44.7, $n = 102$; and 98.4±170.1, $n = 239$) (Table 5).

The available habitat in streams occupied by shiner (Gila-Redrock, Sycamore, and Verde) was quantified (Table 6) and compared as follows:

1) Sycamore Creek (where shiner was in isolation from spikedace) was significantly ($F = 30.4$; $p < 0.0001$; $n = 299$) shallower (mean depth 19.5+15.1 cm, $n = 100$) and slower ($F = 49.2$; $p < 0.0001$; $n = 299$; mean 15.3+11.9 cm/s, $n = 100$) than Gila-Redrock and Verde (where shiner and spikedace co-occurred, means above).

2) All three streams differed significantly as regards mean weighted substrate particle size ($F = 34.4$; $p < 0.001$; $n = 299$). Mean particle size at Sycamore was 41.9±36.0, $n = 100$; values for other streams are given above and In Table 3.

Blue River, which was not statistically compared with other stream reaches, had mean available depth of 19.0+12.6 cm, current velocity of 32.9+16.7 cm/s, and weighted substrate particle size of 61.1±113.6, $n = 230$ for each parameter (Table 3).

TABLE 5. Results of an Analysis of Variance (ANOVA) contrasting differences in available habitat for four selected stream reaches, Arizona and New Mexico. Spikedace was captured in all four streams and loach minnow was in Gila-Gila, and red shiner was found at Gila-Redrock and Verde. Values are log-depth, velocity (cm/s), log-substrate, and sample size (n).

Stream reach	L-depth	Velocity	L-substrate	
West Aravaipa	1.275*	37.6	1.645	102
Gila-Gila	1.335*	38.6	1.603	239
Gila-Redrock	1.408	35.0	2.028**	89
Verde	1.434	38.1	1.865**	110

* F = 13.61; p < 0.0001; n = 540
** F = 24.14; p < 0.0001; n = 540

TABLE 6. Results of an Analysis of Variance (ANOVA) contrasting differences in available habitat for three selected stream reaches, Arizona and New Mexico. Red shiner was captured in all three streams and spikedace was at Gila-Redrock and Verde; loach minnow was not found in any of these reaches. Values are log-depth, velocity (cm/s), log-substrate, and sample size (n).

Stream reach	L-depth	Velocity	L-substrate	
Gila-Redrock	1.408	35.0	2.028***	89
Sycamore	1.234*	15.4**	1.503***	100
Verde	1.434	38.1	1.865***	110

* F = 30.4; p < 0.0001; n = 299
** F = 49.2; p < 0.0001; n = 299
*** F = 34.4; p < 0.0001; N = 299

4. STUDIES OF LOACH MINNOW

Habitat

Loach minnow was collected from shallow, swift riffles of east and west Aravaipa, Blue, and Gila-Gila (Table 2). Descriptive statistics for estimates of available habitat are summarized in Table 3, and their frequency distributions in three streams (east Aravaipa, Blue, and Gila-Gila) are depicted in Figures 2, 4, and 5, respectively. Sample locations where loach minnow were captured at east Aravaipa averaged 20.8+5.2 cm depth, 70.3+22.8 cm/s current velocity, and 37.3+40.1 weighted substrate size (n = 41); at Blue River (n = 99) averages were 15.5+7.5 cm depth, 37.2+14.5 cm/s current velocity, and 27.3+71.8 weighted substrate size; and at Gila-Gila (n = 53) means were 14.7+5.1 cm depth, 43.8+18.6 cm/s current velocity, and 35.5+88.3 weighted subtrate size (Table 7). Frequency distributions of occupied habitat in east Aravalpa, Blue, and Gila-Gila are in Figures 9, 10, and 11, respectively. Loach minnow occurred in only one of 102 samples at west Aravalpa, and descriptive statistics for occupied habitat in that stream reach were not computed.

In all stream reaches where loach minnow was found, it occurred in shallower depths, swifter current velocities, and over smaller substrates than those available on average (compare available [Table 3; Figs. 2, 4, and 5] vs. occupied [Table 7; Figs. 9-11] habitat). We did not specifically examine differences in physical attributes of habitats occupied by loach minnow in the three stream reaches, however, comparisons among most streams (excluding Blue River) was conducted as part of our analysis of spikedace-shiner habitats (Sections 3 and 5).

Loach minnow and shiner co-occurred only at Blue River, where a total of four samples each included a single specimen of the non-native and the two species were taken together in two samples. Comparisons of habitat use were thus impractical because of small sample sizes. Moreover, It was apparent that habitat occupied by loach minnow was so different from that of the shiner that few significant relationships were expected to appear. We concluded that it was unlikely that shifts in habitat use by loach minnow could be explained by presence of shiner, since co-occurrence was rare and occupied habitats differed substantially.

Our results on loach minnow habitat were consistent with findings of others (Barber and Minckley 1966, Minckley 1973, Anderson and Turner 1977, Britt 1982, Propst et al. 1988, Rinne 1989). However, our samples comprised mostly large adults, and thus did not encompass potential, seasonal shifts in habitat use. Propst et al. (1988) found statistically significant differences between both velocity and depth occupied by successive life stages, and among-site comparisons showed significant differences in occupied water velocities and depths, although the latter were less pronounced. Based upon combined data for three NM locations integrated over seasons, Propst et al. (1988) found larval loach minnow occupied waters with currents averaging 7.9 cm/s and depths of 10.6 cm; Juveniles were in swifter (mean 35.1 cm/s) and deeper (mean 16.8 cm) water; and adults occupied current averaging 52.6 cm/s and depths averaging 16.8 cm.

Rinne (1989) quantified and compared loach minnow habitats in Aravalpa Creek (AZ) and Gila, Tularosa, San Francisco, and Middle Fork

TABLE 7. Mean, standard deviation (SD), and sample size (n = number of standard seine or electrofishing areas) depth (cm), current velocity (cm/s), and weighted substrate (WSubs) for habitats occupied by spikedace (Meda), loach minnow (Tiarood) and red shiner (Cyprinella) in seven reaches of five streams, Arizona and New Mexico.

Stream reach	N	Depth	SD	Velocity	SD	WSubs	SD
East Aravaipa							
Meda	41	24.2	6.2	46.2	27.2	109.0	169.0
Tiaroga	44	20.8	5.2	70.3	22.8	37.3	40.1
Cyprinella	0						
West Aravaipa							
Meda	29	19.8	9.1	39.9	16.2	50.1	27.8
Tiaroga	1						
Cyprinella	0						
Blue							
Meda	0						
Tiaroga	99	15.5	7.5	37.2	14.5	27.3	71.8
Cyprinella	4	19.5	5.7	39.5	9.1	17.2	12.6
Gila-Gila							
Meda	66	22.0	13.3	34.7	18.6	80.0	130.8
Tiaroga	53	14.7	5.1	43.8	18.6	35.5	88.3
Cyprinella	0						
Gila-Redrock							
Meda	21	36.1	14.8	31.0	20.0	153.7	179.5
Tiaroga	0						
Cyprinella	21	31.9	13.6	23.5	17.3	189.2	182.6
Sycamore							
Meda	0						
Tiaroga	0						
Cyprinella	89	20.5	15.7	14.3	10.9	40.7	30.1
Verde							
Meda	25	25.3	8.3	48.3	13.0	70.2	32.1
Tiaroga	0						
Cyprinella	22	25.1	11.3	36.2	16.4	136.5	289.0

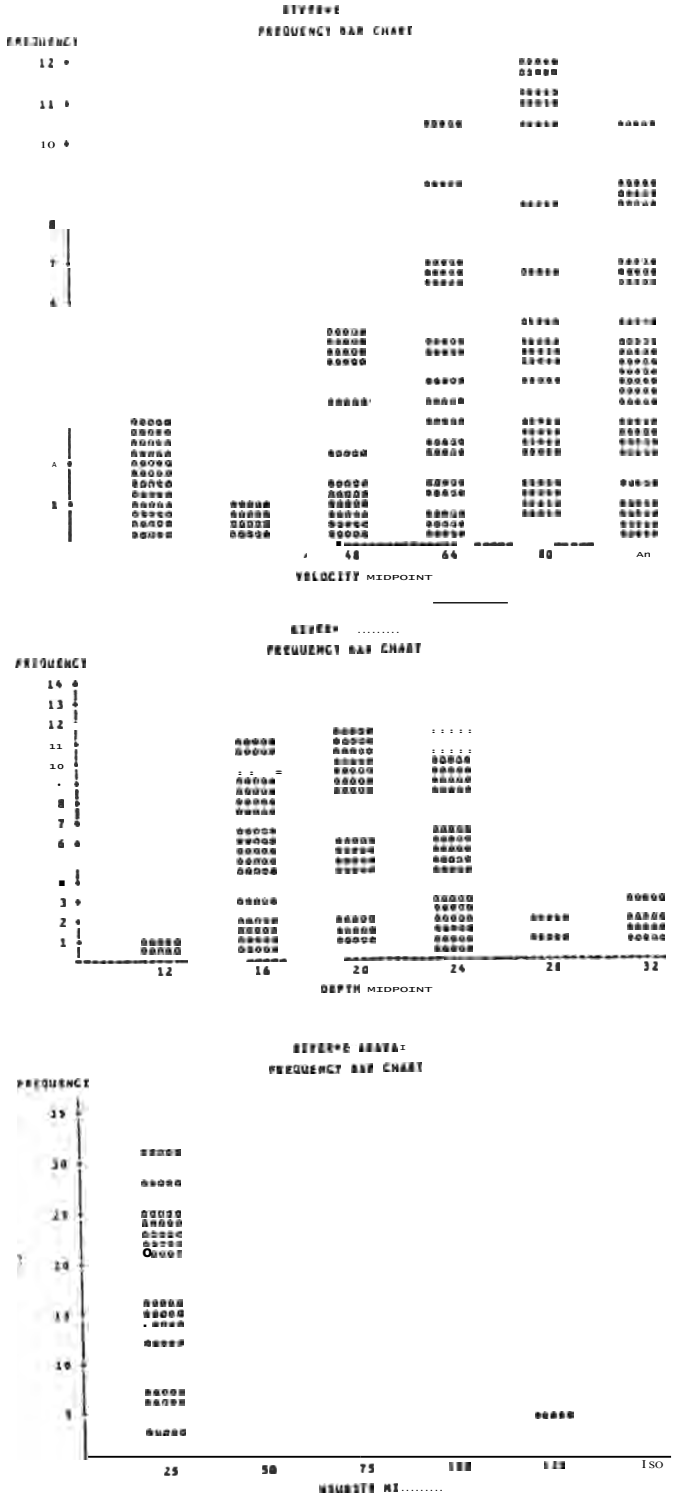

FIGURE 9. Frequency distributions of current velocity (cm/s), depth (cm), and weighted substrate particle size characterizing habitats occupied by loach minnow, east (upper) Aravaipa Creek, Graham County, Arizona.

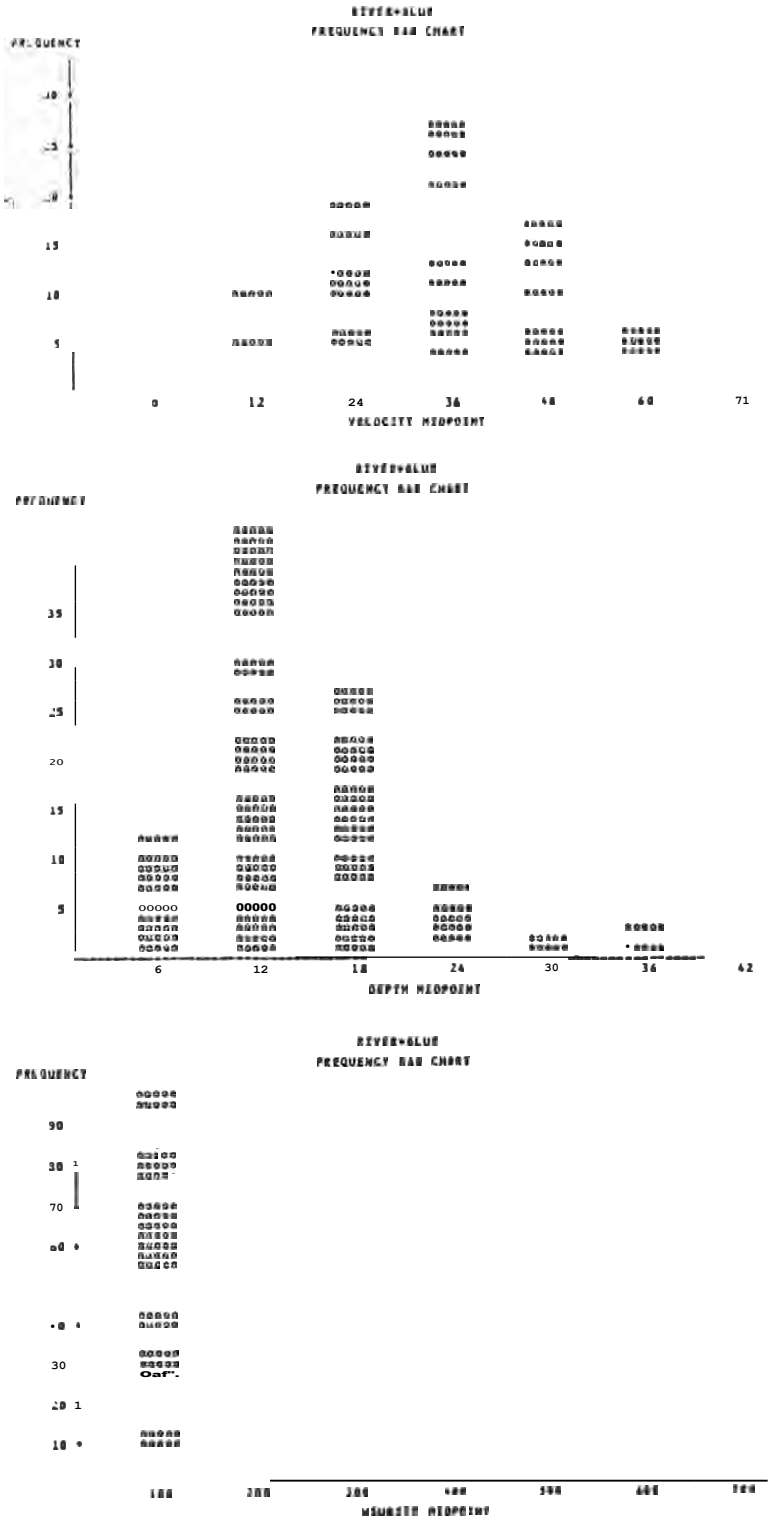

FIGURE 10. Frequency distributions of current velocity (cm/s), depth (cm), and weighted substrate particle size characterizing habitats occupied by loach minnow, Blue River, Greenlee County, Arizona.

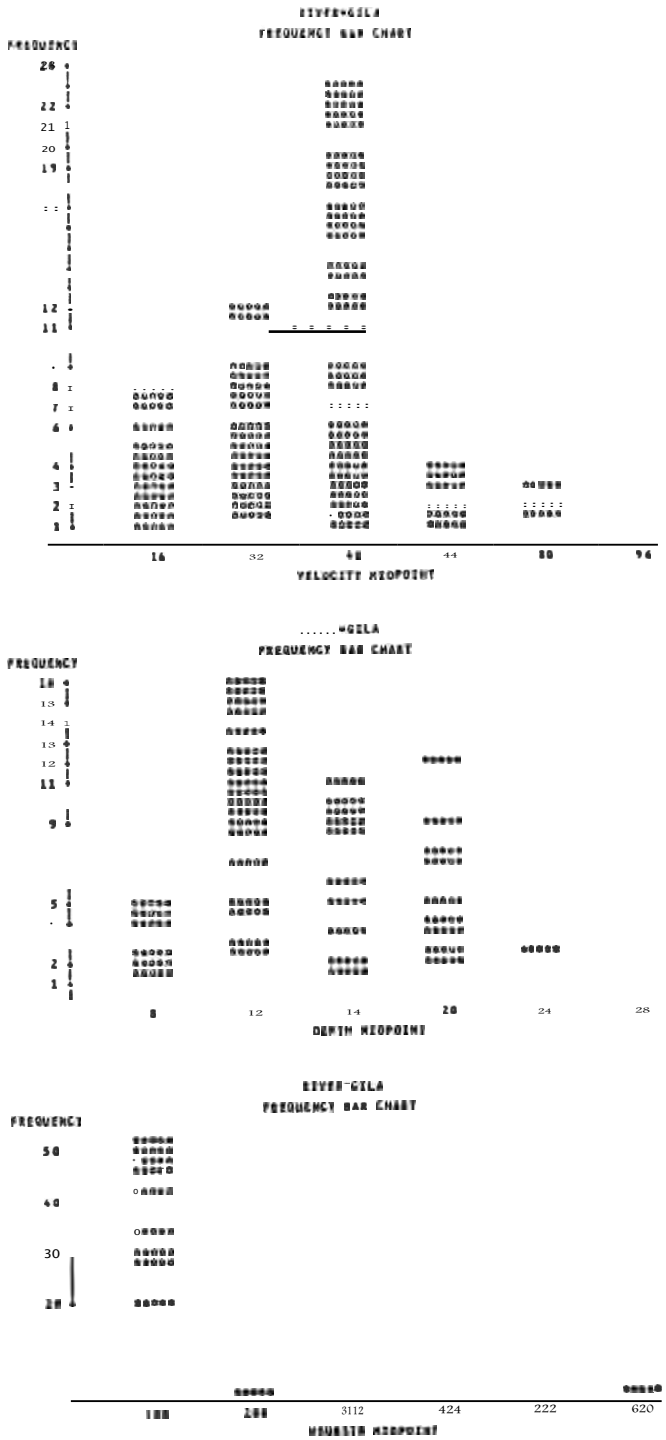

FIGURE 11. Frequency distributions of current velocity (cm/s), depth (cm), and weighted substrate particle size characterizing habitats occupied by loach minnow, Gila River at Gila, Catron County, New Mexico.

Gila rivers (NM). Fish were on riffles in shallow (<20 cm) water with currents of 30 to 40 cm/s over gravel-cobble (16 to 256 mm) substrates. Occupied habitat varied with stream size, and that used by adults differed from that of larvae, but again was similar to that used by juveniles.

