DISTRIBUTION, STATUS, BIOLOGY, AND CONSERVATION OF THE SPIKEDACE (MEDA FULGIDA) IN NEW MEXICO

By

David L. Propst

Kevin R. Bestgen

and

Charles W. Painter

March 7, 1986

New Mexico Department of Game and Fish

Santa Fe, New Mexico 87503

Final Report, Project E-3

4

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

PREFACE

The spikedace is a minnow species that is confined to the Gila Basin of New Mexico and Arizona (see Table 1 in introduction for scientific names). Although the species was first documented in New Mexico in 1872 and has been the subject of a M.S. thesis there (Anderson 1978), no broad investigation of its status in the state had been attempted. In view of this deficiency and because of apparent declines suffered by the species, such an investigation was begun by the New Mexico Department of Game and Fish in November 1982. Initial funding for this work was through the Department's "Nongame Wildlife Studies" project (no. FW-17-R), with the status of the spikedace being examined as part of a broad inventory of the fishes of the Gila Basin of New Mexico. FW-17-R is a federal aid project that includes 75% Dingell-Johnson funding for fish studies, (with the primary focus being on general inventories). The 25% state share is from the New Mexico General Fund, as provided to the Endangered Species Program under the Wildlife Conservation Act (Section 17-2-39). Beginning in September 1983, the major funding for this study was assumed under the Department's "Survey and Management of the Spikedace and Loach Minnow" project (no. E-3). This is a federal aid project that includes 75% funding from Section 6 of the Endangered Species Act, with 25% from the Department's Share with Wildlife Program.

Additional funding for study of the spikedace was under a contractual agreement with the U.S Fish and Wildlife Service, whereby the Department supplied data for habitat preference curves for fishes of the Gila Basin. This information was supplied to the Service both in the form of raw data and as the report authored by Propst et al. 1984. Finally, considerable historic information on the spikedace was available in the files of the Endangered Species Program, including its Fish Data Base. The latter consists of a compendium of museum specimen records of New Mexico fishes, compiled largely under funding from the U.S. Forest Service and through a contract with James E. Sublette, Eastern New Mexico University.

As indicated above, data gathered on the spikedace under FW-17-R resulted from a survey of the ichthyofauna of the warmwater stream reaches of the Gila Basin of New Mexico. That study was designed to determine the species of fishes present in the basin and to document their distribution, abundance, habitat use, population structure, food habits, and related information. In the process of accomplishing those objectives, an effort was made to identify for separate study those areas of the basin where native fishes persisted as viable populations. Some data on native fishes were gathered at the latter sites, those being where one or more species of non-native gamefishes where found to be established.

Under project E-3, the focus of the study was narrowed to the spikedace and to another Gila Basin cyprinid, the **loach** minnow. Specific objectives of that project were: (1) to determine the distribution, abundance, and aspects of life history, ecology, and related features of the spikedace and **loach** minnow in New Mexico; and (2) to investigate the feasibility of management to benefit these species within their historic ranges. The procedures to accomplish these objectives included: (1) surveys to determine the distribution, abundance, and population structure of the spikedace and **loach** minnow in the Gila and San Francisco river drainages in New Mexico; (2) documentation of the life history, ecology, and related features in spikedace and **loach** minnow populations in New Mexico; (3) collection of data as appropriate on all species associated with the spikedace and **loach** minnow in New Mexico; (4) determination, as appropriate, of habitat parameters associated with sampling stations to include: (a) water temperature, (b) water chemistry, (c) aquatic vegetation, (d) riparian vegetation, (e) stream configuration, (f) flow rate, (5) investigation of the feasibility of acquiring control over areas of occupied or potential habitat for the spikedace and **loach** minnow to maintain, enhance, or establish populations in New Mexico; (6) investigation of the feasibility of transplanting spikedace and **loach** minnow to portions of their historic New Mexico range that are presently unoccupied--John P. Hubbard.

INTRODUCTION

In 1851, J.H. Clark, attached to the U.S. and Mexican Boundary Survey under the command of Col. J.D. Graham, collected the first museum specimens of the spikedace, *Meda fulgida*, from the San Pedro River in southeastern Arizona (Girard 1856). Subsequent ichthyological investigations revealed that the spikedace belonged to an assemblage of minnows endemic to the lower Colorado River basin of the American Southwest (Girard 1859; Cope 1874; Cope and Yarrow 1875; Gilbert and Scofield 1898; Fowler 1925; Hubbs 1955). This assemblage comprises the tribe Plagopterini and contains three genera and six species (Miller and Hubbs 1960). In addition to the genus *Meda*, which contains only the spikedace, the genera in this tribe are *Lepidomeda* and *Plagopterus* (Table 1). *Lepidomeda* has four species, of which the White River spinedace and Virgin River spinedace occur only in portions of the Virgin River drainage of Nevada, Utah, and Arizona (Cope 1874; Miller and Hubbs 1960; Rinne 1971; Cross 1975). The Pahranagat spinedace, endemic to springs and outflows of the pluvial White River in Nevada, is now extinct (Miller and Hubbs 1960; Miller 1961; Rinne 1980). The Little Colorado River spinedace is restricted to the upper Little Colorado River in Arizona (Miller 1963; Minckley and Carufel 1967). The monotypic woundfin historically was found in the Virgin, lower Gila, and lower Salt rivers, but it is now limited to the Virgin River (Miller and Hubbs 1960; Deacon and Bradley 1972; Uyeno and Miller 1973; Minckley 1973; Minckley 1980).

In Arizona, the spikedace once occurred in the Agua Fria River and much of the Gila River drainage upstream of Phoenix. However, it is now found in that state only in Aravaipa and Eagle creeks and a limited reach of the Verde River. In New Mexico, the species is now confined to portions of the Gila River, although it formerly occurred in the San Francisco River (Koster 1957). Associated with the reduction of its range, the spikedace has also declined precipitously in abundance (Miller 1961 and 1964; Minckley 1973; Barrett, et al. 1985; Propst, et al. 1985). Currently, the largest populations of the species exist in portions of Aravaipa Creek (Barber and Minckley 1966), the Verde River (Barrett et al. 1985), and in the lower Cliff-Gila Valley of the Gila River in New Mexico (Anderson 1978; this study). Populations in Eagle Creek and other reaches of the Gila River in New Mexico (i.e., the lowermost reaches of the Middle and West forks, upper East Fork, and the mouth of the Middle Box) are limited and subject to elimination (Minckley 1973; Propst et al. 1985; this study).

TABLE 1. Fish species referred to in the text. A = present in the Gila-San Francisco River basin, New Mexico (study area), B = extirpated from the study area, C = hypothetical in study area, D = present in the lower Colorado River basin outside the study area.

Native Species	Status
Apache trout (Salmo apache)	D
Gila trout (Salmo gilae)	A
longfin dace (Agosia chrysogaster)	A
bonytail chub (Gila elegans)	D
Gila chub (Gila intermedia)	B
roundtail chub (Gila robusta)	A
White River spinedace (Lepidomeda albivallis)	D
Pahranagat spinedace (Lepidomeda mollispinis)*	D
Virgin River spinedace (Lepidomeda vittata)	D
spikedace (Meda fulgida)	A
woundfin (Plagopterus argentissimus)	D
Colorado squawfish (Ptychocheilus lucius)	C
speckled dace (Rhinichthys osculus)	A
loach minnow (Tiaroga cobitis)	A
flannelmouth sucker (Catostomus latipinnis)	C
Sonoran sucker (Catostomus insignis)	A
desert sucker (Pantosteus clarki)	A
razorback sucker (Xyrauchen texanus)	C
desert pupfish (Cyprinodon macularius)	D
Gila topminnow (Poeciliopsis occidentalis)	B
Non-native Species	
rainbow trout (Salmo gairdneri)	A
brown trout (Slamo trutta)	A
central stoneroller (Campostoma anomalum)	B
common carp (Cyprinus carpio)	A
flathead chub (Hybopsis gracilis)	B
red shiner (Notropis lutrensis)	A
fathead minnow (Pimephales promelas)	A
Rio Grande sucker (Pantosteus plebeius)	A
black bullhead (Ictalurus melas)	A
yellow bullhead (Ictalurus natalis)	A
brown bullhead (Ictalurus nebulosus)	B
channel catfish (Ictalurus punctatus)	A
flathead catfish (Pylodictis olivaris)	A
mosquitofish (Gambusia affinis)	A
green sunfish (Lepomis cyanellus)	A
bluegill (Lepomis macrochirus)	A
smallmouth bass (Micropterus dolomieui)	A
largemouth bass (Micropterus salmoides)	A

* Extinct species.