Weighted mean current velocities for samples containing loach minnow from our study reaches (n = 196) were intermediate between those found by Propst et al. (1988) and Rinne (1989) for juveniles and adults (46.4 cm/s), and indistinguishable as regards mean occupied depth (16.5).

Propst et al. (1988) and Rinne (1989) both attributed much of the variation in apparent microhabitat utilization by loach minnow to habitat availability on the basis of stream size. We agree, since measured current velocities probably did not accurately reflect those actually experienced by individual fish, especially benthic kinds like loach minnow. Measures of current speed in various streams thus represented hydrologic differences among sites, and may have little bearing on loach minnow microhabitat (see also Rinne 1989). This is apparent from our data on occupied vs. available habitat, which failed to discriminate the magnitude of difference between obviously-unique riffle habitat occupied by loach minnow and that available on average to fishes in the streams. Further, larger streams tended to have larger substrate particles (e.g., Aravalpa Creek vs. Gila River), which was reflected in apparent habitat use.

Food Habits

Specimens of loach minnow for examination of food habits were obtained in June or August 1987 from east Aravaipa Creek, Blue River, and the Gila River at Gila. Samples at all sites were collected during both day and night. Mean percentage fullness varied between sites and among samples within each site (Fig. 12). For any given time of day, fish at Blue River were fuller than those from the Gila, and these in turn were fuller than fish from east Aravlapa; however, we attach no particular importance to this result. Fullness at noon and midnight, respectively, were 45 and 14% at east Aravalpa, 88 and 73% at Blue, and 70 and 55% at Gila-Gila (Fig. 12), suggesting feeding is more prevalent in daytime. Loach minnow further displayed an increase in fullness between afternoon and near-dark samples at Blue River and east Aravaipa, indicating crepuscular feeding. Fullness decreased steadily after onset of darkness, and likely began to increase after sunrise. Feeding also apparently slowed during early hours of the afternoon.

Loach minnow at east Aravaipa in August 1987 consumed a few representatives each of ephemeropterans, trichopterans, and dipterans, plus detritus and insects of undetermined identity and origin (Table 8). Larval chironomids were in digestive tracts at all times of day and night (6 samples), immature baetids and simuliids were absent only from early morning samples, and other foods were in one- to four collections (Table 8). Diversity of foods was greatest (10 Items) near dark (1800 hrs), and lowest (four items) in the middle of the night (Table 8). Larval chironomids and simuliids comprised a substantial proportion of the diet throughout the 24-hr period, and were the most important foods during daylight hours (Table 9). Other foods were significant during afternoon hours, and according to different measures of use: baetids

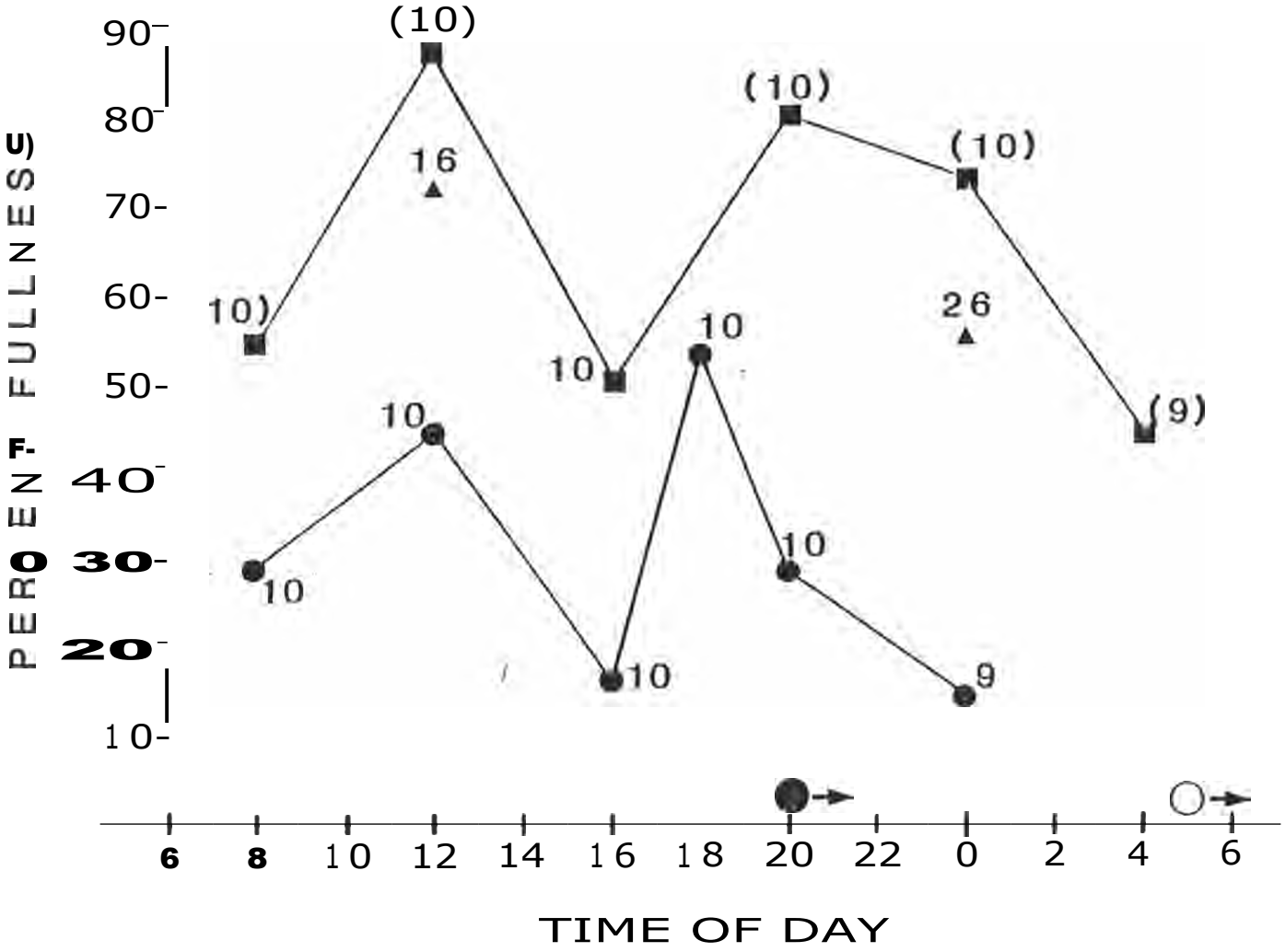

FIGURE 12. Percentage fullness of loach minnow digestive tracts collected at different times of day and night from Blue River, Greenlee County and east (upper) Aravalpa Creek, Graham County, Arizona, and Gila River at Gila, Catron County, New Mexico. Sample sizes in parentheses.

TABLE 8. Summary of digestive tract contents of loach minnow captured at different hours of day and night from East Aravaipa Creek, Arizona, August 1987 (X indicates presence).

	Time of day (hr)					
Food item	0800	1200	1600	1800	2000	0000
Ephemeroptera						
undetermined parts			X			
undetermined nymph		X		X		
Baetidae		X	X	X	X	X
Ephemerellidae				X		
Trichoptera						
undetermined adult	X	X		X	X	
undetermined larva				X		
Hellcopsychidae	X	X				
Hydropsychidae	X		X	X	X	
Hydroptilidae		X				
Diptera						
Chironomidae	X	X	X	X	X	X
Simuliidae		X	X	X	X	X
Undetermined insect parts		X	X			X
Detritus	X			X		
Sand				X		
Number of items	5	8	6	10	5	4
Number of fish	10	10	10	10	10	9
Number of empty tracts	5	1	4	0	3	5
mean fullness (%)	28	45	16	53	28	14

TABLE 9. Digestive tract contents of loach minnow captured from East Aravalpa Creek, Arizona, at different times of day and night, August 1987. Values are mean volume (V), number (N), and frequency of occurrence (F), expressed as percentage of digestive tracts containing food.

	Time of day (hr)								
	0800			1200			1600		
Food item	V	N	F	V	N	F	V	N	F
Ephemeroptera									
undet. parts	0	0	0	8	--	11	1	--	17
Baetidae	0	0	0	9	25	33	8	32	67
Trichoptera									
Undetermined adult	15	3	20	8	3	11	0	0	0
Helicopsychidae	0	0	0	1	3	11	0	0	0
Hydropsychidae	10	3	20	0	0	0	7	8	33
Hydroptilidae	4	3	20	3	3	11	0	0	0
Diptera									
Chironomidae	22	92	40	10	59	56	3	20	33
Simuliidae	0	0	0	1	6	11	7	40	17
Undet. insect parts	0	0	0	3		11	0	0	0
Detritus	3	--	20	0	0	0	0	0	0
Number of fish		10			10			10	
Mean, SD, and range in total length	45+10 (36-59)			47+13 (31-65)			54+07 (34-60)		

TABLE 9 (concluded).

	Time of day (hr)								
	0800			1200			1600		
Food item	V	N	F	V	N	F	V	N	F
Ephemeroptera									
Undetermined nymph	1	4	10	0	0	0	0	0	0
Baetldae	6	7	30	4	9	29	4	2	25
Ephemerellidae	2	2	10	0	0	0	0	0	0
Trichoptera									
Undetermined adult	19	12	40	19	12	29	0	0	0
Undetermined larva	3	3	10	0	0	0	0	0	0
Hydropsychidae	5	3	20	0	0	0	20	3	50
Diptera									
Chironomidae	2	9	20	4	33	29	4	$	50
Simuliidae	17	60	60	13	46	29	3	2	25
Undet. Insect parts	0	0	0	0	0	0	5		25
Detritus	6		40	0	0	0	0	0	0
Sand	1		10	0	0	0	0	0	0
Number of fish	10			10			09		
Mean, SD, and range in total length	46+09 (35-58)			49+11 (31-62)			55+06 (39-61)		

were volumetrically predominant at 1600 hrs, and occurred in most digestive tracts at 1600 and 2000 hrs; undetermined adult trichopterans were volumetrically most important at 1800 and 2000 hrs, and occurred in a high proportion of tracts at 2000 hrs; and larval hydropsychids were predominant by all three measures at midnight (Table 9).

Loach minnow inhabitaing Blue River in June 1987 consumed a variety of Immature ephemeropterans and trichopterans, a dipteran, a pyralid (aquatic moth), and gastropods (Table 10). Larval hydropsychids and chironomids were present in tracts collected at all times of day and night, baetids and ephemeropteran parts were in five of six samples, and other items each were in one to four samples (Table 10). Diversity among food items (excluding sand) ranged from five (0400 hrs) to nine (0800), but remained near eight during most of the day (Table 10). Nymphal baetids or undetermined ephemeropteran parts were predominant foods during daylight hours, while larval hydropsychidae, ephemeropterans, and chironomids were important at night (Table 11). Immature Ephemerellidae (Ephemeroptera) were the most important food by all three measures during evening (2000 hrs) (Table 11)

The diet of loach minnow at Gila-Gila in June 1987 consisted almost entirely of immature stages of only a few kinds of aquatic macro-invertebrates; detritus and inorganic material (sand) were found in small quantities (Table 12). During daytime (noon), the most important foods (according to method of estimation) were tricorythid mayfly nymphs and disarticulated parts of mayfly nymphs (volumetric), baetid mayfly nymphs and larval chironomids (numerical), and chironomids (frequency of occurrence). Emphemeropterans, because of their contribution to total mass of food in the gut, probably were energetically the most important daytime food. Among night-time (midnight) samples, larval hydropsychid caddisflies were predominant according to all three measures of food use. Baetids and chironomids were also Important numerically, and each occurred in at least a third of the digestive tracts. Immature ephemeropterans (in sum) plus hydropsychids were the most important night-time foods.

Diversity of foods eaten, predominant food items, and differential use of particular items during daytime and after dark were generally consistent among the three stream reaches. Furthermore, our results agree with those reported in Aravaipa Creek (Schreiber and Minckley 1981, Abarca 1987) and in the Gila River in Cliff-Gila Valley (Britt 1982, Propst et al. 1988). As stated above and by FWS (1988a), loach minnow are opportunistic benthic insectivores, which rely largely on ephemeropteran and dipteran larvae, with other insect groups becoming seasonally Important as available.

5. HABITAT INTERRELATIONS BETWEEN WILD POPULATIONS OF SPIKEDACE AND SHINER

Comparisons for spikedace

Spikedace were found to the exclusion of shiner at east and west Aravaipa Creek and Gila-Gila. Physical differences in available habitat among these three stream reaches were detailed in Section 3, above. In summary, west Aravaipa was significantly shallower than east Aravaipa and Gila-Gila, and east Aravaipa had significantly faster current

TABLE 10. Summary of digestive tract contents of loach minnow captured at different hours of day and night from Blue River, Arizona, June 1987 (X indicates presence).

	Time of day (hr)					
Food item	0800	1200	1600	2000	0000	0400
Ephemeroptera						
Undetermined parts	X	X	X		X	X
Undetermined nymph				X		
Baetidae	X	X	X	X	X	
Ephemerellidae				X	X	
Heptageniidae			X		X	
Leptophlebildae				X		
Siphlonuridae	X	X		X	X	
Tricorythidae		X	X		X	X
Trichoptera						
Undetermined parts	X	X	X			
Leptoceridae			X			
Hydropsychidae	X	X	X	X	X	X
Diptera						
Chironomidae	X	X	X	X	X	X
Lepidoptera						
Pyralidae						X
Gastropoda	X					
Sand	X	X	X		X	
Number of Items	9	7	8	8	8	5
Number of fish	10	10	10	10	10	9
Number of empty tracts	2	0	0	0	2	2
mean fullness (%)	55	88	80	80	73	44

TABLE 11. Digestive tract contents of loach minnow captured from Blue River, Arizona, at different times of day and night, June 1987. Values are mean volume (V), number (N), and frequency of occurrence (F), expressed as percentage of digestive tracts containing food.

	Time of day (hr)								
	0800			1200			1600		
Food item	V	N	F	V	N	F	V	N	F
Ephemeroptera									
Undetermined parts	26	--	63	13	--	20	19	--	89
Baetidae	19	54	38	58	74	90	9	47	22
Heptageniidae	0	0	0	0	0	0	1	4	11
Siphlonuridae	1	3	13	1	1	10	0	0	0
Siphlonuridae parts	4	--	13	0	0	0	0	0	0
Tricorythidae	0	0	0	1	1	10	2	4	44
Trichoptera									
Undetermined parts	6	--	13	2	--	10	3	--	11
Hydropsychidae	7	29	38	6	6	20	13	21	44
Leptoceridae	0	0	0	0	0	0	1	2	11
Diptera									
Chironomidae parts	1	--	13	0	0	0	0	0	0
Chironomidae	1	1	25	7	18	50	7	23	68
Gastropooda	1	3	13	0	0	0	0	0	0
Sand	3	--	50	1	--	50	1	--	11
Number of fish	10			10			09		
Mean, SD, and range in total length	43+14 (29-65)			51+14 (25-67)			46+17 (23-63)		

TABLE 11 (concluded).

	Time of day (hr)								
	2000			0000			0400		
Food item	V	N	F	V	N	F	V	N	F
Ephemeroptera									
Undetermined parts	0	0	0	10	--	13	19	--	71
Undetermined nymph	13	12	20	0	0	0	0	0	0
Baetidae	13	27	20	6	3	13	0	0	0
Ephemerillidae	26	39	50	13	3	13	0	0	0
Heptagenlidae	0	0	0	1	3	13	0	0	0
Leptophlebilidae	1	1	10	0	0	0	0	0	0
Slphlonuridae	6	1	10	18	12	50	0	0	0
Tricorythidae	0	0	0	9	3	13	21	22	58
Trichoptera									
Hydropsychidae	0	0	0	32	47	88	12	44	43
Hydroptilidae	22	16	50	0	0	0	0	0	0
Lepidoptera									
Pyralidae	0	0	0	0	0	0	1	4	14
Diptera									
Chironomidae	2	3	20	3	9	13	3	30	43
Number of fish	10			10			09		
Mean, SD, and range in total length	57+06 (47-65)			47+11 (30-55)			41+14 (28-60)		

TABLE 12. Digestive tract contents of loach minnow captured from Gila River at Gila, New Mexico, at different times of day and night, June 1987. Values are mean volume (V), number (N), and frequency of occurrence (F), expressed as percentage of digestive tracts containing food.

	Time of day (hr)					
	1200			0000		
Food item	V	N	F	V	N	F
Ephemeroptera						
Undetermined parts	18	--	31	10	--	24
Undetermined adult	0	0	0	1	1	5
Baetidae	7	20	25	9	25	33
Heptageniidae	0	0	0	1	1	5
Siphlonuridae	0	0	0	8	10	14
Tricorythidae	18	17	31	1	1	5
Trichoptera						
Undeterminde parts	10	--	31	5	--	14
Hydropsychidae	6	17	25	22	41	52
Diptera						
Chironomidae	10	46	88	5	21	38
Tabanidae	0	0	0	1	1	5
Detritus	1		6	0	0	0
Sand	1		6	1	0	10
Number of items	7			10		
Number of fish	16			24		
Number of empty tracts	0			3		
Mean fullness (%)	70			52		
Mean, SD, and range in total length	29+10 (25-66)			40+15 (24-70)		

velocity than west Aravaipa and Gila-Gila (Table 4; see also Figs. 2, 3, and 5). Characteristics of habitats occupied by spikedace are given in Table 7, and frequency distributions are in Figures 13 through 15.

Mean depth, velocity, and substrate for seine hauls that did not include spikedace (absence, n = 304) were statistically indistinguishable from mean values for the total pooled sample for the three stream reaches (available, n = 440). However, analysis of seine hauls which contained spikedace in all three systems (n = 136) indicated that the native fish occupied current velocities and substrates significantly slower (39.3 vs. 45.6 cm/s; F = 22.93; p <0.0001; N = 439) and smaller in particle size (38.0 vs. 43.6 mean particle size; F = 7.28; p = 0.007; N = 439), respectively, than those where the species was absent (Table 13; also, compare Figs. 2, 3, and 5 vs. 13-15).).