The preferred habitat of the spikedace is in low-to-moderate gradient, intermediate-sized streams. In such streams, the substrate varies among sand, gravel, and cobble, and water velocities are slow to moderate. For much of the year, the spikedace moves about these rather broad and shallow streams in aggregations, feeding upon drifting macroinvertebrates. As water temperatures decline during the autumn, the spikedace tends to move into areas of slow-velocity water, where it is most common through the winter.

Within a typical year in the Gila Basin, flows fluctuate seasonally as snowmelt causes spring pulses and occasional floods, and late-summer rains produce spates (or floods) of varying intensity and duration. Late-spring and early-summer droughts may reduce flows to a fraction of base levels. Within these natural flow regimes, the spikedace has evolved strategies that have adapted it to cope with these and other vicissitudes of southwestern streams. Indeed, high flows resurrect and resuscitate essential spikedace spawning and foraging habitat.

In primeval streams, the spikedace occurred with two piscivorous fish species, the roundtail chub and Colorado squawfish (Kirsch 1888; Minckley 1973). These predators are mainly deep-water fishes that do not normally occupy the shallow-water habitats favored by the spikedace. Both species, however, entered such areas for feeding and, no doubt, preyed upon spikedace.

The reasons for the decline of the spikedace are intimately related to land and water use practices in the region (e.g., Miller 1961; Pister 1974). Among the first areas settled by Europeans were the valleys through which flowed the streams having preferred spikedace habitat. The development of agriculture in these valleys caused various stream modifications. Diversion of water for irrigation caused the desiccation of some reaches and reduction of flows in others. The return of irrigation water from fields increased the silt-burden of the streams. Livestock foraged upon riparian vegetation and trampled stream banks, destroying bank stability and exacerbating sedimentation problems. Overgrazing, timber cutting, and the subsequent denuding of watersheds caused severe erosion and arroyo-cutting, which elevated sediment and bedload transport in the streams. Ground-water pumping lowered water tables, and caused the dewatering of many streams and reductions of flow in others (Hendrickson and Minckley 1984 and citations therein). Streams were channelized to accelerate water transport and, ostensibly, to reduce the effects of floods. Dams inundated many lotic habitats and altered the amplitude and periodicity of natural fluvial regimes. In addition to

physical changes, dams disrupted natural nutrient transport, and thus, altered primary and secondary in <u>situ</u> productivity in downstream
reaches (Ward 1982). Dams also diminished or eliminated the cleansing action of floods (Ward and Stanford 1979 and citations therein; Minckley and Meffe in press). In addition to the above detrimental modifications, water quality has also declined as a result of inflows of toxic wastes from mine tailings and other sources, industrial discharges, and agricultural and muncipal effluents.

Although the foregoing habitat modifications were sufficient to reduce, or eliminate, the spikedace (and other native fishes) from many stream reaches, additional pressures were imposed by the introduction and establishment of non-native fishes throughout the Gila Basin. In many, if not most, instances it is impossible to separate the declines caused by habitat degradation from those caused by negative interactions with non-native fishes. Indeed, in many situations both factors may have acted concurrently and synergistically. Negative interactions between native and non-native fishes probably occurred mainly through two mechanisms. More apparent, and easier to document, is predation. More subtle, but no less insidious, is competition for resources that may be limiting. Some non-native fishes probably interact in both ways with the spikedace, as well as other native fishes.

Among the first non-native fish species to become established in the Gila Basin were the brown and rainbow trouts. Non-native trouts deleteriously affect native trouts (Gila and Apache) of the Gila Basin through hybridization, competition, and predation. However, because of their small area of sympatry, it is doubtful that non-native trouts have had more than a minor impact upon the spikedace.

Non-native warmwater fish species were reported in the Gila Basin as early as the 1890's (Miller 1961), and several were well-established by the 1940's (LaBounty and Minckley 1972; Marsh and Minckley 1982). In the New Mexico portion of the basin, several warmwater species had been introduced and were probably established by the 1930's. These introductions occurred in an era when almost all native species were viewed most benignly as "forage" fish, and commonly dismissed as "trash" fish. Such an attitude resulted in many efforts to establish and expand populations of non-native gamefishes regardless of impacts upon native species. Among the gamefishes introduced were the channel catfish and smallmouth bass. In addition to the intentional introductions of gamefishes, other non-natives became established. These included the common carp, which was originally introduced as a food fish, but it is now considered a nuisance in most areas. The mosquitofish was introduced for insect control while several others, such as the fathead minnow and red shiner, were introduced as bait or forage fish. At least a few non-natives were established by accident, while other introductions have failed.

Among the introduced warmwater fishes, the channel catfish, flathead catfish, and smallmouth bass probably negatively impact native Gila Basin warmwater fishes mainly through predation. The mosquitofish also preys upon some native southwestern fishes (Schoenherr 1981; Meffe 1985); however, because it occupies different habitat, it is doubtful the mosquitofish has more than a minor impact upon spikedace populations. The establishment and increasing range of the red shiner, and the concomitant decline of spikedace populations in several localities (Minckley and Deacon 1968), has implicated that non-native as a causative factor in the reduction of spikedace range and abundance. Other non-native, warmwater fishes may have negative impacts upon native fishes, but incriminating evidence of such is generally lacking.

DESCRIPTION OF THE GILA-SAN FRANCISCO BASIN, NEW MEXICO

The study area comprised the warmwater reaches of the Gila and San Francisco river drainages in Catron, Grant, and Hidalgo counties of New Mexico (Figure 1). The Gila River arises on the Mogollon Plateau and flows southward and westward to exit the state near Virden. The San Francisco River originates on the plateau in Arizona, enters New Mexico near the village of Luna, and flows southward and westward to exit the state southwest of the settlement of Pleasanton. The two rivers join near Clifton, Greenlee County, Arizona.

From its origins at elevations exceeding 2750 m, the Gila River descends to 1145 m at the New Mexico-Arizona border. The initial reach of the river features steep canyon topography, which prevails to near its confluence with Mogollon Creek (elevation 1525 m). At that point, the largely anastomosed river emerges from the mountains, and flows mainly through broad floodplains to the border. In the Middle Box and the Narrows, the river is constrained by canyons. The Gila River is perennial throughout the study area and is normally low in turbidity and sediment transport.

Unlike the Gila River, the San Francisco River flows through canyons for most of its course in New Mexico. It emerges for short distances (generally less than 20 km)