A similar analysis, performed individually for each stream, indicated slightly more variation (Table 14). Spikedace at west Aravaipa showed no statistical preference for a particular current velocity (39.9 cm/s where present vs. 37.6 cm/s where absent). On the other hand, at east Aravalpa, which had mean available current significantly swifter than the other two reaches (Tables 3 and 4), spikedace occupied current that was significantly (F = 42.32; p <0.0001; n = 98) slower on average (46.2 cm/s, n = 41) than that where the fish was absent (73.6 cm/s, n = 58)(Table 14). At Gila-Gila, spikedace also occurred in significantly (F = 8.36; p <0.004; N = 238) slower currents (34.7 vs. 40.0 cm/s), much as it did at east Aravaipa (Table 14). It seems clear based upon these analyses that spikedace occupied, apparently preferred, and may have actively sought, water of variable depth and substrate, but with significantly slower than average velocities.

Comparisons for shiner

Among sites sampled, shiner was in isolation from spikedace only at Sycamore Creek (Maricopa County, AZ), where it was collected in significantly deeper (F = 6.44; p <0.01; n = 100) and slower (F = 6.98; p <0.009; n = 100) water than where it was absent (Table 15). Habitat occupied by shiner (n = 89) averaged 14.3+10.9 cm/s current velocity, was 20.5+15.7 cm deep, and had 40.7+30.1 mean substrate size (Table 7, Fig. 16). Habitat where shiner was absent (n = 11) averaged 24.1 cm/s current velocity, 11.5 cm deep, and had 35.8 average substrate size. Available habitat (Table 3, Fig. 7) averaged 19.5+15.1 cm deep, 15.3 cm/s current velocity, and 41.9+36.0 mean weighted substrate size (n = 100).

Comparisons of spikedace vs. shiner

Spikedace and shiner co-occurred at Gila-Redrock and Verde. Habitat occupied by spikedace in syntopy with shiner (Table 7; Figs. 17 and 18) could thus be compared to that used by the native species in isolation (Table 7, Figs. 13-15).

Focus upon spikedace.--Slower water current seems influential to the distribution of spikedace (Table 4). Hence, a comparison of spikedace in isolation vs. spikedace in syntopy with shiner would involve a comparison of pooled samples from west Aravaipa and Gila-Gila (where spikedace was isolated from shiner) vs. those from Gila-Redrock

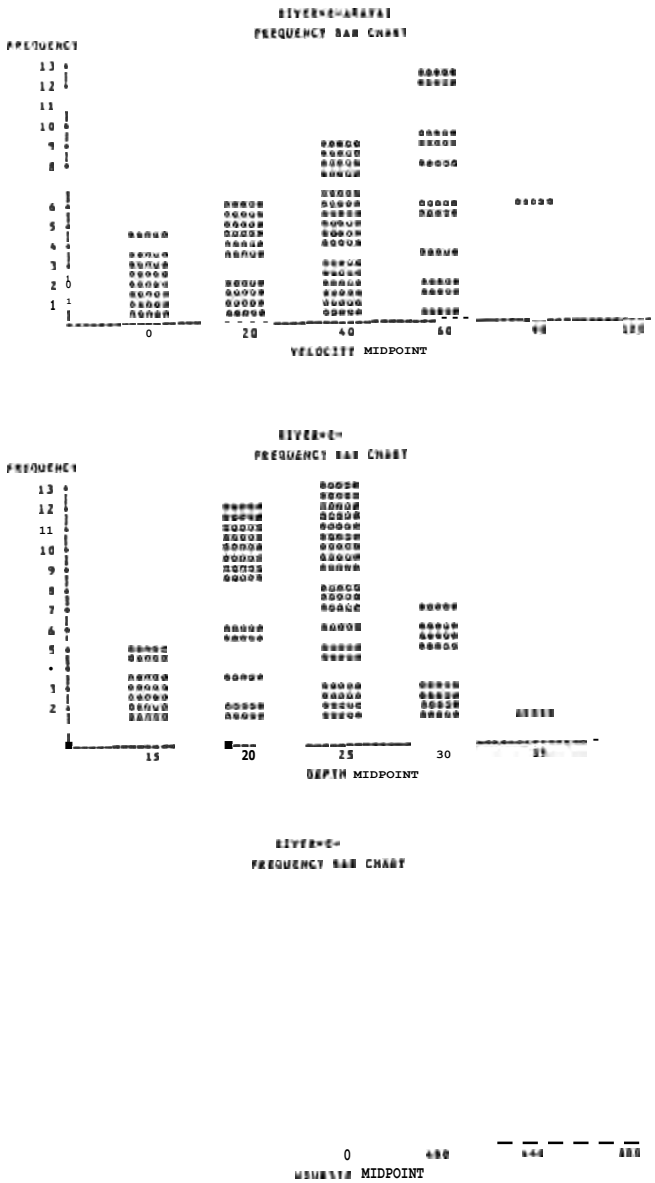

FIGURE 13. Frequency distributions of current velocity (cm/s), depth (cm), and weighted substrate particle size characterizing habitats occupied by spikedace, east (upper) Aravaipa Creek, Graham County, Arizona.

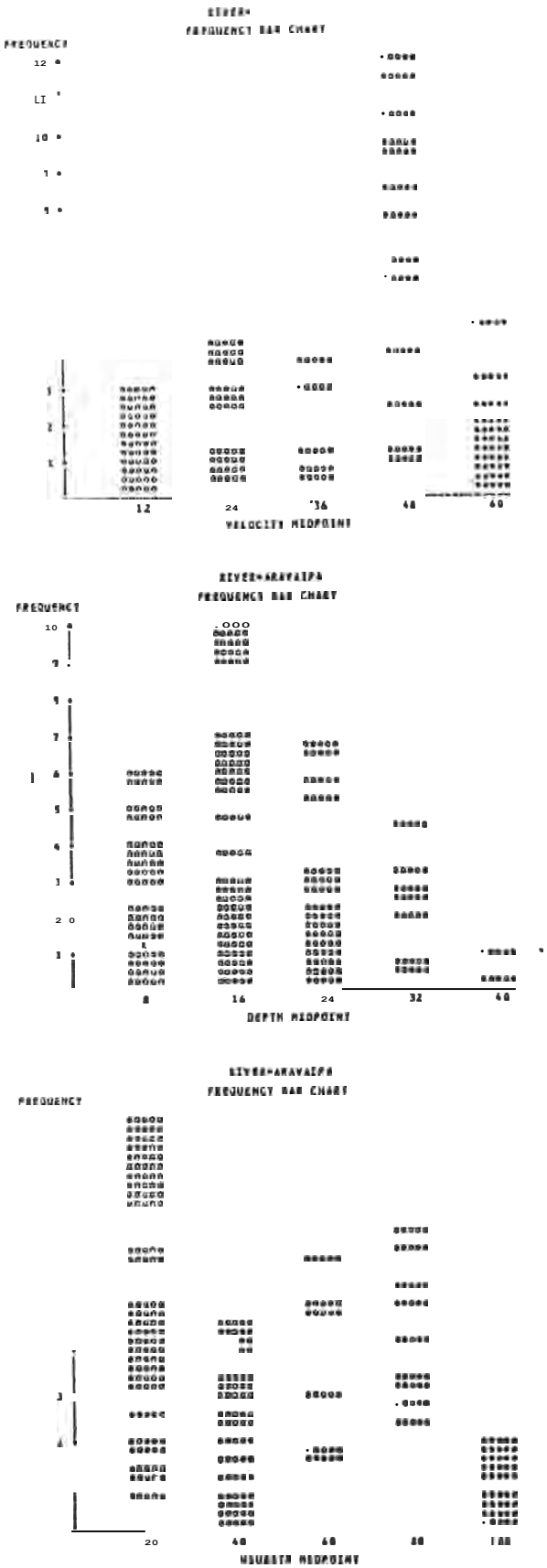

FIGURE 14. Frequency distributions of current velocity (cm/s), depth (cm), and weighted substrate particle size characterizing habitats occupied by spikedace, west (lower) Aravaipa Creek, Pinal County, Arizona.

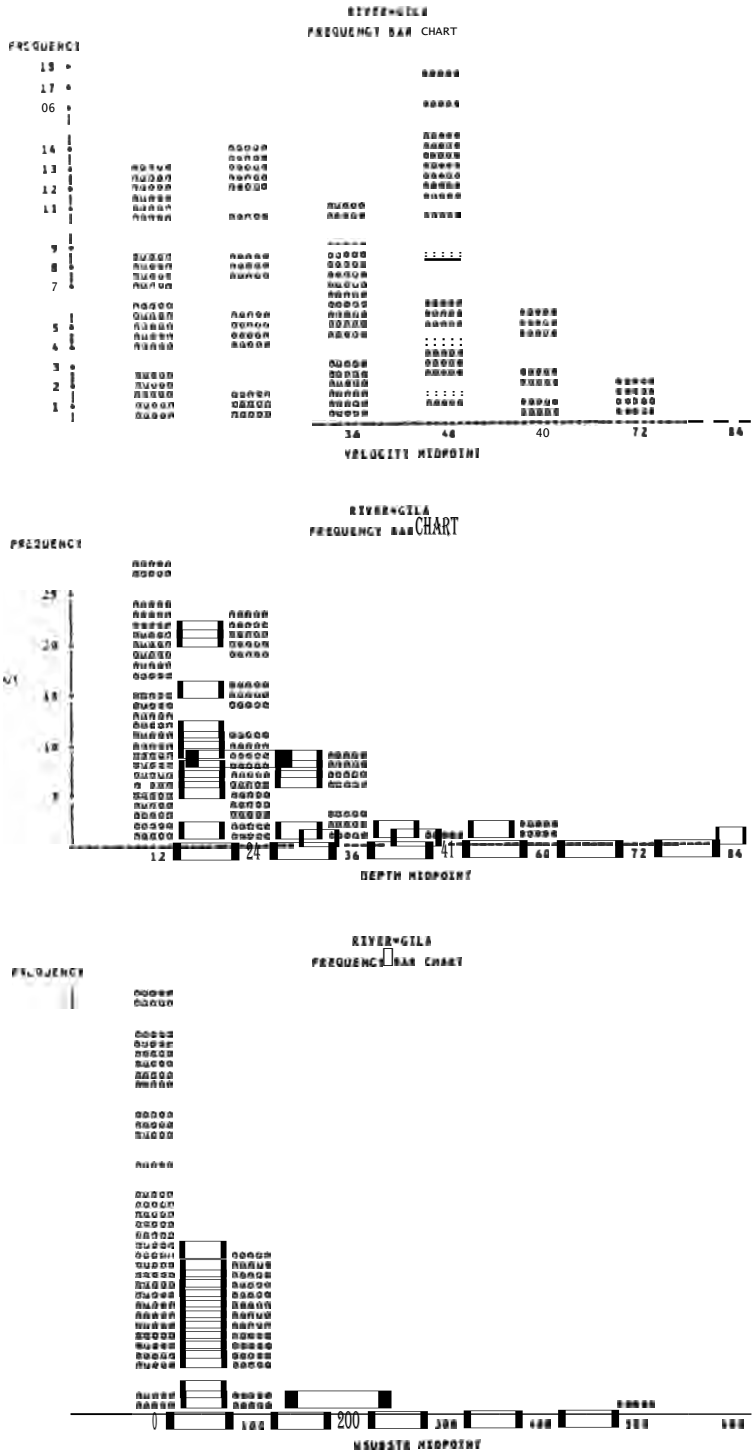

FIGURE 15. Frequency distributions of current velocity (cm/s), depth (cm), and weighted substrate particle size characterizing habitats occupied by spikedace, Gila River at Gila, Catron County, New Mexico.

TABLE 13. Results of a weighted Analysis of Variance (ANOVA) contrasting differences in habitats where spikedace was present vs. those where in was absent (occurrence) In stream reaches where spikedace was found to the exclusion of red shiner (East and West Aravaipa Creek, Arizona, and Gila River at Gila, New Mexico). Values are log-depth, velocity (cm/s), log-substrate, and sample size (n).

Occurrence	L-depth	Velocity	L-substrate	
Present	1.324	39.3*	1.580**	136
Absent	1.331	45.6	1.639	304

* F = 22.93; p < 0.0001; n = 439
** F = 7.28; p < 0.0070; n = 439

TABLE 14. Results of a weighted Analysis of Variance (ANOVA) contrasting differences in habitats where spikedace was present vs, those where in was absent within each stream reach where spikedace was found to the exclusion of red shiner (East and West Aravaipa Creek, Arizona, and Gila River at Gila, New Mexico). Values are log-depth, velocity (cm/s), log-substrate, and sample size (n).

Stream reach	Occurrence	L depth	Velocity	L Substrate	
East Aravaipa	present	1.389	46.2*	1.752**	41
	absent	1.357	73.6	1.384	48
West Aravaipa	present	1.274	39.9	1.626	29
	absent	1.276	36.7	1.653	73
Gila-Gila	present	1.306	34.7***	1.574	66
	absent	1.345	40.0	1.615	173

* F = 42.32; p < 0.0001; n = 98
** F = 6.27; p < 0.0100; n = 98
*** F = 8.36; p < 0.0040; n = 238

TABLE 15. Results of a weighted Analysis of Variance (ANOVA) contrasting differences in habitats where red shiner was present vs. those where in was absent within Sycamore Creek, Arizona, where red shiner was found to the exclusion of spikedace. Values are log-depth, velocity (cm/s), log-substrate, and sample size (n).

Occurrence	L-depth	Velocity	L-substrate	
Present	1.256*	14.3**	1.497	89
Absent	1.061	24.1	1.554	11

* F = 6.44; p < 0.010; n = 100
** F = 6.98; p < 0.009; n = 100

TABLE 16. Results of a weighted Analysis of Variance (ANOVA) contrasting differences in habitats occupied by spikedace in West Aravalpa Creek, Arizona and the Gila River at Gila, New Mexico (where spikedace was found to the exclusion of red shiner) vs. the Gila River at Redrock, New Mexico and Verde River, Arizona (where spikedcae and red shiner were found together). Values are log-depth, velocity (cm/s), log-substrate, and sample size (n).

Stream reaches	L-depth	Velocity	L-substrate	
West Aravalpa and Gila-Gila	1.296*	36.3**	1.590***	95
Gila-Redrock and Verde	1.461	40.4	1.876	46

* F = 34.57; p < 0.0001; n = 141
** F = 4.34; p < 0.0300; n = 141
*** F = 16.68; p < 0.0001; n = 141

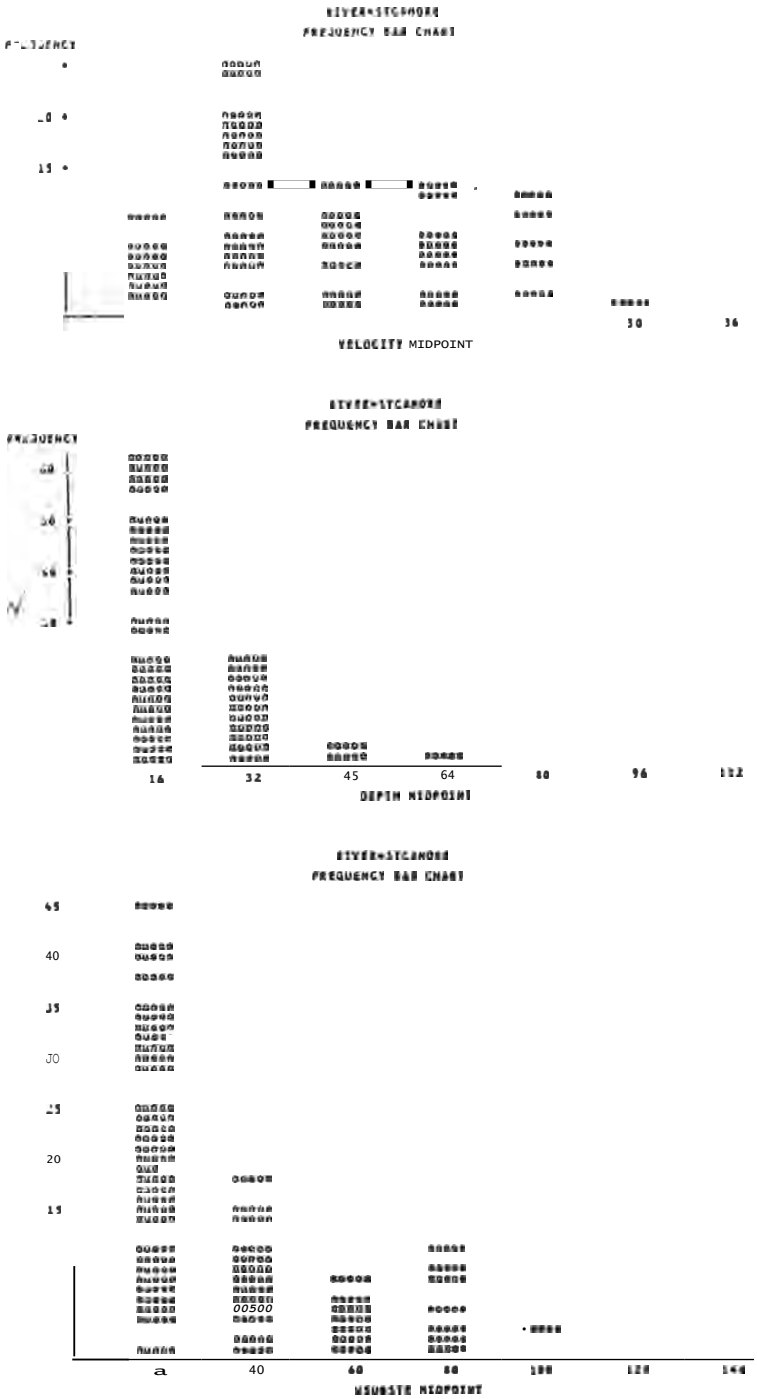

FIGURE 16. Frequency distributions of current velocity (cm/s), depth (cm), and weighted substrate particle size characterizing habitats occupied by red shiner, Sycamore Creek, Maricopa County, Arizona.