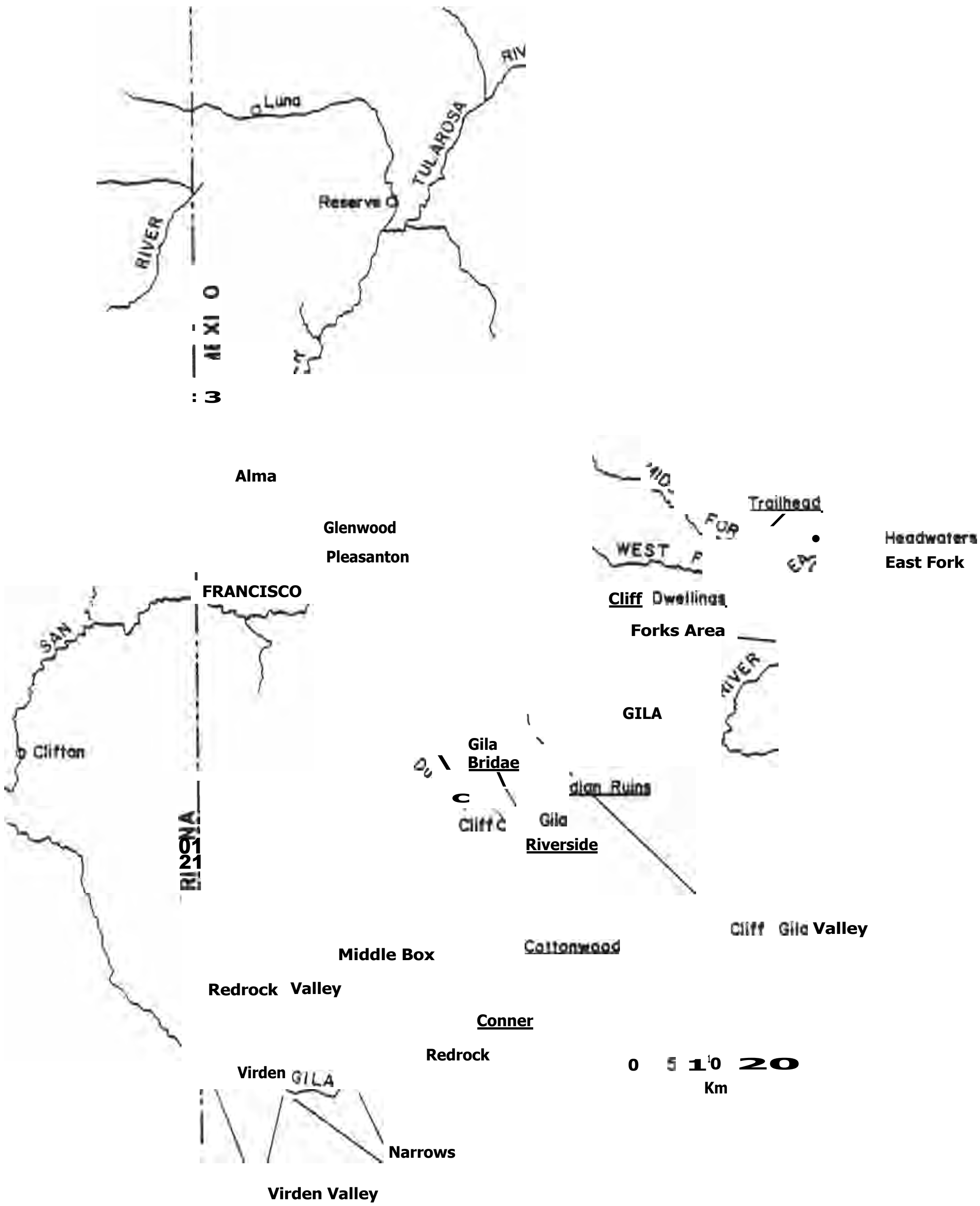


Figure 1. The Gila-San Francisco River basin, New Mexico. Specific study sites are underlined and important stream reaches discussed in the text are delineated.

onto broader floodplains near the settlements of Luna, Reserve, Alma, Glenwood, and Pleasanton. However, because of irrigation diversions, the stream is often dry by late summer in these reaches. In contrast, the flow is usually permanent in canyon reaches. Sediment transport is moderate, as evidenced by frequent high turbidity and sand deposition in almost all reaches. The upstream elevations of the San Francisco River are similar to those of the Gila, but the exit elevation is higher (1410 m). The drainage area of the San Francisco River in New Mexico is about 5,000 sq. km, while that of the Gila River is about 8,300 sq. km.

Discharge volumes of the streams in the Gila-San Francisco Basin of New Mexico are highly variable, depending upon the intensity and duration of late summer (mid-July through September) rains and the amount of spring snowmelt. Spates may occur in any season, but floods most commonly occur from October through March (USGS annual records).

METHODS

The historic distribution and status of the spikedace in New Mexico was determined by examining the museum records for the Gila-San Francisco basin, which are contained in the Fish Data Base compiled by the New Mexico Department of Game and Fish. Complete names of referenced museums are provided in Appendix I. Museum accession numbers are given for important records that are not available in the referenced literature. Other accession numbers can be obtained from the New Mexico Department of Game and Fish. For some records, important collection information was lacking or vague. If a precise locality and date could not be assigned to a given collection, it was not used in the evaluation of the historic distribution and status of the spikedace. The only exception to this was E.D. Cope's 1872 collections, which are simply attributed to the San Francisco River in New Mexico.

The historic record was divided into two periods to facilitate assessment of trends. The early historic period extends from the 1800's through 1960. Most collections in this period were made from the late-1930's to the early-1950's. The recent historic period is 1961-1980, and sampling through it was evenly dispersed temporally. Much of the sampling in each of these periods, particularly the early historic, was done where access was easiest. However, in the recent historic period, a greater effort was made to inventory the entire basin.

Sampling to determine the current distribution, status, and biology of the spikedace in New Mexico began in December 1982 and continued through September 1985. The basic survey objective was to sample all warmwater stream reaches that might support the spikedace. To this end, many intermittent and all permanent streams in the warmwater reaches of the basin were sampled (Figure 2). On stream reaches found to have suitable spikedace habitat, sample sites were located 1 to 4 km apart. Site locations on other streams were dependent upon accessibility, flow characteristics, and probability of a particular reach supporting the spikedace. Overall, the survey effort resulted in the sampling of all warmwater stream reaches that had even a remote possibility of supporting the spikedace.

Site-length varied, but each site was of sufficient length to include representative riffle, run, and pool habitat. Site-length was usually 75-100 m on small streams, 100-150 m on intermediate-sized streams, and as long as 300 m on large streams.

Several methods were used to sample the fish populations, depending upon the extent and mix of habitats, stream size, and the species likely to be present. Typically, a Smith-Root backpack electroshocker (Type VII A) with pulsed DC current was used. Stunned fish were collected with dipnets or seines and placed in holding pens or preserved for later examination. Seines (1.2 x 0.9, 3.0 x 1.2, 6.1 x 1.2, and 9.1 x 1.2 m; all 6.4 mm mesh) were often used to supplement collections obtained by electroshocking, and at times this was the only method utilized. Gill nets (22.9 x 1.8 m) with three panels (22.2, 25.4, and 31.8 mm mesh) were used to collect large specimens from deep pools. Larval fish were collected with 1 mm mesh aquarium dipnets or with drift nets (0.5 in square mouth, 4 m long, and 560 micron mesh).

Released specimens (usually 100 mm or greater) were weighed to the nearest 1.0 g on an AccuWeight dial scale and measured to the nearest 1.0 mm standard length (SL). Specimens retained for examination were fixed in 10% formalin for at least 10 days, soaked in water for 3 days, and preserved in 45% isopropanol. (For complete description and/or definition of terms and measurements used in this report, the reader is referred to Lagler [1956], Everhart et al. [1975], Snyder [1981], and Nielson and Johnson [1983]).

Permanent sampling sites were established (underlining indicates the name of the site) on the West Fork of the Gila River near the Gila <u>Cliff Dwellings</u> (T12S R14W) in January 1983, Middle Fork of the Gila River near the Middle Fork <u>Trailhead</u> (T12S R14W Sec25) in January 1983, Gila River near the village of <u>Riverside</u> (T16S R17W Sec 4) in June 1983, and Gila River near the mouth of the Middle Box (<u>Conner</u> Site; T18S R18W Sec23) in June 1983. Each of these sites was

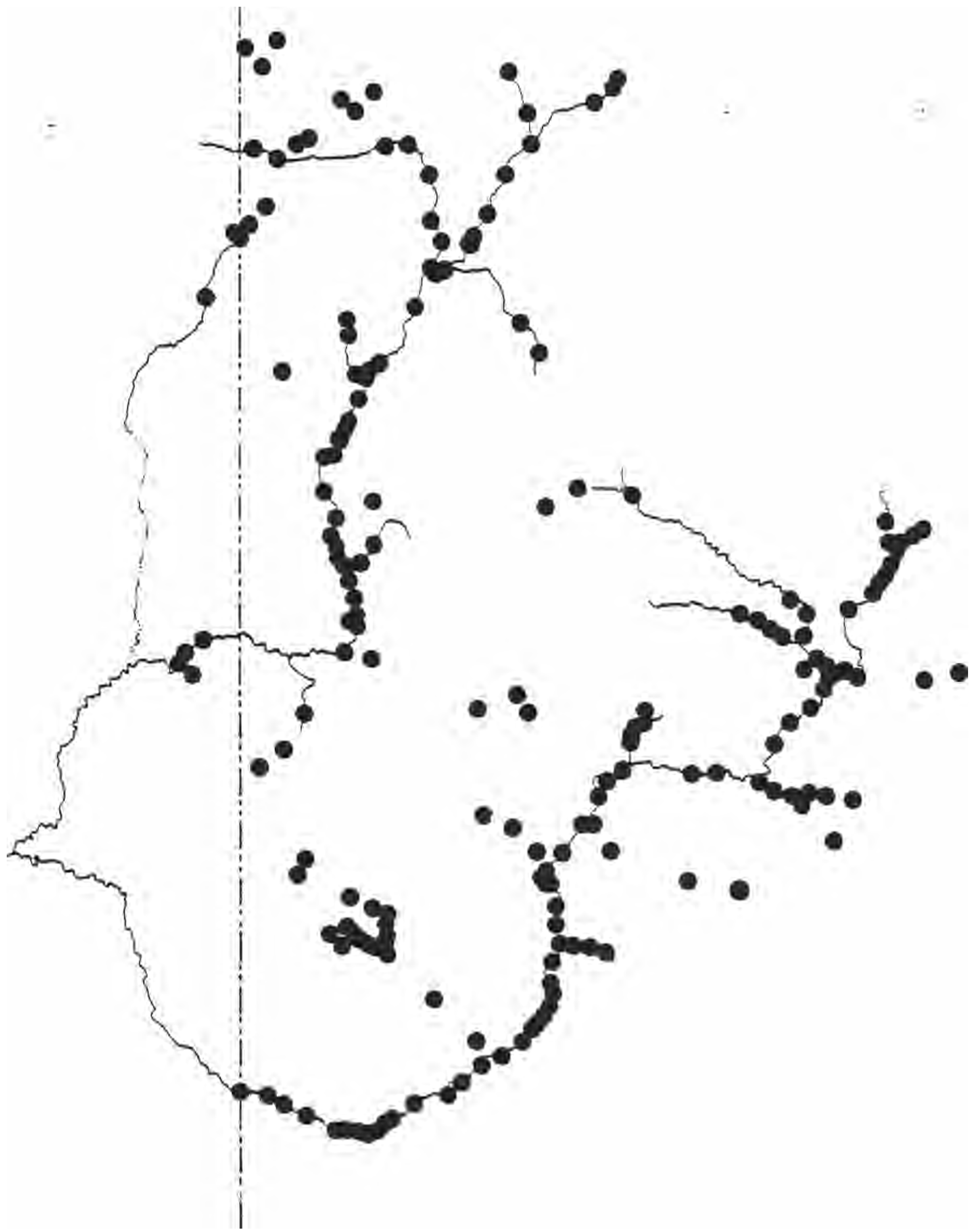


Figure 2. Ichthyological sampling sites in the Gila-San Francisco basin, New Mexico and Arizona, 1982-1985.

sampled on at least a seasonal basis and as often as biweekly. These sites were selected for regular sampling because among them they contained the array of habitats presently occupied by the spikedace in New Mexico. Several additional sites in the Cliff-Gila Valley were sampled on several occasions, and data from these sites were utilized to augment those obtained from the four permanent sites (Figure 1).

In 1984, studies were initiated on the Gila River at Cottonwood (T17S R17W Sec 9) and Conner to investigate larval drift ecology (Figure 1). Drift sampling began on 26 March and continued through 5 June. Larval drift collections were made with conical plankton nets (described on previous page) over a 24 hr period at intervals of 7-10 days at each site. Generally, two nets were deployed simultaneously at a site, one in midstream and one near the stream margin. Each net was in place for about 1 hr at intervals corresponding to noon, dusk, midnight, and dawn. Drift samples were fixed in 10% formalin, and specimens were preserved in 3% buffered formalin. Water velocity and depth at net mouth and stream discharge were measured at the end of each sampling period. Air and water temperatures were determined at the time each net was set.

Microhabitat sampling sites were established at each of the above sampling sites, except for Conner. Adult and juvenile fish were electroshocked and seined, and larval fish were obtained with an aquarium dipnet. Seining was more efficient as a sampling method when the spikedace was observed in large aggregations in shallow water. Sampling began at the downstream terminus of a site and proceeded upstream in a zigzag pattern. At each point that a fish was collected and/or observed, a numbered flag was anchored. Flag number, species of fish, and total length (TL) of collected specimen(s) were recorded. Care was taken to avoid frightening a fish before we detected it. If we suspected our activities influenced fish position, no measurements were made for that particular observation.

After fish positions were flagged, we returned and measured water velocity, water depth, and substrate composition at each flag. Water velocity (30.5 mm/sec or 0.1 ft/sec accuracy) was determined with a Marsh-McBirney flowmeter mounted on a topset rod at 0.6 of column depth. Water depth was measured to 30.5 mm (0.1 ft) accuracy with the topset rod. Substrate was characterized on the basis of its composition in a 150 mm radius around each flag. The seven substrate categories used were silt (grain size ≤0.05 mm), sand (0.06-2.0 mm), gravel (2.1-50.0 mm), cobble (51.0-150.0 mm), rubble (151.0-300.0 mm), boulder (>301 mm), and bedrock. Dominant and sub-dominant substrate components were recorded. For statistical comparisons, velocity and depth data were clustered in 15.2 cm (0.5 ft) increments. Data sets for developmental, seasonal, and geographical microhabitat usage were compared through Chi-square analysis, with significance set at 0.95.

Water and air temperature were measured with a mercury thermometer, and dissolved oxygen concentration was determined with a Hach Field Ecology Kit. Mean stream width and depth were determined with a 50 m tape and topset rod, respectively, at each site. Stream discharge was estimated at each site by making depth and velocity measurements at 10 or more equidistant points across the channel where flow was laminar.

Life history data for the spikedace were obtained primarily from specimens collected in the Cliff-Gila Valley. Preserved specimens were measured to the nearest 1.0 mm SL and weighed (after sponging dry) to the nearest 0.01 g on a Precisa Model 900C-3000D Balance. Representative specimens from collections made in the Cliff-Gila Valley between June 1983 and July 1984 were eviscerated to determine diet, sex, and gonadal development. All food items were identified to the most practical taxonomic level.

The ovarian mass removed from each female spikedace was sponged dry and weighed to the nearest 0.01 g. Ova from a weighed subsample of the ovary were teased from the periviteline membrane. These ova were then segregated into maturity modes (after Barber et al. 1970), and the greatest diameter of at least 10 ova in each mode present were measured to the nearest 0.01 mm with a micrometer mounted in a Bausch and Lomb dissecting scope. The modes of Barber et al. were; 0.3-1.1 mm = pre-recruitment, 1.1-1.5 mm = recruitment, and larger than 1.5mm = mature. The ova in each mode in the subsample were counted. The total number of ova in each mode in each ovary was determined by comparing the ratio of ova in each mode in the subsample to the total weight of the ovary. A gonadal-somatic-index (GSI) was calculated for each examined specimen by dividing ovarian weight by total body weight and multiplying the result by 100.

The age structure of the Cliff-Gila Valley spikedace population was determined from length-frequency histograms. Specimens were grouped into 2 mm size-classes for length-frequency analysis.

All specimens collected during this study are housed at the New Mexico Department of Game and Fish Laboratory in Santa Fe.

RESULTS AND DISCUSSION

Distribution and Status

Historic Distribution and Status

The spikedace once occurred throughout much of the upper Gila Basin in Arizona and New Mexico (Minckley 1973). Its range may have extended into Sonora, Mexico, via the San Pedro River (Miller and Winn 1951). In Arizona, the major river systems occupied by spikedace were the Agua Fria, Verde, Gila, Salt, and San Pedro. The species was at least moderately common in these systems until about 1890, when Anglo-Europeans began to divert, channelize, dewater, impound, and pollute the streams (Miller 1961; Minckley and Deacon 1968). The spikedace, as well as several other native fishes, has since been extirpated from almost all streams of historic occurrence in Arizona. Currently, the spikedace inhabits the Verde River between Sullivan Lake and Sycamore Creek (Barrett et al. 1985), Eagle Creek (a tributary of the Gila River) (Propst et al. 1985), and Aravaipa Creek (a tributary of the San Pedro River) supports a moderate-sized population of the spikedace (Barber and Minckley 1966; Minckley 1981). The species has not been documented in recent years in any other formerly occupied streams in Arizona (Minckley and Deacon 1968; Minckley 1973; Propst, et al. 1985). (More detailed accounts of the range and status of the spikedace in Arizona are provided in Miller and Hubbs [1960], Miller [1964], Barber and Minckley [1966], Barber et al. [1970], Minckley [1973], and Barrett et al. [1985]).

The limited historical record precludes precise delineation of the original range of the spikedace in New Mexico. Nevertheless, collection records, coupled with knowledge of the species' preferred habitat (Minckley 1973; Anderson 1978; this study), permitted a reasonable approximation of its primeval distribution. Then, as now, the spikedace was presumably restricted to meandering, moderate-sized to large streams, of slight-to-intermediate gradient, with sand, gravel and small cobble substrates. The upper elevational limits of the spikedace, as dictated by its winter-low temperature tolerance level and absence of suitable habitat, probably occurred about 2100 m. Its lower elevational limits were about 500 m, and occurred in Arizona.