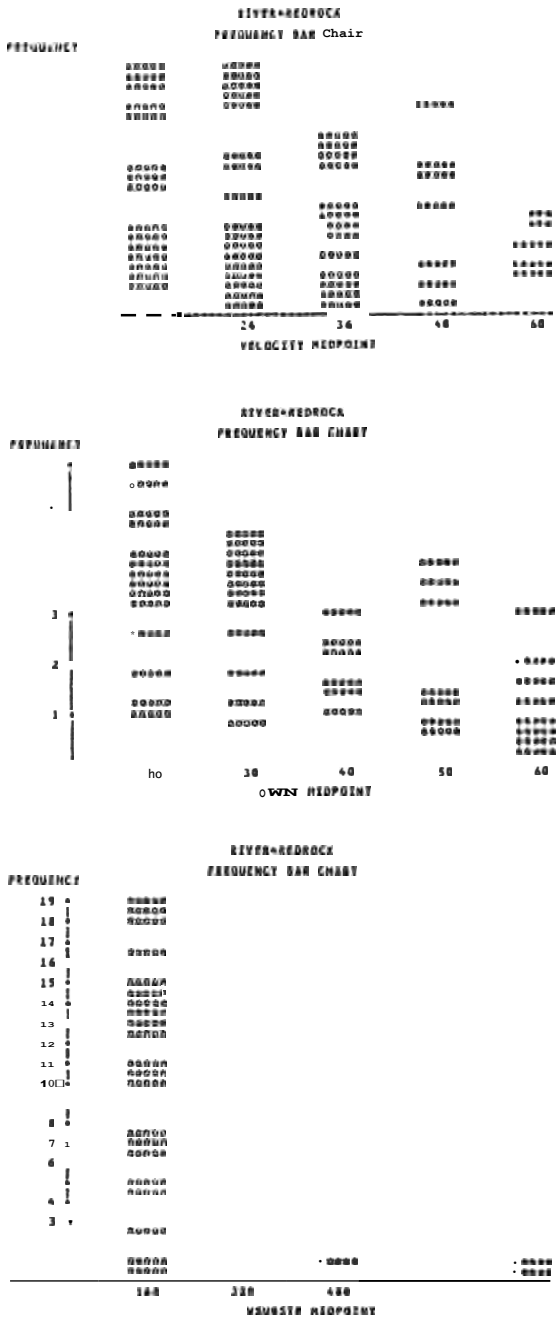

FIGURE 17. Frequency distributions of current velocity (cm/s), depth (cm), and weighted substrate particle size characterizing habitats occupied by spikedace, Gila River at Redrock, Catron County, New Mexico.

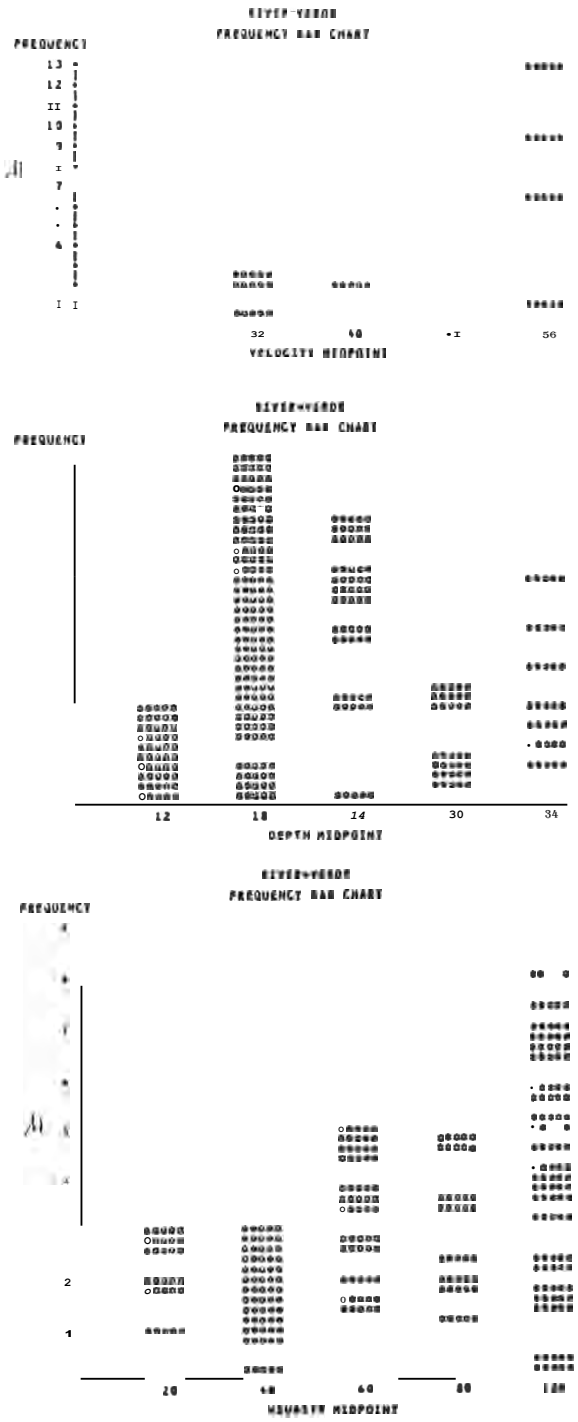

FIGURE 18. Frequency distributions of current velocity (cm/s), depth (cm), and weighted substrate particle size characterizing habitats occupied by spikedace, Verde River, Yavapai County, Arizona.

and Verde (where spikedace occurred in syntopy with shiner). East Aravaipa (where spikedace was also found in isolation from shiner) was excluded from this particular analysis because it had significantly faster available current speed (Table 4), which would add unnecessary complexity to the analysis.

Habitats of these streams were detailed in Section 3 (see Table 5; Figs. 3, 5, 6, and 8). In summary, available habitat for the four selected stream reaches did not differ significantly with regard to current velocities. However, west Aravaipa and Gila-Gila were significantly shallower than the others, and both Gila-Redrock and Verde differed significantly from the other stream reaches as regards average substrate particle size.

An analysis evaluating presence of spikedace in pooled samples from west Aravaipa and Gila-Gila (where it occurred in isolation) vs. Gila-Redrock and Verde (where it was syntopic with shiner) showed that spikedace when alone inhabited significantly shallower waters with slower current speeds, over smaller substrates (Table 16). Spikedace at west Aravalpa and Gila-Gila vs. Gila-Redrock and Verde occupied water respectively averaging 19.8 cm vs. 28.9 cm deep ($F = 34.57$; $p < 0.0001$; $n = 141$), 36.3 cm/s vs. 40.4 cm/s current velocity ($F = 4.34$; $p < 0.03$; $n = 141$), and 38.9 vs. 75.2 weigted substrate size ($F = 16.68$; $p < 0.0001$; $n = 141$). Habitat use by spikedace was thus significantly different in isolation as compared with syntopy with shiner, particularly as regards current velocity. Depth and weighted substrate (also significant in Table 16) cannot be accepted as different because these parameters differed significantly between the two groups of streams (Table 5).

These results confirm previous indications that spikedace occupy and may select significantly slower currents in variable depths. Although smaller substrate sizes may play a role here as well, the role of current velocity seems most demonstrative.

<u>Focus upon red</u> shiner.--Although spikedace was the primary focus of our study, we felt that it was necessary to perform a brace of analyses to evaluate habitat use of the introduced shiner. In this way, a better understanding could be gained of the displacement potentials exhibited by this transplanted generalist.

Following our previous protocol, the habitat available for use by shiner was first quantified in those streams in which the species occurred (Section 3; Table 6). Sycamore Creek (Fig. 7) was significantly shallower and slower than Gila-Redrock (Fig. 6) and Verde (Fig. 8), and all three streams differed significantly with regard to substrate particle size (Table 6).

Habitat occupation by shiner in these streams (Figs. 16, 19, and 20) involved water of variable depths, but significantly ($F = 86.2$; $p < 0.0001$; $n = 299$) slower current velocities (19.4 cm/s where present vs. 37.6 cm/s where absent), passing over bottoms consisting of significantly ($F = 18.0$; $p < 0.0001$; $n = 299$) smaller substrate sizes (45.9 vs. 78.7) (Table 17).

A similar evaluation, but based on Individual streams, was more variable (Table 18). Shiner at Verde showed no significant differences in habitat use with regards to its occurrence vs. its absence. However, at Sycamore and Gila-Redrock, shiner occupied slower and deeper water than that where the species was absent. Occupied vs. unoccupied habitats (Table 18) at Sycamore respectively averaged 18.0 vs. 11.5 cm

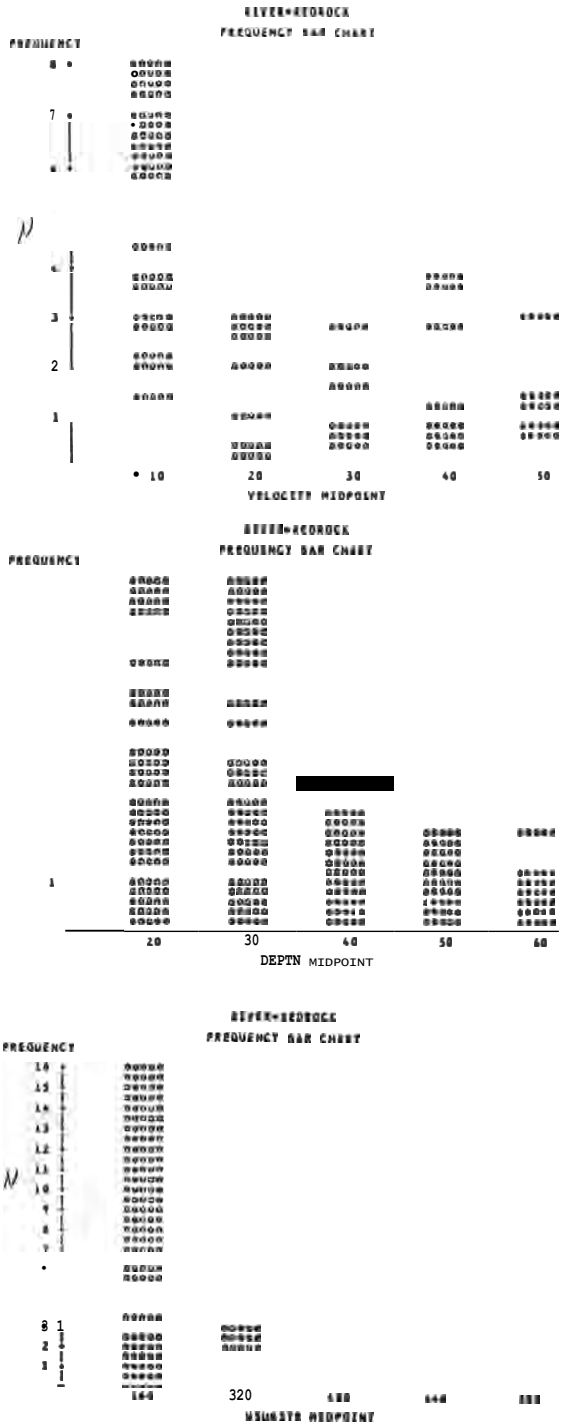

FIGURE 19. Frequency distributions of current velocity (cm/s), depth (cm), and weighted substrate particle size characterizing habitats occupied by red shiner, Gila River at Redrock, Catron County, New Mexico.

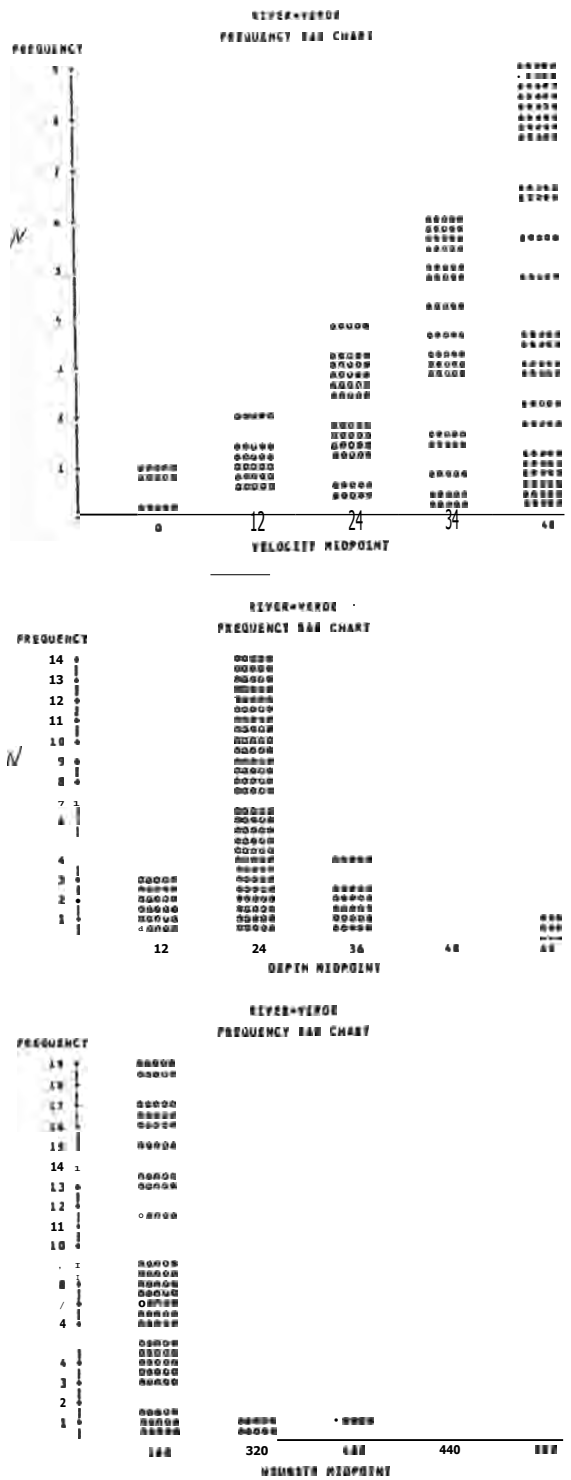

FIGURE 20. Frequency distributions of current velocity (cm/s), depth (cm), and weighted substrate particle size characterizing habitats occupied by red shiner, Verde River, Yavapai County, Arizona.

TABLE 17. Results of a weighted Analysis of Variance (ANOVA) contrasting differences in habitats where red shiner was present vs. those where in was absent across three stream reaches where the species was found (Gila River at Redrock, New Mexico, and Sycamore Creek and Verde River, Arizona. Values are log-depth, velocity (cm/s), log-substrate, and sample size (n).

Occurrence	L-depth	Velocity	L-substrate	
Present	1.314	19.4*	1.662**	132
Absent	1.395	37.6	1.896	167

* F = 86.2; p < 0.0001; n = 299
** F = 18.0; p < 0.0001; n = 299

TABLE 18. Results of a weighted Analysis of Variance (ANOVA) contrasting differences in habitats where red shiner was present vs. those where in was absent within each stream reach where the species was found. Values are log-depth, velocity (cm/s), log-substrate, and sample size (n).

Stream reach	Occurrence	L depth	Velocity	L Substrate	
Gila-Redrock	present	1.483*	23.5**	2.155	21
	absent	1.384	38.5	1.989	68
Sycamore	present	1.256***	14.3****	1.497	89
	absent	1.061	24.1	1.554	11
Verde	present	1.387	36.2	1.857	88
	absent	1.446	38.6	1.867	22

* F = 5.32; p < 0.020; n = 89
** F = 11.20; p < 0.001; n = 89
*** F = 6.44; p < 0.010; n = 100
**** F = 6.97; p < 0.009; n = 100

deep (F = 6.44; p <0.01; n = 100) and 14.3 vs. 24.1 cm/s current velocity (F = 6.97; p <0.009; n = 100), and at Gila-Redrock averaged 30.4 vs. 24.2 cm deep (F = 5.32; p <0.02; n = 89) and 23.5 vs. 38.5 cm/s current velocity (F = 11.20; p <0.001; n = 89). Shiner thus appeared to occupy similar habitat wherever it occurred, whether alone (Sycamore, Fig. 16) or In syntopy with spikedace (Gila-Redrock, Fig. 19). This habitat consisted of deeper and slower water than was generally available.

Syntopy: habitat utilization in the same stream.--Spikedace and shiner co-occurred only at Gila-Redrock and Verde. It was previously demonstrated (Table 5) that these two stream reaches had statistically similar mean depths and current velocities, while average substrate size was significantly smaller at Verde.

One method to evaluate possible interactions between spikedace and shiner is to compare differences in habitat use within the same stream. At Verde, shiner (in samples that did not include spikedace) occurred in current velocities significantly (F = 7.86; p <0.001; n = 41) slower than those In which spikedace were also found (i.e., 32.6 vs. 48.4 cm/s, Table 19). Mixed samples of shiner and spikedace occurred in significantly shallower water (19.1 vs. 26.1 cm deep; F = 7.78; p <0.001; n = 41) and over smaller substrates (49.3 vs. 80.0 weighted particle size; F = 3.65; p <0.035; n = 41) than samples In which shiner was collected alone (Table 19),

At Gila-Redrock, there were no statistical differences between depth, velocity, or substrate where shiner or spikedace occurred to the exclusion of the other species (Table 19). Although spikedace in the absence of shiner were In faster current, the relationship was not statistically significant. Spikedace and shiner were captured together in significantly (F = 3.48; p <0.04; n = 34) deeper water than that occupied by either species alone at Gila-Redrock (average 43.6 cm for mixed samples, 24.5 cm for shiner, and 30.5 cm for spikedace) (Table 19). In addition, shiner in syntopy with spikedace occupied slower water velocities (mean 24.4 cm/s), similar to that which it used when in isolation from the native species (21.4 cm/s).

Syntopy: habitat use In different streams.--Rather than compare differences in habitat occupied within each stream by various species-combinations (i.e., spikedace and shiner alone or in mixed samples), a second method is to evaluate use by each combination across stream reaches using weighted analyses (Table 20). In this approach, shiner showed no significant differences in occupied habitat at Verde or Gila-Redrock. The same relationship held for spikedace (i.e., the native fish occupied that same habitat when alone at both Gila-Redrock and Verde). Thus, while each species occupied the same habitat within both streams (Table 20), their habitats differed between streams, with shiner occupying slower average currents at both Gila-Redrock and Verde (Table 19). Slower current speeds have previously been demonstrated as those used, and possibly preferred, by spikedace (Table 16).

Thus, spikedace, when in syntopy with shiner, occupied and may select current velocities significantly faster than those In which they occurred when in isolation. Displacement due to some level of species interaction is therefore indicated.