In New Mexico, the spikedace probably occurred in the San Francisco River from the Arizona-New Mexico border upstream to the vicinity of the town of Reserve (Figure 3). If it occupied tributary streams, the species was probably restricted to the lowermost reaches of those streams, with

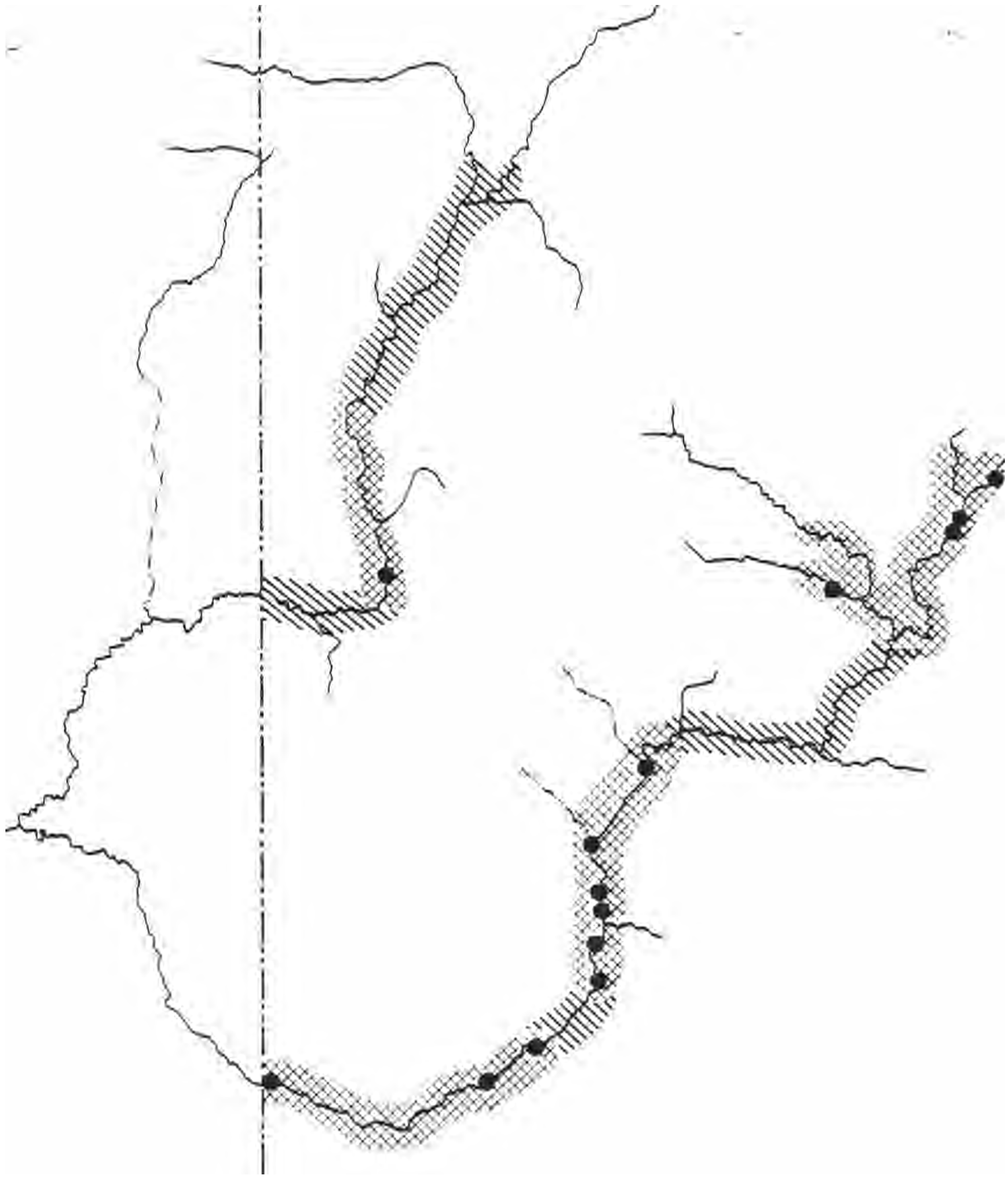


Figure 3. Distribution of the spikedace in the Gila-San Francisco basin, New Mexico, prior to 1961. Solid dots are sites of record, cross-hatched areas indicate stream reaches of verified or probable occurrence, and hatched areas indicate stream reaches of possible but unverified occurrence.

the possible exception of the Tularosa River. In the Tularosa River, the spikedace may have occurred several km upstream from the stream's mouth. Within the mainstem of the San Francisco River, the species would have occurred mainly in floodplain reaches such as occur near Reserve, Alma, Glenwood, and Pleasanton. The abundance and distribution of spikedace in canyon reaches were limited by the paucity of habitat.

The distribution of the spikedace in the New Mexico portion of the Gila River was probably not continuous from the Arizona-New Mexico border upstream to the confluence of the West and East forks. Within this reach, suitable habitat was generally lacking in the lowermost section of the Middle Box (about 10 km of stream), and the reach from the confluence of the West and East forks downstream to the mouth of Turkey Creek. However, short stretches of suitable habitat occurred within both of these reaches, particularly the latter. There, the spikedace was almost certainly present only sporadically. Few perennial tributaries empty into the mainstem Gila River below the confluence of the West and East forks. Of these, only lowermost Sapillo, Duck (which is no longer perennial), and Mangas creeks had habitat that the spikedace might have found suitable.

From the juncture of the East and West forks of the Gila River, the spikedace extended upstream variable distances in each of the main tributaries. The species probably occurred throughout the East Fork, from its confluence with the West Fork upstream to Taylor and Beaver creeks. The upstream distributional limit in the West Fork was probably 3 km or less above the Gila Cliff Dwellings. In the Middle Fork, the spikedace ranged upstream as far as Little Bear Canyon. Few, if any, of the tributaries of these forks have spikedace habitat. Therefore, the fish probably occupied only the lowermost sections, of such tributaries.

Recent and Current Distribution and Status

San Francisco River

E.D. Cope was the first collector to record the spikedace in New Mexico. His 1872 San Francisco River collections (ANSP 18999-19087 and 19151-19248) did not include precise locality information, but they were probably made in the vicinity of present-day Pleasanton, Glenwood, and/or Alma. His retention of 89 and 96 specimens in two collections suggests the species was moderately common in the area. No other inventories were made in the San Francisco River until the middle of this century, when W.J. Koster collected three spikedace (UNM 1247 and 1255) in 1948 and

1950 near the Frisco Hot Springs, and R.R. Miller found one (UMMZ 162728) in the same area in 1950 (Figure 3). No subsequent records of spikedace exist in the San Francisco River in New Mexico (Huntington 1955; LaBounty and Minckley 1972; Anderson and Turner 1977; Anderson 1978; this study). Recent surveys in the Arizona portion of the drainage, including Blue River, also failed to locate the species (James M. Montgomery, Inc. 1985; this study). Thus, the spikedace has evidently been extirpated from the San Francisco River drainage in both New Mexico and Arizona.

Gila River

In the Gila drainage of New Mexico, ichthyofaunal collecting was concentrated in four areas. Among them, these represent the primary river reaches of historic occupancy and the array of habitats suitable for spikedace. Within each area, marked changes have occurred in the abundance and distribution of the species (and the entire fish community) since the first scientific collections were made in the 1930's. Because each area differs in physical characteristics, degree of recent ecological change, and sampling intensity, they are discussed separately.

East Fork of the Gila River: Headwaters. This area encompasses the permanent portions of Beaver and Taylor creeks, plus the East Fork of the Gila River downstream to the Gila Wilderness Boundary (T12S R13W Sec 2). Within this area, collecting prior to 1960 was concentrated near the confluence of Beaver and Taylor creeks. Early inventories (1935-1937) documented an intact native ichthyofauna comprised of seven species. Numerically, the longfin dace was the dominant species, but the spikedace, speckled dace, desert sucker, and Sonoran sucker were also common (Table 2). Although the roundtail chub was uncommon, it was regularly collected. The loach minnow constituted a very minor component of the pre-1960 collections.

The first non-native species to be collected in the area was the rainbow trout in 1937, and was followed by the mosquitofish in 1949. Three non-natives (central stoneroller, flathead chub, and red shiner) were collected in 1951 near Wall Lake (on Taylor Creek), but these introductions did not survive. The fathead minnow, channel catfish, and smallmouth bass were introduced and established by the early 1950's.

Over the next 20+ years, distinct changes occurred in the fish community of the East Fork. The native fish community retained all pre-1960 elements, but the abundance of each species decreased markedly. Whereas the spikedace was relatively common (14.8%) in pre-1960 collections, it was

TABLE 2. Fish species recorded (indicated by X) in the headwaters of the East Fork of the Gila River through 1960. Relative abundance is based on total number of specimens collected in the period.

Native Species	Year of Record							Relative
	1935	1936	1937	1949	1951	1952	1953	Abundance
longfin dace	X	X	X	X	X	X	X	36.3
roundtail chub	X	X	X	X		X		3.0
spikedace	X	X			X	X	X	14.8
speckled dace	X	X		X	X		X	11.4
loach minnow					X			<0.1
Sonoran sucker		X		X	X	X		14.0
desert sucker	X		X	X	X	X	X	14.0
								93.6
Non-native Species								
rainbow trout			X	X	X			0.5
central stoneroller					X			1.1
flathead chub					X			0.2
red shiner					X			0.3
fathead minnow					X			1.2
channel catfish					X		X	0.2
mosquitofish				X	X			2.8
								6.3

collected only once (five specimens) in the 1961-1980 period (Figure 4). The longfin dace and desert sucker remained the most common natives, although each was less abundant in the 1961-1980 period than the pre-1960 period (Table 3).

While the native fish community experienced a decline in absolute and relative abundance, the non-native community exhibited concomittant increases. In addition to the established fathead minnow, channel catfish, smallmouth bass, and mosquitofish, four other non-natives were reported between 1961 and 1980. Of these, the black bullhead has been reported continuously since its first appearance in the collecting record and is considered an established component of the ichthyofauna. The rainbow trout has been frequently collected in the area, but its survival there is probably aided by periodic stockings. The green sunfish and largemouth bass were collected in this period, but neither has been found there subsequently.

Sampling in 1983 confirmed the increasing numerical dominance of non-native over native fishes. Collections made in April and September on Beaver and Taylor creeks, as well as in the uppermost portion of the East Fork, revealed only four native and four non-native species, all in low numbers (Table 4). The longfin dace, once the most common fish, was represented by one specimen. Ten adult (>150 mm TL) roundtail chub were found in two pools in TaylorCreek. The two sucker species were represented mainly by adults (190-310 mm TL). In April, larval suckers (<30 mm TL) were found along stream margins, but no Age 0 fish or juveniles were collected in September. The size range of specimens indicated that little in situ recruitment had recently occurred in the sucker population. No spikedace or loach minnow were found. Mosquitofish was collected from cover that included vegetated stream margins and spring seeps adjacent to the main channel. Black bullhead and channel catfish were not common, and only juveniles and adults of both species were found. Among non-natives, the smallmouth bass was the most common, and it was represented primarily by adults over 200 mm TL.

At sites located progressively further downstream from the vicinity of Beaver and Taylor creeks, non-native species decreased and natives increased in abundance. The loach minnow and speckled dace were found in low numbers at the two most downstream sites, whereas non-natives were absent at these sites.

In addition to almost certain declines caused by predation by non-native species, the native fish community of the East Fork was deleteriously affected by habitat

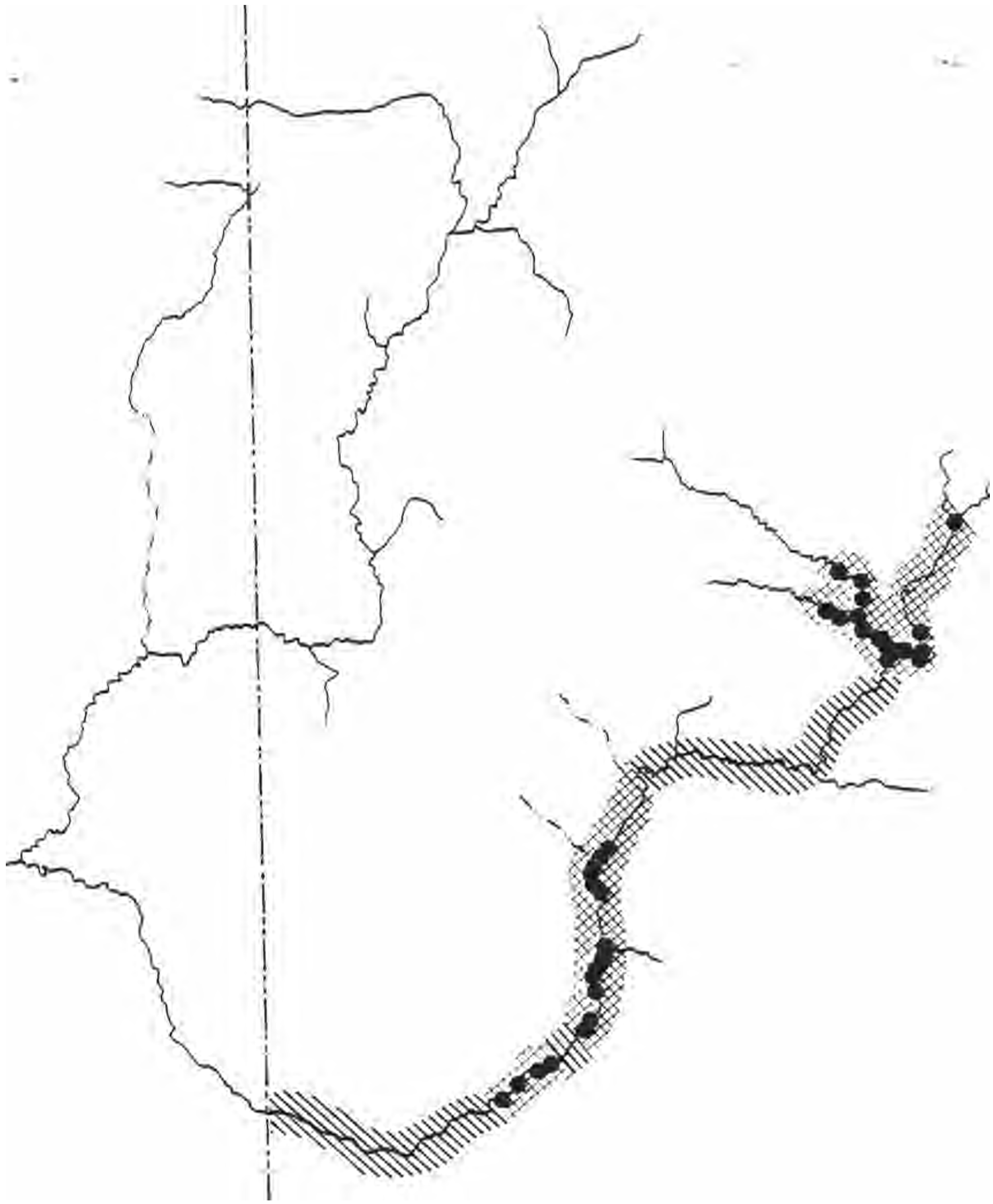


Figure 4. Distribution of the spikedace in the Gila-San Francisco basin, New Mexico, between 1961 and 1980. Solid dots are sites of record, cross-hatched areas indicate stream reaches of verified or probable occurrence, and hatched areas indicate stream reaches of possible but unverified occurrence.

TABLE 3. Fish species recorded (indicated by X) in the headwaters of the East Fork of the Gila River from 1961 through 1980. Relative abundance is based on total number of specimens collected in the period.

Native Species	Year of Record 1965	1971	1973	1976	1977	Relative Abundance
longfin dace	X	X		X		29.9
roundtail chub				X	X	3.5
spikedace					X	1.4
speckled dace	X			X		1.9
loach minnow			X			0.3
Sonoran sucker	X	X			X	17.2
desert sucker	X	X			X	4.6
						58.8
Non-native Species						
rainbow trout		X				1.6
fathead minnow		X			X	5.4
black bullhead	X				X	1.1
channel catfish		X				2.2
mosquitofish		X		X	X	27.2
green sunfish	X				X	3.0
smallmouth bass					X	0.3
largemouth bass	X					0.3
						41.1

TABLE 4. Fish species recorded (indicated by X) in the headwaters of the East Fork of the Gila River in 1983 and 1985. Relative abundance is based on total number of specimens collected in the period.