TABLE 19. Results of a weighted Analysis of Variance (ANOVA) contrasting habitats occupied by spikedace and red shiner in stream reaches where the two species occurred together. Weighted analyses were performed for those samples (seine hauls) in which spikedace and red shiner each was captured alone, and for those In which the two species were captured together. Values are log-depth, velocity (cm/s), log-substrate, and sample size (n).

Stream reach	Species	L depth	Velocity	L substrate	
Gila-Redrock	spikedace	1.485	35.6	1.836	14
	red shiner	1.405	24.4	2.126	14
	both	1.639*	21.7	2.213	7
Verde	spikedace	1.427	48.3	1.831	20
	red shiner	1.417	32.6**	1.903	17
	both	1.282***	48.2	1.693****	5

* F = 3.48; p < 0.040; n = 34
** F = 7.86; p < 0.001; n = 41
*** F = 7.78; p < 0.001; n = 41
**** F = 3.65; p < 0.035; n = 41

TABLE 20. Results of a weighted Analysis of Variance (ANOVA) contrasting habitats occupied by spikedace and red shiner In stream reaches where the two species co-occurred. Values are log-depth, velocity (cm/s), log-substrate, and sample size (n).

Species	Stream reach	L depth	Velocity	L substrate	
Spikedace	Gila-Gila	1.485	35.6	1.831	14
	Verde	1.427	48.3	1.836	20
Red shiner	Gila-Gila	1.405	24.4	2.126	14
	Verde	1.412	32.3	1.903	17

Comparisons with other data

Propst et al. (1987) reported quantitative estimates for selected physical parameters of habitats occupied by spikedace in the Cliff-Gila Valley reach of the Gila River, NM. Measurements were taken at specific points where one or more spikedace were captured by seine. They demonstrated ontogenetic and seasonal shifts in microhabitat use, and suggested that geographical differences might also exist.

In their study, Juvenile (26 to 35 mm TL) spikedace were found in water averaging 16.8 cm/s current velocity and 16.1 cm deep (n = 219), while adults (≥36 mm TL) occupied water that was significantly (chi-square test, p = 0.05) swifter (49.1 cm/s) but of similar depth (19.3 cm) (n = 189).

In a geographical comparison, adult spikedace occupied significantly swifter and shallower water at their Cliff-Gila than Forks study sites (respectively 36.3 vs. 21.0 cm/s and 10.2 vs. 21.3 cm). However, they suggested that apparent geographical differences may actually have been due to local differences between streams.

Propst et al. (1987) further compared microhabitat use by adult spikedace during warm (June to November) and cold (December to May) seasons at the Cliff-Gila and Forks sites. At Cliff-Gila, occupied habitat was significantly swifter during warm vs. cold seasons (49.1 vs. 39.4 cm/s), but similar as regards depth (19.3 vs. 18.2 cm). In contrast, at the Forks site, occupied velocities were similar during the two seasons (18.8 vs. 21.4 cm/s), but depths were significantly greater during the warm (23.1 cm) than cold season (17.3 cm). They suggested that shifts in apparent habitat use was due to a combination of selection for and differential availability of specific microhabitats.

Habitats occupied by spikedace in Aravaipa Creek during winter, spring, and summer seasons were examined by Rinne and Kroger (in press). Few significant differences were found between occupied and unoccupied habitats during any season, and use appeared related to availability. Seasonal differences in occupied habitat showed no discernable pattern. Means of occupied depth, current velocity, and substrate, respectively, were 20 cm, 35 cm/s, and gravel-pebble (3-64 mm). Larger schools of spikedace (210 fish), compared with individuals alone, were in deeper (27 vs. 16 cm) and slower (25 vs. 37 cm/s) water.

The above estimates broadly overlap and are generally congruent with ours for habitats occupied by spikedace (life stages combined) in five stream reaches, which varied in current velocity from 31.0 to 48.3 cm/s and in depth from 19.5 to 36.1 cm (Table 7). Habitats occupied by spikedace in our samples from the Gila River at Gila, NM, within the study area of Propst et al (1987), averaged 34.7 cm/s current velocity and 22.0 cm deep. Rinne and Kroger (in press) did not specify their sample localities in Aravaipa Creek; our data for two locations in that stream indicated habitats occupied by spikedace had mean depths of 19.8 and 24.2 cm, and current velocities of 39.9 and 46.2 cm/s (Table 7). Minor differences among the various data sets undoubtedly reflect a combination of factors, including different sampling protocols, and influences of demonstrated ontogenetic, seasonal, and geographic differences in microhabitat use. Because Propst et al. (1987) did not estimate habitat availability, nor was the shiner a target for their or Rinne and Kroger's investigations; further comparisons with our data are not indicated.

Few quantitative data are available on shiner habitats; none are from the arid southwest. Matthews and Hill (1979) reported that red shiner in the South Canadian River, OK, consistently selected water deeper than 20 cm with negligible current. The species typically avoided turbulent flow, unsheltered areas, and clean, unstable sand bottoms. Shiner in streams of the Gila basin were found primarily in water deeper than 20 cm, and with at least moderate current velocity (Tables 7, 15; Fig. 17). These differences likely are due to availability. Otherwise, qualitative features of occupied habitats do not appear distinctive for the shiner in its native range compared to that in the arid southwest.

6. COMPARATIVE ANALYSIS OF FOOD USE AMONG WILD POPULATIONS OF SPIKEDACE AND RED SHINER

Competition between spikedace and shiner for food resources is another form of interaction that could adversely impact the native minnow. Demonstration of competition for food requires, in a strict sense, that both species have an obligate requirement at the same time for the same resource, and that the resource be available in limited supply. However, other forms of interference may occur if the two fishes utilize the same foods, even if the resource is neither an obligate requirement nor limiting. We attempted to examine the possibility of competition or other interference interaction between spikedace and shiner by comparative analysis of food habits and resource availabiltiy of wild populations.

Food habits of spikedace

Foods of spikedace from Verde River in June 1987 were predominated by post-emergent, adult trichopterans, which comprised 75% of total volume and 61% of total number of food items, occurred in 91% of digestive tracts, and had an index of relative importance (IRI) greater than 10,500 (Table 21). Other commonly-consumed foods included plant seeds, ephemeropteran nymphs, hydropsychid larvae, chironomid larvae, adult veliids, and larval pyralids, however, these each contributed at most 7.0% to total volume of eaten. Dietary diversity of spikedace in Verde River was low (10 items) compared with that at other sites (see below); however, that result may in part be due to the small sample size. Analyses of additional specimens (n = 50) collected in August 1989 will be reported by Francisco J. Abarca.

Trichopteran pupae were predominant among foods of 60 spikedace collected from Aravaipa Creek in August 1987. These contributed 28% of total volume and 30% of total numbers, occurred in 28% of digestive tracts, and had an IRI of 1662 (Table 22). Immature forms of benthic insects, especially baetid nymphs, emergent adults, and terrestrial invertebrates were among other important forms. Diversity of foods was higher among fish from Aravaipa Creek (23 items) than from Verde River.

Spikedace from Gila River in June 1987 (n = 43) consumed primarily ephemeropteran nymphs and trichopteran larvae, which predominated volume and numbers, had highest frequencies of occurrence, and largest IRSs (Table 23). Items of relatively minor importance were adults and larvae

TABLE 21. Digestive tract contents of spikedace (n = 11) captured from Verde River, Arizona, June 1987. Values are mean volume (V), number (N), and frequency of occurrence (F), expressed as percentage of stomachs containing food, and index of relative Importance, IRI = F(V + N); tr = trace (< 0.5).

Food item	V	N	F	IRI
Ephemeroptera				
Undetermined adult	5	2	9	62
Undetermined nymph	tr	2	9	23
Slphlonuridae	2	3	18	97
Hemiptera				
Velildae	2	2	9	31
Trichoptera				
Undetermined adult	69	59	82	10536
Hydropsychidae adult	5	2	9	62
Hydropsychidae	7	7	27	367
Lepidoptera				
Pyralidae	4	3	18	138
Diptera				
Chironomidae	2	21	27	632
Plant material				
Seeds	2		9	

TABLE 22. Digestive tract contents of spikedace (n = 60) captured from east (upper) Aravaipa, Arizona, August 1987. Values are mean volume (V), number (N), and frequency of occurrence (F), expressed as percentage of stomachs containing food, and Index of relative Importance, IRI = F(V + N); tr = trace (< 0.5).

Food item	V	N	F	IRI
Ephemeroptera				
Undetermined adult	tr	2	3	8
Undetermined nymph	tr	2	2	4
Baetidae parts	2	tr	2	4
Baetidae	9	21	18	554
Siphlonuridae	tr	tr	2	2
Tricorythidae	tr	tr	2	2
Trichoptera				
Undetermined adult	6	6	7	2
Undetermined pupa	28	30	28	1662
Undetermined parts	2	--	2	--
Hydropsychidae	6	10	10	163
Hydroptilidae	tr	tr	2	2
Coleoptera				
Undetermined adult	3	3	3	18
Diptera				
Undetermined adult	1	2	3	9
Undetermined pupa	tr	tr	2	2
Ceratopogonidae	tr	tr	2	2
Chironomidae	1	6	3	24
Simuliidae pupa	tr	tr	2	3
Simuliidae	5	9	15	209
Formicidae	6	4	8	86
Undetermined Insect parts	10		27	
Undetermined Insect eggs	9		23	
Plant Material				
Seeds	2		15	
Detritus	5		15	

TABLE 23. Digestive tract contents of spikedace (n = 43) captured from Gila River at Gila, New Mexico, June 1987. Values are mean volume (V), number (N), and frequency of occurrence (F), expressed as percentage of stomachs containing food, and index of relative importance, IRI = F(V + N); tr = trace (< 0.5).

Food item	V	N	F	IRI
Ephemeroptera				
Undetermined parts	31		47	
Undetermined adult	2	2	2	8
Undetermined nymph	3	5	7	60
Baetidae	3	15	16	304
Heptageniidae	10	15	19	463
Siphlonuridae	2	2	5	15
Siphlonuridae parts	3		7	
Odonata				
Anisoptera	1	tr	2	4
Hemiptera				
Corixidae parts	tr	tr	2	4
Corixidae adult	1	2	5	13
Naucoridae	tr	2	5	10
Trichoptera				
Undetermined parts	16		26	
Undetermined larva	2	4	5	27
Hydropsychidae	12	41	40	2108
Lepidoptera				
Pyralidae	tr	tr	2	2
Diptera				
Chironomidae	2	9	21	210
Simuliidae	tr	tr	2	3
Gastropoda	tr		2	
Formicidae	tr	tr	2	3
Arachnida	tr	tr	2	2
Undetermined Insect parts	tr	tr	2	2
Detritus	6		19	
Sand	tr		2	

of other aquatic insect groups, and miscellaneous materials. Diversity of foods among spikdace from Gila River was the same as those from Aravaipa Creek (23 items); although some items differed qualitatively (compare Tables 22 and 23).

Diets of spikedace were similar among Verde River, Aravaipa Creek and Gila River, In that trichopterans, either larvae, pupae, or adults were in each instance the most important single food. Immature ephemeropterans were also important contributors to total biomass eaten for spikedace from Gila River; this group was relatively less important to fish from Aravaipa Creek, and scarcely used by spikedace from Verde River. Our results were unremarkable in comparison to data for spikedace in the upper Gila basin, NM (Anderson 1978) and Aravaipa Creek (Schreiber and Minckley 1981, Barber and Minckley 1983), which indicated that ephemeropterans and trichopterans were among most important foods. These last studies further demonstrated seasonal and ontogenetic changes in diet, which we did not examine.

Spikedace and shiner co-occurred only among our samples from Verde River, and the native in that stream had lowest diversity of diet among sites examined. It is unknown if that situation related to presence of shiner, availability of resources, small sample size, seasonal (short-term) variability in foods consumed, or other factors.

Food habits of red shiner

A total of 32 food Items representing nine major categories was identified from our June 1987 sample of shiner (n = 186) from the Verde River. Organic matter, adult and nymphal ephemeropterans, larval Hydropsychidae and Chironomidae, and unidentified insect parts were the most important contributors of volume and numbers of foods eaten, and had highest frequencies of occurrence and IRI (Table 24). Larval chironomids were numerically most important. Although several foods were consumed in trace quantities, there was a relatively even contribution among the various Items.

Foods of 205 shiners from Sycamore Creek in October 1987 were predominated by amorphous organic matter, a variety of larval and adult dipterans, coleopterans, and minor insect groups (Table 25). Chironomid larvae were numerically most abundant. Diversity of consumed foods (48 items among nine major categories) was highest among species and sites examined. Contributions of individual foods were well distributed within the total diet.

Diet of red shiner in a variety of habitats included plankton, aquatic and terrestrial invertebrates, algae, vascular plant material, and young of other fishes (Hale 1963, Divine 1968, Laser and Carlander 1971, Becker 1983), but studies of food habits in small southwestern streams are unknown to us. In the lower Colorado River, a system quite unlike our study area, shiner consumed primarily detritus, zooplanktonic crustaceans, and a suite of benthic and terrestrial invertebrates often dominated by chironomids (Minckley 1982, Marsh and Minckley 1987). The species thus appears omnivorous wherever it is found, with detritus and chironomids as consistently important dietary components; other foods are added opportunistically, as available.

Compared with spikedace, shiner consumed a wider variety of food types with less apparent reliance on one to a few major resources (compare among Tables 21-25). Ephemeropterans and trichopterans

TABLE 24. Digestive tract contents of red shiner (n = 186) captured from Verde River, Arizona, June 1987. Values are mean volume (V), number (N), and frequency of occurrence (F), expressed as percentage of stomachs containing food, and index of relative importance, IRI = F(V + N); tr = trace (< 0.5).

Food item	V	N	F	IRI
Ephemeroptera				
Undetermined adult	16	29	13	611
Undetermined parts	8		17	--
Undetermined nymph	2	tr	2	5
Baetidae	1	1	4	8
Odonata				
Anisoptera	tr	tr	tr	tr
Hemiptera				
Cicadellidae adult	tr	tr	2	2
Corixidae parts	tr		tr	
Corixidae adult	tr	tr	2	2
Trichoptera				
Undetermined adult	2	2	4	15
Undetermined parts	3	--	10	--
Undetermined larva	2	2	3	10
Glossosomatidae	tr	2	tr	1
Hydropsychidae	8	9	22	381
Leptoceridae	tr	tr	3	4
Lepidoptera				
Pyralidae	6	5	13	140
Coleoptera				
Undetermined parts	tr		tr	
Undetermined adult	tr	tr	1	tr
Elmidae larva	tr	tr	tr	tr
Diptera				
Undetermined parts	3		12	
Undetermined adult	tr	1	2	4
Chironomidae	7	41	40	1932
Simuliidae	tr	tr	tr	tr

(continued).

TABLE 24 (concluded).

Food Item	V	N	F	IRI
Undetermined insect parts	17		25	
Undetermined Insect eggs	5		9	
Undetermined fish	tr	1	tr	1
Gastropoda	tr	2	2	4
Cestoda	1	tr	3	6
Nematoda	tr	tr	2	1
Plant Material				
Vascular	tr		tr	
Filamentous alga	2		10	
Nostoc	tr		tr	
Detritus	11		25	280

TABLE 25. Digestive tract co ntents of red shiner (n = 205) captured from Sycamore Creek, Arizona, October 1987. Values are mean volume (V), number (N), and frequency of occurrence (F), expressed as percentage of stomachs containing food, and Index of relative importance, IRI = F(V + N); tr = trace (< 0.5).

Food item	V			IRI
Ephemeroptera				
Undetermined parts	tr		2	
Undetermined nymph	tr	tr	2	3
Baetidae	tr	1	2	3
Odonata				
Anisoptera	1	tr	tr	1
Coenagrionidae	tr	tr	tr	1
Libellulidae	tr	tr	tr	tr
Gomphidae	tr	tr	tr	tr
Hem iptera				
Velliidae		tr	tr	1
Trichoptera				
Undetermined adult	2	1	3	11
Undeterminde larva	1	1	2	6
Hydropsychidae	3	2	5	29
Hydroptilidae	tr	tr	tr	2
Lepidoptera				
Pyralidae	2	1	2	4
Coleoptera				
Undetermined adult	3	3	4	19
Undetermined larva	tr	tr	tr	tr
Dytiscidae larva	2	3	3	14
Elmidae larva	tr	1	2	4
Gyrinidae larva	1	tr	tr	1
Haliplidae larva	tr	tr	tr	tr
Hydroptilidae larva	4	8	10	125
Diptera				
Undetermined adult	6	12	7	124
Undetermined pupa	1	1	3	11
Undetermined larva	tr	tr	tr	tr
Ceratopogonidae adult	2	tr	2	5
Ceratopogonidae	2	2	7	32
Chironomidae	3	20	19	438
Culicidae	tr	tr	tr	tr
Ephydridae	tr	tr	tr	tr
Stratiomyidae	4	5	9	81
Tabanidae	1	tr	tr	2
Tipulidae	tr	tr	tr	tr

(continued).

TABLE 25 (concluded).

Food item	V	N	F	IRI
Gastropoda	tr	tr	tr	1
Cestoda	tr	tr	tr	tr
Nematoda	2	8	7	76
Ostracoda	tr	1	2	3
Turbellaria	tr	tr	tr	tr
Arachnida	1	2	4	14
Formicidae	5	4	9	90
Hymenoptera	tr	tr	tr	tr
Taeniopterygidae	1	tr	tr	1
Undetermined insect parts	9		10	
Undetermined insect eggs	2		2	
Plant material				
Seeds	tr	tr	tr	
Vascular			2	
Filamentous alga	2		9	
Detritus	21		43	
Sand	2		3	

constituted major foods of splkedace, while shiner consumed primarily organic matter and larval chironomids along with a diverse suite of other items. Based on simple inspection, there appeared few similarities in food resource use by spikedace and shiner.

Quantitative measures of dietary overlap

Three overlap indices (Horn 1966, Levins 1968, and Schoener 1970) were calculated on bases of both volumetric and numerical percentages. The Horn and Schoener indices give a maximum potential range of values from 0 (no overlap) to 1.0 (complete overlap), while that of Levins ranges from 0 to slightly more than 1.0. Index values exceeding 0.60 are generally considered biologically meaningful (i.e., indicative of dietary overlap that could Imply competition between species; Zaret and Rand 1971, Mathur 1977, Wallace 1981); however, we are unaware of any statistical justification for that assumption.