	Year of Record		Relative Abundance	
Native Species	1983	1985	1983	1985
longfin dace	X	X	<0.1	10.8
roundtail chub	X	X	2.1	0.9
spikedace		X	0	15.6
speckled dace	X	X	4.5	0.3
loach minnow	X	X	0.7	1.0
Sonoran sucker	X	X	12.0	42.3
desert sucker	X	X	30.6	22.8
			82.6	93.7
Non-native Species				
fathead minnow	X	X	4.7	1.0
black bullhead	X	X	2.5	0.6
channel catfish	X	X	0.9	0.4
mosquitofish	X	X	4.7	2.1
smallmouth bass	X	X	4.7	2.1
			17.4	6.2

degradation. This degradation was manifested mainly by bank destabilization and increased sediment transport. However, other stream reaches have suffered similar deterioration of habitat without such precipitous declines in native fishes. Consequently, predation by non-natives, particularly smallmouth bass and channel catfish, is believed to be mainly responsible for the depressed abundance of native fishes in April and September 1983.

In October 1983 and December 1984, the East Fork experienced major floods. During the same period, livestock grazing in the floodplain was greatly reduced. Results of a sampling foray in September 1985 indicated that the combined effects of these events apparently produced a resurgence in native fish numbers and a decline in the abundance of non-native fishes. Age 0 and older desert and Sonoran suckers were common throughout the area. Longfin dace was found further upstream and in much higher numbers than in 1983. Only adult roundtail chubs were collected in 1983, whereas Age 0 and older were found at several sites in 1985. Although the loach minnow and speckled dace remained uncommon, each was more widely distributed in 1985 than 1983. The spikedace, apparently absent in the East Fork in 1983, was present in low-to-moderate numbers at several locations in 1985.

The spikedace found in 1985 had two possible origins. It is possible, and likely, that a small, residual population existed in the upper reaches of the East Fork during our sampling in 1983. However, because of its very restricted range, it was not collected. As habitat conditions improved, and non-native predator numbers declined, spikedace numbers and range expanded. Alternatively, the spikedace found in the East Fork in 1985 may have orginated from the West or Middle forks of the Gila River. However, such an origin would have required the progenitors of the current East Fork population to have moved upstream at least 20 km, which seems unlikely.

Gila River: Forks Area. The Gila River Forks area includes the East Fork from Tom Moore Canyon downstream to its confluence with the West Fork, the Middle Fork from Little Bear Canyon downstream to the confluence with the West Fork, and the West Fork from EE Canyon downstream to the confluence with the East Fork.

Sampling in the Forks area prior to 1960 was limited by the difficult accessibility to the area. Such sampling as occurred revealed a fish community composed entirely of native fishes, except for the rainbow trout (Table 5).

TABLE 5. Fish species recorded (indicated by X) in the Forks area of the Gila River through 1960. Relative abundance is based on total number of specimens collected in the period.

Native Species	Year of Record 1951	1952	Relative Abundance
longfin dace	X	X	1.0
roundtail chub	X	X	1.0
spikedace	X	X	15.4
speckled dace	X	X	34.6
loach minnow	X	X	11.5
Sonoran sucker	X	X	8.7
desert sucker	X	X	17.3
			89.4
Non-native Species			
rainbow trout	X		10.6
			10.6

The speckled dace was most common, but other natives were also well-represented. The longfin dace and roundtail chub were not common in these early collections.

Between 1961 and 1980, the Forks area was intensively sampled. This sampling provides a detailed record of the changes in the fish fauna that have occurred there since 1960 (Table 6). Throughout the 1961-1980 period, native fishes numerically dominated the community. Desert and Sonoran suckers were most common, and spikedace, speckled dace, and loach minnow were present in moderate numbers. Only the longfin dace and roundtail chub were comparatively uncommon. Ten non-native species were recorded, but only the fathead minnow and mosquitofish were semi-regularly collected during this period. Among the other non-natives, rainbow and brown trout were probably maintained by periodic stocking and/or dispersed into the area from upstream, coldwater habitats, where each is established. Catfishes (black and yellow bullheads and channel catfish) periodically inhabited the Forks area. Although smallmouth bass was occasionally collected, it was not common in the 1961-1980 collections. Green sunfish and bluegill were present but apparently failed to become established.

Collections made in 1983 and 1984 revealed the native fish fauna of the area was still largely intact. However, within discrete segments of the area, dramatic changes in community composition had occurred since Anderson's (1978) work in 1976 and 1977 (Table 7). In particular, the largely native-dominated lower East Fork community had become much reduced in numbers and partially replaced by non-native fishes. In 1976-1977, Anderson reported a fish community comprised of the expected seven native fishes and eight non-natives (14 samples). All non-natives were quite rare, and, in toto, constituted only 4.3% of the specimens collected. By 1983-1984, the native fish community of the lower East Fork had been greatly reduced in diversity and numbers. We collected only 178 specimens, of which 65% were native. Adult desert and Sonoran suckers were the most common species (64%), with the roundtail chub and loach minnow represented by one specimen each. We did not collect any spikedace, speckled dace, or longfin dace. Although the total number of individuals was rather low (62), five non-native species were present, including the piscivorous black bullhead and smallmouth bass. Habitat degradation appeared to be the primary reason for the low abundance of native fishes. Prior to 1978, the East Fork contained habitats preferred by native fishes; however, the severe flooding of 1978 eliminated much of that by deeply incising the river channel (P.R. Turner pers. comm.). Indeed, the low numbers of non-natives in this reach also indicated a lack of suitable habitat for these species.

TABLE 6. Fish species recorded (indicated by X) in the Forks area of the Gila River from 1961 through 1980. Relative abundance is based on total number of specimens collected in the period.

Native Species	Year of Record									Relative Abundance
	1965	1966	1967	1971	1973	1975	1976	1977	1978	
longfin dace	X	X	X	X	X		X	X	X	3.4
roundtail chub		X			X		X	X		0.7
spikedace	X	X	X	X	X		X	X		17.0
speckled dace	X	X	X	X	X		X	X		14.1
loach minnow	X	X	X	X	X		X	X		6.2
Sonoran sucker	X	X	X	X	X	X	X			17.3
desert sucker	X	X	X	X	X	X	X	X		35.6
										94.4
Non-native Species										
rainbow trout			X			X	X			0.2
brown trout							X	X		0.2
fathead minnow	X	X			X		X	X		0.6
black bullhead		X			X		X	X		0.4
yellow bullhead								X		<0.1
channel catfish		X						X		0.2
mosquitofish	X	X	X	X				X		3.3
green sunfish		X			X		X			0.3
bluegill		X								<0.1
smallmouth bass		X			X		X			0.2
										5.6

TABLE 7. Fish species recorded (indicated by X) in the Forks area of the Gila River from 1983 through 1984. Relative abundance is based on total number of specimens collected in the period.

Native Species	Year of Record 1983	1984	Relative Abundance
longfin dace	X	X	19.5
roundtail chub	X	X	2.7
spikedace	X	X	7.0
speckled dace	X	X	33.9
loach minnow	X	X	3.2
Sonoran sucker	X	X	20.7
desert sucker	X	X	14.5
			95.4
Non-native Species			
rainbow trout	X	X	0.5
brown trout	X		<0.1
fathead minnow	X	X	0.3
yellow bullhead	X	X	2.2
mosquitofish	X	X	0.9
smallmouth bass	X	X	0.7
			4.6

Regular sampling of the Middle Fork above its confluence with the West Fork provided another illustration of the changing fish community in the Gila River basin. In 1976 and 1977, Anderson (1978) made five collections in this stream. These contained 97.1% natives (seven species) and 2.9% non-natives (two species). In 1983-1984, we found a slight decrease in the relative abundance of native fishes (91.4% and seven species), a change within normal sampling error and natural population fluctuations. More important was the change in the non-natives present. In addition to the brown and rainbow trouts reported by Anderson, we found yellow bullhead, smallmouth bass, and fathead minnow. Given that natives only declined by 5.7% from 1976-1977 to 1983-1984, it cannot be demonstrated conclusively that non-natives were responsible for this change. Nevertheless, the persistence of yellow bullhead and smallmouth bass, plus a pattern of decreasing abundance of native species in our later samples, suggests negative impacts were being imposed upon the native fishes.

During our study, the spikedace was a comparatively minor component of the Middle Fork community. Anderson (1978) found a similar pattern of abundance, except for one sample in which he recorded 134 specimens. Near the end of our study, the spikedace was less common in the area than in earlier stages. Again, this may be a reflection of natural population variation; however, it could also reflect a downward trend in abundance due to competition and/or predation by non-natives.