There was no "significant" (i.e., >0.60) overlap by any measure in foods consumed by splkedace and shiner taken together in samples from Verde River, where the two species were syntopic (Table 26). Among 10 other, hypothetical combinations (30 estimates of overlap), there were only two Instances where significant values were obtained (i.e., Schoener Index = 0.686 for volume percentage overlap between spikedace In Aravalpa Creek and shiner from Verde River, and Levins Index = 0.624 for numerical percentage overlap between spikedace from Verde River and shiner from Sycamore Creek, Table 26). These last results could be interpreted to suggest that dietary overlap might occur if spikedace and shiner were syntopic in Aravaipa or Sycamore creeks. We consider such a conclusion unjustified because overlap did not occur In Verde River, where the two actually co-occurred. Furthermore, samples were collected at different times (June to October 1987), and seasonal changes in diet could mask other hypothetical comparisons of dietary overlap. Regardless, our results do not indicate significant interaction relative to food resource use between shiner and spikedace.

No comparative data are available for spikedace and shiner. In Virgin River, UT, dietary overlap (Schoener Index) between woundfin (a close relative of spikedace) and shiner was significant for two of six estimates at two sites over four months of study (0.68 in February and 0.75 in September); other estimates were <0.50 (Greger and Deacon 1988). Results were interpreted to suggest that competition for food may be Important at some times and places. However, close comparisons with our data for spikedace and shiner seem inappropriate because the native fishes of Interest are quite different in ecology, and the physical and biological environments of the Virgin River are unlike those of our study streams.

TABLE 26. Estimates of dietary overlap between spikedace and red shiner where the two species co-occurred (Verde River, Arizona) and for hypothetical comparisons where the two species are presenty allopatric. Each of three indices of overlap (Levins 1968, Horn 1966, and Schoener 1970) was computed on a volumetric (V) and numerical (N) basis.

Species and stream reach	basis	Levins	Horn	Schoener
Spikedace, Verde River vs.	V	0.332	0.109	0.213
Red shiner, Verde River	N	0.409	0.326	0.346
Spikedace, Aravaipa Creek vs.	V	0.375	0.329	0.686
Red shiner, Verde River	N	0.167	0.207	0.509
Spikedace, Gila River vs.	V	0.570	0.433	0.530
Red shiner, Verde River	N	0.299	0.332	0.379
Spikedace, Verde River vs.	V	0.281	0.070	0.138
Red shiner, Sycamore Creek	N	0.624	0.214	0.256
Spikedace, Aravaipa Creek vs.	V	0.417	0.303	0.351
Red shiner, Sycamore Creek	N	0.264	0.177	0.255
Spikedace, Gila River, vs.	V	0.313	0.194	0.182
Red shiner, Sycamore Creek	N	0.350	0.186	0.165

7. HABITAT RELATIONS OF SPIKEDACE AND RED SHINER IN ARTIFICIAL SYSTEMS

Field studies of wild populations of spikedace and shiner provided evidence that the native occupied different microhabitats when found alone than where syntopic with the non-native. To further examine this phenomenon and potentially garner insight as to the nature of apparent interaction between the two species resulting in a habitat shift by spikedace, experimental, In-stream studies of spikedace and shiner were designed. These studies were to be implemented in Sycamore Creek, AZ, not later than March 1988. Toward that end, we provided AZGF with a completed Environmental Assessment Checklist (EAC), including a project description and analysis of positive responses. However, delays were experienced in gaining necessary permits from U.S. Forest Service (Sycamore Creek flows through Tonto National Forest) and U.S. Army Corps of Engineers (which exercises authority over dredge and fill activities), such that proposed studies could not be initiated in time to insure completion within the contract timeframe. Studies of spikedace and shiner in an artificial system were thus substituted for experiments in nature.

An artificial stream was constructed on grounds of the ASU Research Park, Tempe. An attempt was made, within logistic constraints, to qualitatively represent within the system those microhabitats differentially used by spikedace and shiner in nature (i.e., areas of relatively slower and faster current velocity). Using this controlled environment, it then was possible to directly observe habitat use and species interaction, and to quantify physical characteristics of occupied microhabitats. A test of results obtained through field investigations was thus available.

Methods

The artificial system consisted of a linear array of nine, replicate, alternating pool-run segments (Fig. 21). Nominal dimensions of pools were 1.1 m diameter X 0.2 m maximum depth, and runs were 1.6 m long X 0.2 m maximum depth, and tapered in width from 0.35 m upstream to 0.41 m downstream. Actual water depths were approximately 2.5 cm less than nominal due to addition of substrates. Runs entered pools at a horizontal angle of 15°, and overflowed at the same angle from the opposite (downstream) end. Experimental units, which consisted of one upstream pool overflowing into one run, were separated at the downstream end of each run by framed, rigid, plastic netting (0.64 cm) to prevent movement of fishes among sections. In each case, therefore, fish had access to available habitat in one pool and one run. The entire system was canopied at ca. 1.2 m with 0.64-cm mesh plastic netting for shade.

Untreated, lake (irrigation) water was supplied through a float-activated check valve in a 550-L nalgene-lined sump at the downstream end of the system, then pumped upstream through 7.6 cm diameter PVC piping to a 200-L, constant-head tank (Fig. 21), and allowed to gravity-feed through the series of experimental sections. Water flow was adjustable by a gate valve installed between the pump and head tank, which allowed control over discharge (and thus current velocity) through the system. Overall stream gradient (vertical drop) was a constant 1.0%, and discharge was maintained near 0.04 m3/sec.

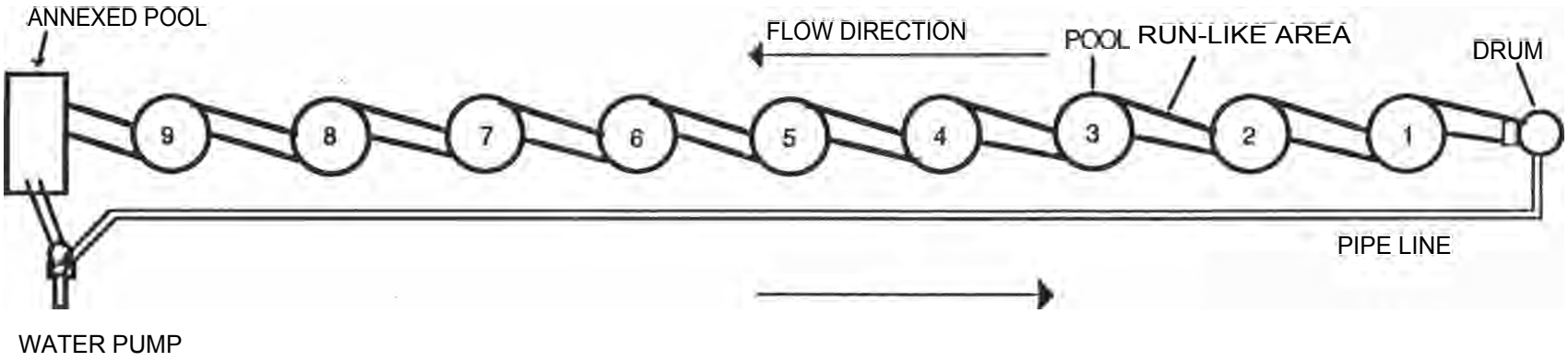

FIGURE 21. Schematic representation of the artificial stream system, showing the linear array of pool and run sections (1 to 9), head tank (drum), sump (annexed pool), water pump, and return pipeline. Makeup water was added through a float-activated valve to the sump, and a gate valve in the return pipeline was used to control flow through the system.

Pool and run bottoms were covered throughout to a depth of ca. 2.5 cm with washed sand, and natural stream substrates from Aravaipa Creek, including inorganic particles to cobble size, plus attached or otherwise contained biological material (i.e., the macroalga Cladophora glomerata, and a suite of benthic macroinvertebrates) were used to seed the system with potential foods. Placement of larger substrate particles was uniform among pools and runs. The system was also provided an aquatic microflora and fauna contained in stream water used to transport substrates. Benthic macroinvertebrates and the alga flourished in the system within 30 days, and natural autochthonous production, plus allochthonous terrestrial inputs, provided the only food for experimental animals; we did not estimate food availability, but had no reason to suspect that quantity or quality were wanting.

Experimental animals were obtained in July and October from wild populations in Aravaipa Creek (spikedace), and Verde River and ASU Research Park lakes (shiner). These were treated for disease (particularly Ichthyophthirius multifiliis) and held until needed in separate, 200-L, flow-through tanks at ASU. All fish were adults ranging in total length from 40 to 60 mm.

Once the system achieved hydraulic stability, current velocities were measured throughout (nearest 0.01 m/sec) with a Marsh-McBirny direct-reading meter. Finest substrates (organics, clays, silts, and fine sand) were suspended in the water column in response to agitation associated with initial system start-up, and hydraulic stability was assumed when these sedimented out downstream of larger substrates, in pool inflows and pool-run transitions, and in the bottom of the sump.

Pools and runs were subdivided into eight observational areas, five in each pool (A1, A2, A3, B1 and B2) and three (C1, C2, and C3) in each run (Fig. 22) on the basis of current velocities. By design, current velocities were fastest (mean 8.0 cm/sec, n = 93) in the middle of pools (A1-A3), slowest (mean <1.0 cm/sec, n = 62) along pool margins (B1, B2), and intermediate (mean 3.0 cm/sec, n = 93) through the runs (C1-C3; Fig. 22). Mean current velocities were significantly different (ANOVA; F = 14.24; p <0.0001; n = 248) among the three subunit groups (i.e., A, B, and C), but did not differ (p >0.35) among subunits within groups (i.e., A1, A2 and A3 were the same, B1 and B2 were the same, and C1, C2, and C3 were the same). Vertical profiles indicated current was nil near bottom, highest in mid-column, and intermediate at the surface (compare Figs. 23 and 24). Using this scheme, current velocities occupied by fishes (either individually or in aggregations) could be determined without disturbance to either the animals or the system.

Physical characteristics of the artificial stream did not duplicate those occupied by target fishes in the wild. Habiats where spikedace and shiner were captured in nature (see Section 5) varied in average depth from 19.5 to 36.1 cm and in current velocity from 14.3 to 46.2 cm/s (Table 7). Depth was uniform throughout the artificial stream (about 17.5 cm) and only slightly shallower than most wild-capture locations, while current velocities in the artificial stream were generally slower (range 0.0 to 20.0 cm/s) than those in natural habitats where target fishes were captured. The artificial system nonetheless provided fish with distinct choices in current velocity, a parameter shown to be influential to relative distributions of spikedace and shiner in nature. Quantitative measures were not made of substrate in

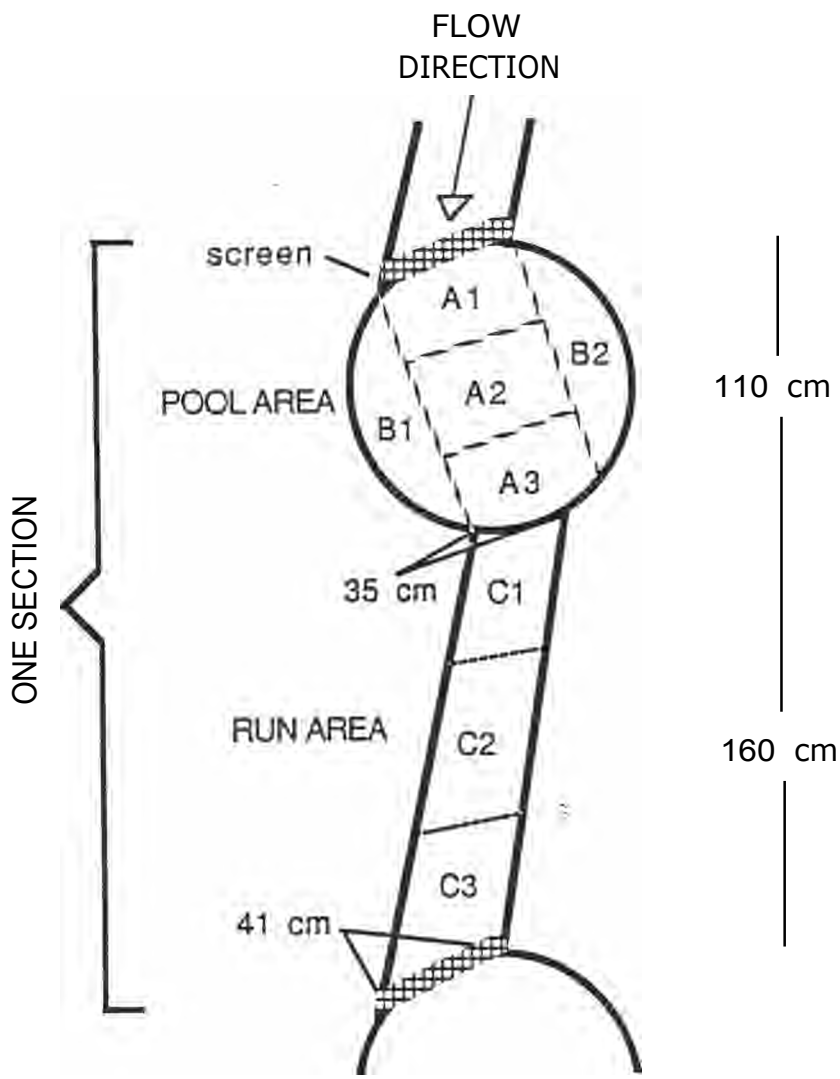

FIGURE 22. Subunits of pool and run sections of the artificial stream system used to describe fish locations. Range in current velocities (cm/sec) within subunits were 1.0-12.0 (A1); 3.0-20.0 (A2); 2.0-9.0 (A3); 0-2.0 (B1); 0-1.0 (B2); 1.0-5.0 (C1); 1.0-4.0 (C2); and 1.0-4.0 (C3). Current velocities within each subunit were similar among sections. Surface (Figure 23), mid-column (Figure 24) and bottom current velocities differed within subunits; the last was nil.

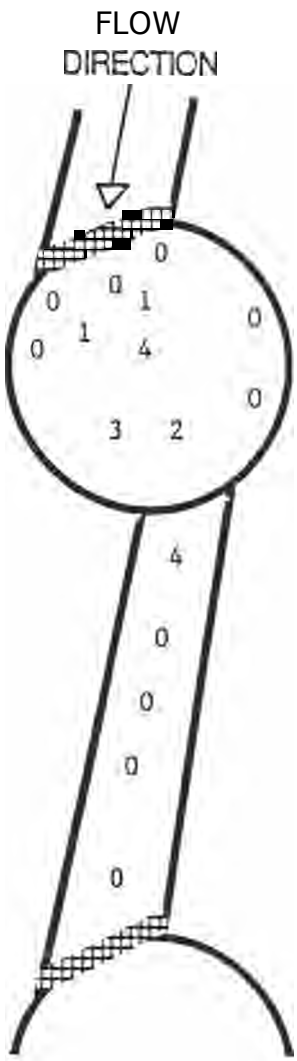

FIGURE 23. Typical water surface current velocities (cm/sec) within artificial stream sections.

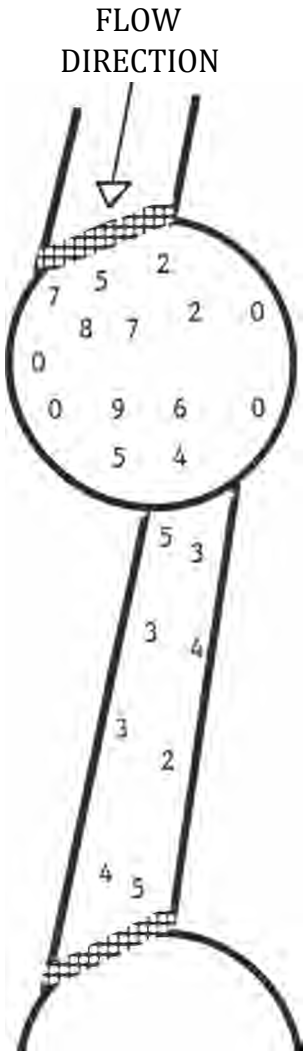

FIGURE 24. Typical mid-column current velocities (cm/sec) within artificial stream sections.

the artificial stream, but field studies suggested this parameter was not particularly important in potential interactions.

Data were collected during three seasonal phases: 1) a mid-summer shake-down period (July-August); 2) autumn (September-October); and 3) winter (November-December). Daily water temperatures ranged from 23 to 35 C during mid-summer, from 20 to 31 C during autumn, and from 16 to 25 C in winter (Fig. 25). Mean daily temperatures and daily variations in the artificial stream were within the range measured in Aravaipa Creek (Minckley 1981), where spikedace is common. However, daily maxima were generally warmer by 1.0 to 2.0 C in the artificial stream. Temperatures in the artificial stream were generally cooler than recorded in Sycamore Creek (Grimm 1985), where the shiner is a predominant component of the fish community. Thus, water temperature should not have unduly influenced fishes in the system.

The initial, mid-summer period provided opportunity to fine-tune the physical plant, acquire expertise at making valid observations, and resolve problems associated with inclement weather (i.e., stream flooding due to local runoff during intense thunderstorms) and nuances of fish behavior. Observations were not possible during and immediately after flooding because immediate effects of flooding and overflow occurred before personnel arrived at the site, turbidity precluded determination of fish locations, some fish were redistributed outside the confines of the experimental stream while those remaining were redistributed among sections, and physical maintenence that disrupted normal behaviors of the fish was usually required to reset the system.

Each observational phase was initiated by assignment of fish(es) to the nine replicate sections: three each for spikedace (only), shiner (only), and spikedace plus shiner. The total number of fish in each section was kept at 20 individuals; where spikedace and shiner were together, 10 of each was used. Care was exercised to select fish of like size, within the available range, when the two were stocked together. Otherwise, fish were sampled at random from holding tanks. Mortalities in the stream were replaced by similar-sized individuals of the appropriate species. Mortality was not different between the stream and holding facilities, and averaged 10% among all stocks over the period of study.

Both species tended to remain aggregated within pool-run sections, making detailed observation of individuals impractical. Thus, habitat preference reported here refers to the sub-areas (above) occupied by >70% of fish (14 fish where species were isolated, seven fish of a species where the two were together) during a continuous, five-minute observation period. Typically, the observation period was preceded by 10 to 30 minutes, during which the observer sat quietly and allowed any agitation of fishes to subside. Observations were made only when fish had apparently settled into normal behavioral patterns. Locations of isolated fish (one to five individuals), when possible, was also recorded. For example, when 16 fish were aggregated in one area of the pool, locations of the remaining four was also determined. Current velocity and water temperature were measured at least twice weekly in each experimental section.

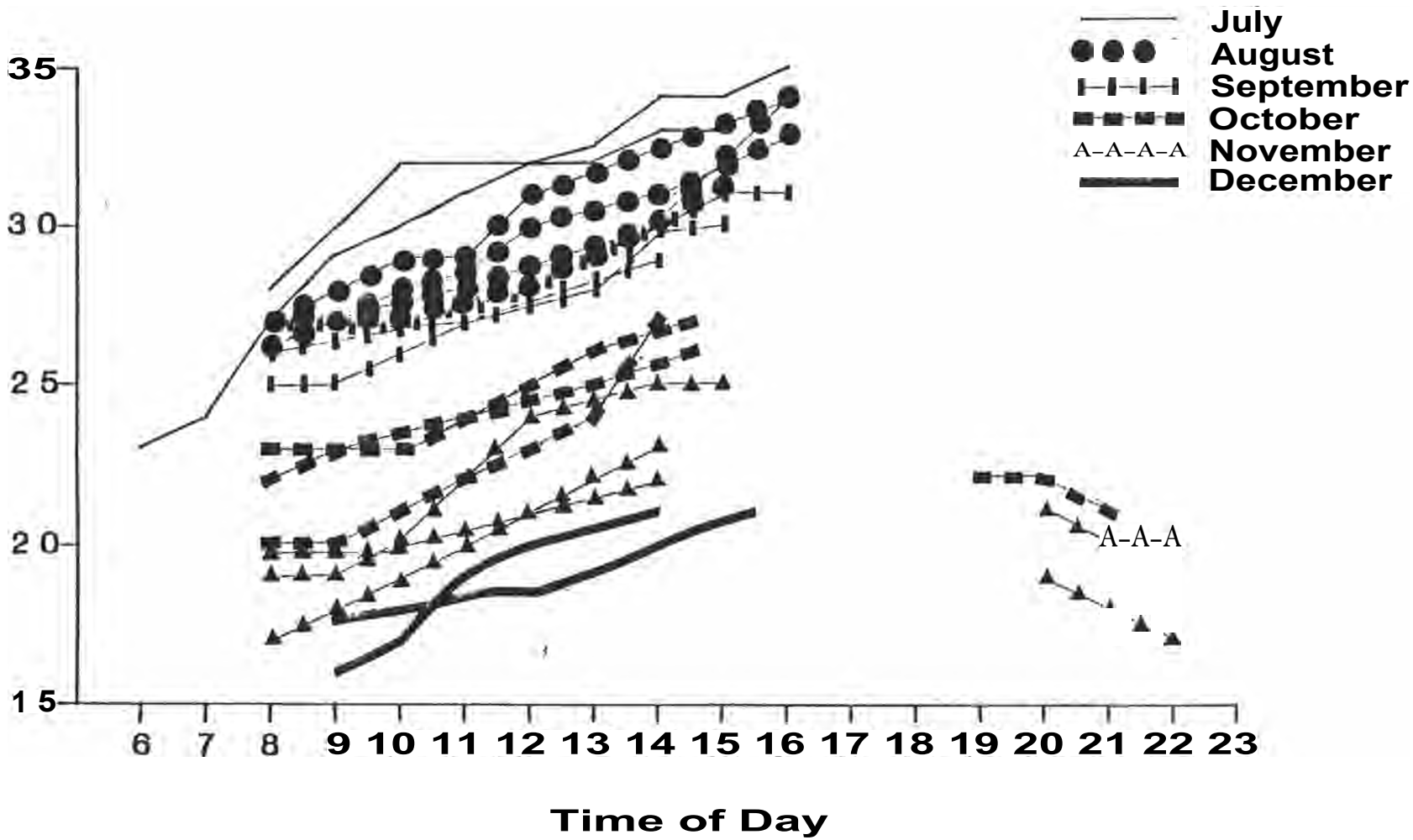

FIGURE 25. Daily and monthly temperature (C) variation in the artificial stream system.

Results

Initial observations were of fish response to transfer from holding facilities to the artificial stream. General patterns of aggregation and movements by spikedace, shiner, and the two species in combination were noted. The sequence of fright, recognition, and residency described below occurred with both species and each new group of fish introduced to the system.

Typically, all fish demonstrated an intial fright; movements were frequent, rapid, and apparently erratic. This was followed by a "recognition" period, characterized by loose aggregations, and often including all fishes in a section swimming in a circular pattern around the perimeter of the pool. This distinctive behavior typically persisted for 15 to 20 minutes. Following the recognition period, fish appeared more relaxed, assumed a head-upstream orientation, and apparently established residency. Movements became directed and gradual, rather than flighty, and some semblance of microhabitat fidelity was established. Typically, spikedace attained residency status sooner than shiner; however, all fishes were in this mode within three to five days. Quantitative information on habitat utilization was not recorded until residency had been firmly established.

July-August.--Observations during July were confounded by several floods, which increased turbidity (often to the point of reducing water clarity to a few centimeters and rendering observation of fishes impossible) and on several occasions resulted in water exceeding the confines of the system. Overflow resulted in redistribution of fishes, requiring a complete resetting of the system. Also, mortality was increased because some individuals moved out of the stream to shallow (<1.0 cm) flooded areas on the ground adjacent to the system, where they became vulnerable to avian predators. Although quantitative data were not acquired, differential displacement of spikedace and shiner, either within or outside the stream, was not apparent during flooding. Flood events in the artificial stream were not of the violent, catastrophic nature associated with flash flooding in desert streams (Fisher and Minckley 1978, Fisher et al. 1982), which has been linked to differential selection of native vs. non-native fishes (Minckley and Meffe 1987). Rather, flooding was gradual, modestly-disruptive, and of limited and relatively small magnitude that would not be expected to differentially affect spikedace and shiner.

During July, aggregations of spikedace alone showed a clear preference for subunits A1 to A3 (Table 27), where water from upstream entered the pool. The fish was less often along margins of the pool (subunits B1 and B2), and only rarely was observed in the run portion of the section (Table 27). Their occupation of the run may have been influenced, in part, by external disturbance, either by the observer or by passing motor vehicle traffic. Runs were essentially identical, and while fish were unable because of barrier nets to move upstream into runs, they were nonetheless free to move into the run downstream. Aggregations of shiners alone (Table 28) were seen most often in headwaters of the pool (subunits A1 and A2); pool margins (unit B) and the run (unit C) were used infrequently. Occupied habitats of aggregations remained the same where the two species occurred together, i.e., there was clear preference for the pool (Table 29). Use of the run by adults of either species was infrequent when they were together (see Tables 29 and 31).

TABLE 27. Percentage of 5-minute observation periods (obs) each month during which aggregations (>70% of available fish) of splkedace occupied each of eight specific subunits of pools (A, B) and runs (C) in an artificial stream system. Total obs/subunit Is the number of observation periods during which fish occupied each subunit (all months), total obs/month is the total number of observation periods each month (all subunits), and percent of total obs proportion of total obs/subunit obs periods (all subunits and all months) during which fish occupied a particular subunit. See text, Figures 22-24 for locations and physical characteristics of subunits.

	Percentage of observations							
Subunit	Jul	Aug	Sep	Oct	Nov	Dec	Total obs/ subunit	Percent of total obs
A1	33	43	39	48	19	25	48	38
A2	22	38	48	43	75	75	56	44
A3	6	7	9	4	6	0	8	6
B1	22	5	0	4	0	0	7	6
B2	6	2	4	0	0	0	3	2
C1	0	2	4	0	0	0	1	1
C2	11	0	0	0	0	0	2	2
C3	0	2	0	0	0	0	1	1
Total obs/ month	18	42	23	23	16	4	126	100

TABLE 28. Percentage of 5-minute observation periods (obs) each month during which aggregations (>70% of available fish) of red shiner occupied each of eight specific subunits of pools (A, B) and runs (C) in an artificial stream system. Total obs/subunit is the number of observation periods during which fish occupied each subunit (all months), total obs/month is the total number of observation periods each month (all subunits), and percent of total obs is the proportion of total observation periods (all subunits and all months) during which fish occupied a particular subunit. See text, Figures 22-24 for locations and physical characteristics of subunits.

	Percentage of observations							
Subunit	Jul	Aug	Sep	Oct	Nov	Dec	Total obs/ subunit	Percent of total obs
A1	38	19	39	38	12	0	36	27
A2	31	35	48	41	71	75	58	44
A3	0	5	9	3	12	0	7	5
B1	19	2	4	3	0	0	6	5
B2	0	0	0	3	0	0	1	1
C1	0	12	0	3	6	0	7	5
C2	13	21	0	7	0	25	14	11
C3	0	7	0	0	0	0	3	2
Total obs/ month	16	43	23	29	17	4	132	100

TABLE 29. Percentage of 5-minute observation periods (obs) each month during which aggregations (>70% of available fish) of spikedace (MF), red shiner (CL) and spikedace plus red shiner combined (M/C) occupied each of eight specific subunits of pools (A, B) and runs (C) in an artificial stream system. Data for September to December are for aggregations of the two species combined. Total obs/subunit (n) is the number of observation periods during which fish occupied each subunit (all months), total obs/month is the total number of observation periods each month (all subunits), and percent of total obs (%n) is the proportion of observation periods (all subunits and all months) during which fish occupied a particular subunit. See text, Figures 22-24 for locations and physical characteristics of subunits.

	Percentage of observations										Total obs/ subunit	
	Jul			Aug			Sep	Oct	Nov	Dec		
Subunit	Mf	Cl	M/C	Mf	Cl	M/C					n	%n
A1	0	0	38	0	0	38	34	48	24	50	50	38
A2	0	0	25	0	5	8	59	41	59	50	60	45
A3	0	0	19	0	0	0	3	3	12	0	7	5
Bi	0	0	13	0	0	5	0	3	0	0	5	4
B2	0	0	0	0	0	0	3	3	0	0	2	2
C1	0	0	0	3	0	3	0	0	0	0	2	2
C2	6	0	0	32	0	3	0	0	3	0	5	4
C3	0	0	0	0	0	3	0	0	0	0	1	1
Total obs/ month		16			37		29	29	17	4	132	101

TABLE 30. Percentage of total 5-minute observation periods (obs) each month during which non-aggregated spikedace (1 to 5 individuals) occupied each of three specific subunits of runs (C) in an artificial stream system. Total obs/subunit is the number of observation periods during which fish occupied each subunit (all months), total obs/month is the total number of observation periods each month (all subunits), and percent of total obs is the proportion of total observation periods (all subunits and all months) during which fish occupied a particular subunit. See text, Figures 22-24 for locations and physical characteristics of subunits. With exception of a single observation period in July when non-aggregated spikedace occupied pool subunit B2, isolated spikedace were not observed in the pool section.

	Percentage of obs							
Subunit	Jul	Aug	Sep	Oct	Nov	Dec	Total obs/ subunit	Percent of total obs
C1	6	5	0	0	6	0	4	3
C2	0	2	0	4	0	0	2	2
C3	0	0	4	0	0	0	1	1
Total obs/ month	18	42	23	23	16	4	126	6

TABLE 31. Percentage of total 5-minute observation periods (obs) each month during which non-aggregated spikedace plus red shiner (1 to 5 individuals) occupied each of three specific subunits of runs (C) in an artificial stream system. Total obs/subunit is the number of observation periods during which fish occupied each subunit (all months), total obs/month is the total number of observation periods each month (all subunits), and percent of total obs is the proportion of total observation periods (all subunits and all months) during which fish occupied a particular subunit. See text, Figures 22-24 for locations and physical characteristics of subunits. With exception of a single observation period in July when non-aggregated spikedace occupied pool subunit B2, isolated spikedace were not observed in the pool section.

	Percentage of obs							
Subunit	Jul	Aug	Sep	Oct	Nov	Dec	Total obs/ subunit	Percent of total obs
C1	6	8	0	0	0	0	4	3
C2	6	11	3	3	6	0	8	6
C3	19	3	0	0	0	0	4	3
Total obs/ month	16	37	29	29	17	4	132	12

Inclement weather did not affect the stream during August. Fish consequently appeared more relaxed and observations were considerably easier to make. Spikedace alone In August maintained uniform, compact aggregations (Fig. 26), with a high preference for pool headwaters (Table 27). Schools were oriented upstream and remained in the same location. While Individual fish moved about over short distances, the school and most fish remained in constant position rather than circulating. Shiners exhibited similar, but distinctive schooling behavior. Aggregations were noticably looser (Fig. 27) than those of spikedace, and movements were more generalized and over greater distances; fish moved frequently both up- and downstream, and laterally.

Shiner habitat use (Table 28) and movements undoubtedly were influenced by spawning behaviors; fish were ripe, mating was repeatedly observed, and many male-female pairs were observed in runs. These last behaviors were not apparent during July, and may have been stimulated by a slight lowering of stream temperature (Fig. 25), photoperiod, or simply restoration of normal reproductive functions after initial stresses of handling, holding, transport, and stocking.

Where spikedace and shiner were together (Tables 29 and 31), the latter was more active and more aggressive than the native. And, typically compact aggregations of spikedace were distinctly less so, mediated at least in part by agonistic behavior of the shiners. Chasing of spikedace was almost constant during periods of observation. As a presumed result of this harassment, spikedace frequently occupied mid-reaches of runs (subunit C2), a habitat scarcely used when the species was alone, or during July (compare Tables 27 and 29). The frequency of agonistic encounters between shiner and spikedace diminished near the end of August.

Even though recorded observational data (Tables 29-33) suggest that adult spikedace and shiner can coexist for a time In the same microhabitat, the agressive behavior of shiner and apparent habitat shift of spikedace nonetheless indicated displacement of the native, at least during August.

September-October.--Aggregated spikedace and shiner, when alone, both selected pool headwaters (subunits A1 and A2) during autumn (Tables 27, 28, and 31); use of runs by either fish was rare. No difference in habitat use was observed when the two were together (Tables 29 and 31), and both continued to primarily occupy the pools. However, aggregations of spikedace again appeared disrupted by activities of shiner, such that compact groups of the native rarely formed, and even then, were apparently unstable. Aggression by shiner and active chasing of spikedace continued, but was considerably abated compared to that observed in August. Displacement of spikedace to runs was rare, and involved only one or two individuals (Table 28).

Successful reproduction by shiner became apparent during autumn, when free-swimming larvae became abundant. Spawning by spikedace typically occurs between March and June, and the species thus was not expected to reproduce in the artificial stream. Samples of larvae collected throughout the study period were nonetheless examined and included only shiners (n = 200). Numerous, observed attempts by spikedace to eat larval shiners were all unsuccessful, possibly because the non-native possessed sufficient agility to escape predation or because individual spikedace lacked sufficient motiviation to continue

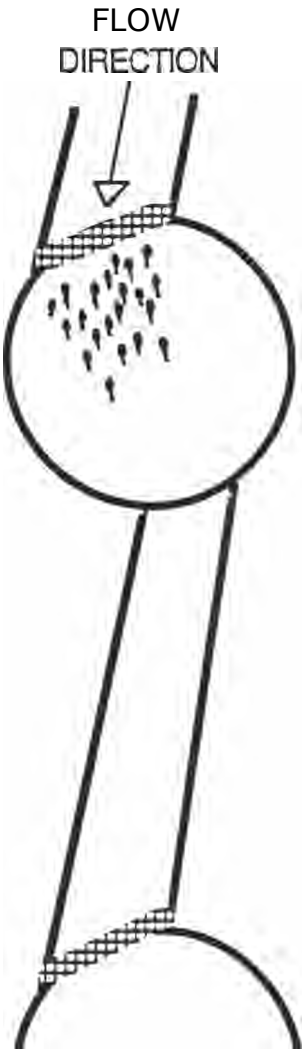

FIGURE 26. Schematic representation of typical, compact aggregations exhibited by spikedace when occupying pool subunits Al and A2 of the artificial stream system. Presence of red shiner resulted In instability and loosening of the aggregation.

FIGURE 27. Schematic representation of typical, loose aggregations exhibited by red shiner when occupying pool subunits A1 and A2 of the artificial stream system. Aggregations of spikedace exhibited a similar spatial pattern when in presence of red shiner (compare Figure 26). Red shiner was typically more active than spikedace, whether alone or in combination with the native.

TABLE 32. Percentage each month of total 5-minute observation periods (obs) during which larval (in parentheses), juvenile (*) and non-aggregated (1 to 5 individuals) adult red shiner, when alone, occupied each of eight specific subunits of pools (A, B) and runs (C) in an artificial stream system. Total/percent of total are the number of observation periods during which fish occupied each subunit (all months) and the proportion of total observation periods (all subunits and all months) during which fish occupied a particular subunit, and total obs/month is the total number of observation periods each month (all subunits). See text, Figures 22-24 for locations and physical characteristics of subunits.

	Percentage of obs						Total/percent of total		
Subunit	Jul	Aug	Sep	Oct	Nov	Dec	Larva	Juvenile	Adult
A1	0	0	0	* 3	*12	0	0/0	3/2	0/0
A2	0	0	0	*10	*18	0	0/0	6/5	0/0
A3	0	0	0	0	0	0	0/0	0/0	0/0
B1	0	0	0	0	0	0	0/0	0/0	0/0
B2	0	0	0	0	0	0	0/0	0/0	0/0
C1	0	5	(22)	* 3	0	0	5/4	1/1	2/2
C2	6	14	(13)	(7)	0	0	5/4	0/0	7/5
C3	6	2	13	0	0	0	0/0	0/0	5/4
Total obs/ month	16	43	23	29	17	4		132	

TABLE 33. Percentage each month of total 5-minute observation periods (obs) during which larval (in parentheses), juvenile (*) and non-aggregated (1 to 5 individuals) adult red shiner, when combined with spikedace, occupied each of eight specific subunits of pools (A, B) and runs (C) in an artificial stream system. Total/percent of total are the number of observation periods during which fish occupied each subunit (all months) and the proportion of total observation periods (all subunits and all months) during which fish occupied a particular subunit, and total obs/month is the total number of observation periods each month (all subunits). See text, Figures 22-24 for locations and physical characteristics of subunits.

	Percentage of obs						Total/percent of total		
Subunit	Jul	Aug	Sep	Oct	Nov	Dec	Larva	Juvenile	Adult
A1	0	0	0	0	0	0	0/0	0/0	0/0
A2	0	0	0	* 7	*18	0	0/0	5/4	0/0
A3	0	0	0	3	0	0	0/0	0/0	1/1
B1	0	0	0	3	0	0	0/0	0/0	1/1
B2	0	3	0	7	0	0	0/0	0/0	3/2
C1	0	11	(10)	(3)	0	0	4/3	0/0	4/3
C2	0	11	(7)	(3)	6	0	2/2	0/0	8/6
C3	0	0	0	0	0	0	0/0	0/0	0/0
Total obs/ month	16	37	29	29	17	4		132	

pursuit to fulfillment, or for other reasons. Larval fishes have previously reported among foods of spikedace from Aravaipa Creek (Minckley 1973), and we have no conclusive explanation of why adult spikedace were unsuccessful. Perhaps what we observed was simply a chasing behavior, and did not involve feeding.

Small shiners (<25 mm TL) produced in situ by the test animals resided almost exclusively in runs (subunits C1-C3, Tables 32 and 33). As juveniles attained lengths >30 mm, they began to penetrate pools, where they typically occupied the margins (subunits B1 and B2). There was no evidence of interaction between adult shiner or spikedace and juvenile shiner. However, the possibility is not precluded that juvenile shiner occupied marginal pool habitats, rather than central areas, because the latter was occupied by adult fishes.

During September and October, terrestrial grasses along the stream margin temporarily provided cover and dense shade to portions of the water surface. An abundant supply of terrestrial invertebrates, primarily homopterans, formicids, and arachnids, found their way from these grasses into the stream. On several occasions, both shiner and spikedace were observed actively feeding on this surface drift. Grass-covered areas, especially where it extended over pool subunits B1 and B2, were frequently occupied by shiner during the 10 to 30 minute pre-observational period. Shiner apparently sought this cover as an immediate response to an observer, but typically redistributed (to subunits A1-A3) after a short time. Cover was removed immediately upon notice that it was being used by fish. This was done because cover was not uniform among stream sections or subunits, and we wished to eliminate potential baises that might arise from unaccounted differences among treatments, and thus minimize confusion as to whether habitat use was a function of cover or interspecific interaction. Fish resumed near-continuous occupation of more central areas of the pools after removal of cover.

November-December.--Microhabitats occupied by spikedace, shiner, and the two combined did not change demonstrably during early winter. Fish continued to preferentially occupy pool headwaters whether species were separated or combined (Tables 27-31). Instability, as detailed above, remained characteristic of spikedace aggregations, although agonism by shiner was clearly diminished.

Because of a dwindling supply of experimental animals, the number of stream sections was reduced from nine to four in late November: one for isolated spikedace, two for shiner, and another for the two species together. Juvenile shiner produced in situ had by this time attained lengths >35 mm, and begun to occupy pool headwaters alongside adults. Thus, virtually all fish occupied subunits A1 and A2, as had been the norm during previous months (Tables 27-33).

tatistical treatment. Comparisons with a uniform distribution.--Because current velocities differed among but not within observational units (i.e., A, B, and C), data for subunits were pooled for testing purposes, and a one-sample (i.e., direction of difference predicted) Kolmogorov-Smirnov (Siegel 1956) test applied (n = 6). This test compared observed percentage frequency distributions of aggregations of adult fish with a hypothetical, uniform distribution (i.e., the probability of fish occupying any particular unit was the same).

Spikedace (alone) were found to have a distribution among units that differed significantly ($p < 0.01$) from random during the months August, September, October, and December, and for all months combined (July through December, inclusive), but there was no difference in unit occupation (i.e., distribution was uniform) during July and November (Table 34). These results are generally compatible with direct interpretation of our observations (above), which indicated spikedace most frequently utilized pool habitats. Lack of significant differences between observed and hypothetical (uniform) distributions in July and December may have been real, or due to disruptions associated with flooding in the former month and relatively small number of fish during the latter.

Distributions of adult shiner (alone) differed significantly from the hypothetical only during September and November; comparisons for other months and for all months combined were non-significant (Table 34). Although shiner occupied central areas of pools (unit A) more during some months than others, there was no apparent temporal pattern associated changes in distribution. We noted that aggregations of shiner became less compact, and the fish appeared to move about more, during August. Increased use of pool margins in September was at least partially associated with incursion there of Juveniles, and a similar pulse was also noted in November (above). We do not have other explanations for the apparently erratic monthly changes in shiner dispersion. Comparison of observations and statistical results for shiner indicate that the two were not always consistent.

Spikedace and shiner together exhibited distributions, relative to a uniform one, that were essentially the same as those of shiner alone (Table 34). The only difference was that spikedace and shiner together were in pool headwaters (unit A) more than they were in other units in December, while shiner alone showed no significant difference during that month. On the other hand, there were three months (August, October, and November) when the comparative distributions of shiner plus spikedace differed from those of spikedace alone, as was also true for all months combined. Thus, on month-to month and overall bases, the distribution of spikedace plus shiner was more similar to that of shiner (alone) than it was to that of spikedace (alone).

Comparisons among distributions of spikedace, shiner, and spikedace plus shiner.--The Kolmogorov-Smirnov two-sample test (Siegel 1956) was used to examine whether distributions of aggregated spikedace or shiner, alone or when together, differed within artificial stream sections. In this two-tailed test, cumulative frequency distributions are compared using a chi-square statistic ($df = 16$) to determine if the two samples (distributions) have been drawn from the same population.

Distribution in August of spikedace (alone) differed significantly ($p < 0.01$) from those of shiner (alone) and spikedace plus shiner (Table 35). No difference during that month was indicated between shiner (alone) vs. shiner plus spikedace (Table 35), and no statistical differences ($p > 0.05$) were found for any other month, or for all months combined. The distribution of shiner was thus the same, whether alone or with spikedace, while the distribution In August of spikedace was different when the species was alone and when it was combined with shiner. These results provide additional evidence that aggressive, agonistic behaviors of spawning shiner resulted in a habitat shift by

Table 34. Summary of results of Kolmogorov-Smirnov one-sample tests comparing monthly distributions of aggregated adult spikedace, red shiner, and spikedace plus red shiner with a standard, uniform distribution among units (df = 6) in an artificial stream system. NS = non-significant ($p > 0.05$); * $p < 0.05$; ** $p < 0.01$. In all significant cases, occupation of the central pool area (unit A) was greater than that of pool margins (unit B) and runs (unit C). See text, Figs. 22-24, for descriptions of observational units.

Month	Spikedace	Red shiner	Spikedace plus Red shiner
July	NS	NS	NS
August	*	NS	NS
September	**	**	**
October	**	NS	NS
Novemeber	NS	**	**
December	**	NS	NS
July-December combined		NS	NS

Table 35. Results of a Kolmogorov-Smirnov two-sample, one-tailed test comparing cumulative frequency distributions in August of aggregated adult spikedace (n_1 = 42), red shiner (n2 = 43), and spikedace plus red shiner (n3 = 37) within observational subunits of an artificial stream system. Columns derived from data in Tables 27-29 as follows: A = cumulative frequency distribution of spikedace, B = distribution of red shiner alone, C = distribution of spikedace plus red shiner; A-B, A-C, and B-C are absolute value differences (Ds) between entries in columns A to C. A chi-square statistic is computed from the maximun D for each contrast as follows: chi-squared = $4D^2(n_1n_2)/(n_1 + n2)$, and compared with tablular values for df = 16. Comparisons within other months and for all months combined were non-significant (p > 0.05); computations are thus not shown.

A	B	C	A-B	A-C	B-C
0.43	0.19	0.38	0.24	0.05	0.19
0.81	0.54	0.52	0.27	0.29	0.03
0.88	0.59	0.52	0.29	0.36	0.07
0.93	0.61	0.57	0.32	0.36	0.04
0.95	0.61	0.57	0.34	0.38	0.04
0.97	0.73	0.62	0.24	0.35	0.11
0.97	0.94	0.97	0.30	0.00	0.03
0.99	1.01	1.00	0.20	0.01	0.01
		Maximum D	0.34	0.38	0.19
		Chi-square	12.27	11.23	2.87
		p	<0.01	<0.01	>0.30

spikedace. We conclude that the shift was due to interactions between the two fishes.

Integration of these results with those derived from comparisons with a uniform distribution leads to similar conclusions. Both indicate a change In distribution of spikedace in the presence of shiner, while also suggesting that distribution of shiner remained relatively constant, whether in treatments alone or with spikedace. It thus appears that spikedace distribution changed ln response to presence of shiner. However, implications of that result have yet to be fully explored.

Isolated fish (one to five individuals) almost exclusively occupied runs (Tables 30 through 33), thus no statistical tests were performed on their distributions. Sample sizes (i.e., number of observations) for larval and juvenile shiner were generally too small (Tables 32 and 33) to allow performance of meaningful tests.

Summary

Results of observations of spikedace and shiner in an artificial stream appeared to contradict those obtained from study in the wild. Where spikedace and shiner were syntopic in nature, the native was apparently displaced into habitats with significantly greater current velocities than those occupied where In isolation from the non-native. In contrast, shiners apparently displaced spikedace lnto areas of slower current velocities in the artificial system. This displacement was observed only during one month (August) during the six-month study period, and was coincident with intensive reproductive activity by shiner. Field studies were conducted from May-September, and thus were inclusive of the timeframe during which active interaction between shiner and spikedace was observed in the experimental stream. However, habitats with higher current velocities were not available in the artificial stream (as they were ln nature), because these were preferentially occupied by aggressive, agonistic shiner. Thus, in both natural and artificial systems, spikedace in the presence of shiner was displaced to habitats that it otherwise did not normally occupy; in the former instance to places with swifter current and in the latter to slower. Results from studies of natural and captive populations are thus consistent.

Comparative interpretation of results from field and experimental stream studies might have been enhanced by use of the same statistical analyses on both data sets. However, specific objectives of each component of the overall study, plus basic differences in kinds of data obtained, dictated use of different tests. The primary objective of field studies was to examine differential habitat use by quantitative determination of differences between habitats respectively occupied by and available to spikedace, shiner, and the two species ln combination. In the case of the artificial stream, available habitats were few (three), invariant, and generally quantitatively distinct from those used by target species in nature. Differences in location of fish(es) within the system were thus of interest, rather than characteristics of the habitats themselves. We therefore justifiably applied different statistical tests to field and experimental data.

Our artificial stream experiments were of too short a duration to fully explore the potential impacts of agonistic shiner on spikedace.

The spawning season of shiner is protracted, and broadly overlaps that of spikedace. It is reasonable to assume that agonistic behaviors we recorded for spawning shiner in August would also occur throughout the spawning season in nature, and likely would have have been observed over an extended period in the artificial system if experiments were continued into spring 1989. Displacement of spikedace by spawning shiner might thus have much greater long-term significance than observed during our short-term experiments.

How such displacement of spikedace by shiner might translate into detrimental impact on populations of the native species remains unknown. We have no evidence of direct impact on individual animals (e.g., physical damage). However, displacement activities could interfere with spikedace reproductive activity, either directly if harassment were to preclude successful spawning, or indirectly if spikedace were forced to occupy habitats unsuitable or sub-optimal for fertilization of gametes, or incubation, hatch, and development of embryos and early larval stages. Further, we have no information on possible predation by shiner on young spikedace, a direct interaction that could have severe effects on populations of the native.

8. SUMMARY AND CONCLUSIONS

Spikedace and loach minnow are small, stream-dwelling cyprinid fishes endemic to the Gila River basin (Colorado River drainage) of southwestern United States and Sonora, Mexico. Once widely distributed and locally abundant, both have experienced severe reductions in range and depletions in numbers. As a result, and because remaining populations are subject to future impacts, both are federally listed as threatened. A number of factors have been suggested contributory to the present imperiled status of these fishes.

The red shiner Is a comparably-small, stream minnow native to the Mississippi and other Gulf drainages of eastern United States. It was introduced to the Colorado basin in the 1950s, and has since spread througout the Gila system, and elsewhere. Declines in spikedace and loach minnow populations have been coincident with the shiner's expansion, and the introduced fish thus has been implicated in reductions and extirpations of the natives. Red shiner now occur in all habitats from which spikedace and loach minnow have been eliminated. However, quantitative data are wanting on the nature and significance of interaction(s), if any, between red shiner and the native minnows.

AZGF, NMGF, and FWS recognized a need to determine the relationship between red shiner and spikedace and loach minnow. Toward that end, ASU was contracted to conduct a two-year study designed to elucidate interactions among these fishes. The research was comprised of two broad components: 1) field studies to quantify habitat use by syntopic and allotopic populations of spikedace, loach minnow, and red shiner; and 2) experimental studies of confined stocks of spikedace and red shiner, both alone and in combination. Field studies were conducted along seven stream reaches: 1) east (upper) and 2) west (lower) Aravaipa Creek, 3) Blue River, 4) Gila River at Gila and 5) Redrock, 6) Sycamore Creek, and 7) Verde River. Gila River reaches were in NM; others were in AZ. In addition to studies that measured depth, current velocity, and substrate of available and occupied habitats, the field

component also included quantification of food habits of the three species. Experimental work was performed in an especially-constructed, artificial stream system. Differential habitat use and behaviors were examined in the artificial stream.

Loach minnow was found in east and west Aravaipa creek (one sample only), Blue River, and Gila River at Gila. Loach minnow habitat was characterized as swift, shallow riffles. Mean depth of occupied habitats ranged among reaches from 14.7 to 20.8 cm; current velocity averaged 37.2 to 70.3 cm/s; and weighted substrate ranged from 27.3 to 37.3. These results were consistent with those of other independent investigators.

Loach minnow and red shiner co-occurred only at Blue River, and in too few samples (n = two) to perform meaningful comparisons. Because leach minnow habitat was obviously distinctive from that occupied by red shiner, it was concluded that interaction with red shiner was unlikely to cause a shift in habitat use by loach minnow.

Primary foods of loach minnow were immature stages of riffle-dwelling benthic invertebrates. Dietary diversity (number of different kinds of food items) was low. Representatives of Ephemeroptera, Trichoptera, and Diptera were most important. Feeding appeared crepuscular, and different kinds of invertebrates were consumed during daytime compared with darkness. Results were unremarkable in context of other loach minnow food habit studies.

Natural populations of spikedace were in east and west Aravaipa creek, the Gila River at Gila and Redrock, and Verde River. Occupied habitat among reaches ranged in mean depth from 19.0 to 36.1 cm, in current velocity from 31.0 to 48.3 cm/s, and In weighted substrate from 50.1 to 153.7.

Red shiner was found in Blue River (n = four samples), Gila River at Redrock, Sycamore Creek, and Verde River. Among reaches, occupied habitat ranged in mean depth from 19.5 to 31.9 cm, mean current velocities were 14.3 to 39.5 cm/s, and mean weighted substrate ranged from 17.2 to 189.2.

Spikedace and red shiner co-occurred in the Gila River at Redrock and in Verde River. Spikedace occupied significantly faster current velocities where it co-occurred with shiners than where it was found in isolation from the non-native fish. It is thus concluded that some level of species interaction resulted in displacement of spikedace by red shiner.

Spikedace consumed a relatively diverse array of foods. The most important dietary constituents were immature and adult trichopterans and ephemeropterans; these were supplemented by a variety of other benthic insect larvae, plus miscellaneous items. Food habits were generally similar among all stream reaches, and were consistent with findings of other workers.

Red shiner foods included a wide variety of items. Most important were amorphous organic matter, adult and nymphal ephemeropterans, larval trichopterans, and larval and adult chironomid dipterans. Red shiner exhibited an opportunistic, omnivorous feeding habit wherever it was found.

Comparative study of food resource utilization demonstrated minimal overlap in diets of spikedace and shiner. For the stream reaches, times of year, and life stages represented among our samples, there was no indication of competlon for food between these species. However, other

researchers have demonstrated spatial, temporal, and ontogenetic shifts in food habits of both spikedace (Anderson 1978, Schreiber and Minckley 1981, Barber and Minckley 1983) and red shiner (Minckley 1982, Marsh and Minckley 1982). Although our samples included several streams and attempted to integrate post-larval sizes of fish, we did not examine effects throughout the range of these variables. Nonetheless, we suspect that competition for food plays a minor role, if any, in explaining declines or extirpations of spikedace in streams where red shiner has become established.

Aggregations of spikedace in an artificial stream were in areas of slower current velocity when red shiner were present compared with areas occupied when spikedace was alone. This habitat shift was observed during only one (August) of six months of the study, and was coincident with intensive reproductive activity by red shiner. Distribution of red shiner was constant, whether or not spikedace was present.

Studies of natural and captive populations of spikedace and red shiner were consistent: the native in both instances occupied different habitats when it was alone than when red shiner was present. Spikedace in the presence of red shiner was apparently displaced to habitats that it otherwise did not occupy. Red shiner was repeatedly observed to physically strike at spikedace in the artificial system, a behavior that could have negative impacts on individual spikedace. Effects at the population level are unknown, but could be realized if aggressive interactions by red shiner were to interfere with reproduction by or early life history stages of spikedace.

It remains to be demonstrated whether or not declines of spikedace populations are a result of red shiner presence, much less what mechanism(s) mediate such interaction. Long-term, life-cycle studies of spikedace and red shiner may be necessary to adequately ascertain the nature and significance of interaction, especially if reproductive processes and/or early life stages are involved. It seems unlikely at this time that meaningful field studies can be designed and conducted to provide necessary answers because collection of required data from natural populations defies present capabilities. Controlled, artificial systems, similar but more elaborate than that described above, may provide suitable environments for conduct of this research, which would include detailed, comparative observations of spawning behaviors and success, plus post-larval recruitment of spikedace with and in the absence of red shiners.

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