Among the stream reaches of the Forks area, the fewest changes in community composition have occurred in the West Fork. Throughout Anderson's (1978) study, non-natives were a very minor component of the community (0.7%). All natives, except the roundtail chub, were at least moderately common. The collections we made revealed little overall change in community composition since 1976-1977, but some changes had occurred in the relative abundance of two species. The loach minnow was less common and the longfin dace more common in our collections than in those of Anderson. These changes may represent natural variation, or they may indicate slight shifts in the availability of the preferred habitat of the two species. The spikedace was moderately common (11.4% in 1976-1977 and 8.7% in 1983-1984) in both sampling periods.

Overall, the spikedace has suffered declines in recent years in the Forks area, most notably in the East Fork. In addition, the Middle Fork-Trailhead population may not be stable. The unpredictability and rapidity with which major changes in spikedace populations can occur was exemplified by the recent history of the lower East Fork population. When Anderson made his lower East Fork collections, the stream supported a comparatively large population of spikedace, perhaps the largest in the Forks area. In less than 7 years, this population was eliminated.

Gila River: Cliff-Gila Valley. The Cliff-Gila Valley extends from the confluence of Mogollon Creek and the Gila River downstream to Ira Canyon, near the upper end of the Middle Box. Collections prior to 1960 were of sufficient number (nine) and distribution to provide an accurate picture of the historic composition of the fish community. In 1938, C.L. Hubbs found only native fishes (desert sucker, UMMZ 124742; Sonoran sucker, UMMZ 124743; roundtail chub, UMMZ 124744; loach minnow, UMMZ 124745; longfin dace, UMMZ 124746; and spikedace, UMMZ 124748), and each was common. He did not collect the speckled dace, which was (and remains) extremely rare in this reach of the Gila River. Collections made between 1949 and 1953 substantiated the essentially native character of the fish community. However, by 1949 several non-native species were present, albeit in generally low numbers (Table 8). Of the native fishes, the longfin dace was most commonly collected (33.6%), followed by the spikedace (24.5%), Sonoran sucker (24.5%), desert sucker (11.9%), roundtail chub (2.3%), and loach minnow (2.3%). Only one speckled dace was collected during this period.

Between 1961 and 1980, the Cliff-Gila reach was intensively sampled. Overall, native fishes dominated, but a greater diversity and slightly higher numbers of non-natives were reported in this period than in the previous (Table 9). Most non-natives were represented by 10 or fewer specimens, but the fathead minnow, channel catfish, and mosquitofish were collected regularly, indicating their establishment in the area.

Within the native fish community, some changes had occurred since 1953. The longfin dace declined in relative abundance (16.5%), and the spikedace became the most commonly collected species (29.3%). The roundtail chub was distinctly less common (<0.1%) than in the previous period, and the speckled dace remained very rare (<0.1%). Some shifts in the relative abundance of the remaining natives were also indicated, but these were not of sufficient magnitude to suggest more than normal variations in populations.

When collections from the 1961-1980 sampling period and our collections in 1983-1984 are compared, it is evident that the native fish community remained very similar. In the most recent period, spikedace (21.1%), Sonoran sucker (21.0%), desert sucker (21.0%), and longfin dace (19.7%) numerically

TABLE 8. Fish species recorded (indicated by X) in the Cliff-Gila Valley of the Gila River through 1960. Relative abundance is based on total number of specimens collected in the period.

Native Species	Year of Record 1938	1947	1949	1950	1953	Relative Abundance
longfin dace	X		X	X	X	33.6
roundtail chub	X		X	X	X	2.3
spikedace	X	X		X	X	24.5
speckled dace			X			<0.1
loach minnow	X		X	X		2.1
Sonoran sucker	X		X	X	X	24.5
desert sucker	X		X	X	X	11.9
						98.9
Non-native Species						
black bullhead			X			0.4
channel catfish			X	X		0.3
mosquitofish					X	0.1
smallmouth bass			X			<0.1
largemouth bass			X			0.1
						1.1

TABLE 9. Fish species recorded (indicated by X) in the Cliff-Gila Valley of the Gila River from 1961 through 1980. Relative abundance is based on total number of specimens collected in the period.

Native Species	Year of Record							
	1961	1963	1964	1965	1966	1970	1971	1973
longfin dace	X	X	X	X	X	X	X	X
roundtail chub								X
spikedace	X	X	X	X	X		X	
speckled dace								
loach minnow		X	X	X	X		X	X
Sonoran sucker	X	X	X	X	X		X	
desert sucker	X	X	X	X	X		X	

	Year of Record						Relative Abundance
	1974	1975	1976	1977	1978	1980	
longfin dace	X	X	X	X	X	X	16.5
roundtail chub	X						0.1
spikedace	X	X	X	X		X	29.3
speckled dace						X	0.1
loach minnow	X	X	X	X	X		6.9
Sonoran sucker	X	X	X	X			19.6
desert sucker	X	X	X	X		X	22.3
							94.7

TABLE 9. (Continued.)

Non-Native Species	Year of Record 1961	1963	1964	1965	1966	1970	1971	1973
rainbow trout			X					
brown trout								
fathead minnow	X	X	X		X	X		X
black bullhead					X		X	
yellow bullhead							X	
channel catfish		X			X		X	X
flathead catfish								X
mosquitofish	X		X		X	X	X	X
green sunfish							X	
smallmouth bass							X	
largemouth bass			X					

	Year of Record 1974	1975	1976	1977	1978	1980	Relative Abundance
rainbow trout							<0.1
brown trout			X				<0.1
fathead minnow	X	X	X	X			0.9
black bullhead				X			<0.1
yellow bullhead				X			0.1
channel catfish	X			X			0.4
flathead catfish							<0.1
mosquitofish	X	X	X				3.7
green sunfish							0.1
smallmouth bass							0.1
largemouth bass							<0.1
							5.3

dominated the community. The loach minnow was moderately common (8.4%), while the roundtail chub (0.4%) and speckled dace (<0.1%) were still very rare (Table 10).

Conversely, several important changes have occurred within the non-native fish community between the 1961-1980 and 1983-1984 periods. Most noteworthy was the apparent establishment of the red shiner. This species was first found in the Cliff-Gila Valley in 1981 (Mueller and Delamore 1981), and has since been irregularly collected in the lower half of the area. The establishment of the fathead minnow, channel catfish, and mosquitofish in the area was confirmed by the fairly regular collection of these species during our study. Others, such as the flathead catfish and green sunfish, may also be established. However, exogenous sources such as borrow pits, farm ponds, and human introductions of these species, and other non-natives collected in low numbers, cannot be excluded as sources for them.

Over the last 40 years, the fish community of the Cliff-Gila Valley has expanded to include several non-native species. During this time, non-natives have increased from 1.1% of the entire population to 8.5%. Native fish abundances have remained, in most instances, fairly constant. Whether this apparent constancy reflects a dynamically stable community, or the beginning of the decline of native fishes (which might be inferred from the increasing diversity and abundance of non-natives), cannot be resolved at this time. If the patterns displayed in other areas are indicative, however, the maintenance of the native fish community in the Cliff-Gila Valley is questionable.

<u>Gila River: Redrock-Virden Valleys.</u> The Redrock and Virden valleys were not extensively sampled prior to 1960. Nevertheless, the six samples made indicate that the ichthyofaunal community had already been modified by human activities (Table 11). The native fish community was comprised of five species. Of these, the longfin dace and Sonoran sucker were the most common (52.9% and 27.3%, respectively), and the spikedace was moderately common (13.0%). The speckled dace and loach minnow were not collected, and neither was probably ever represented by more than a few displaced individuals. Five catfish species constituted the non-native fish assemblage, of which the channel catfish was the most common (1.7%).

Between 1960 and 1980, non-natives increased in diversity and abundance (Table 12). By 1980, non-natives represented 17.9% of the collections. Among them, the common carp, fathead minnow, channel catfish, and mosquitofish appeared to be well-established.

TABLE 10. Fish species recorded (indicated by X) in the Cliff-Gila Valley of the Gila River from 1983 through 1984. Relative abundance is based on total number of specimens collected in the period.

Native Species	Year of Record 1983	1984	Relative Abundance
longfin dace	X	X	19.7
roundtail chub	X	X	0.4
spikedace	X	X	21.1
speckled dace	X	X	<0.1
loach minnow	X	X	8.4
Sonoran sucker	X	X	21.0
desert sucker	X	X	21.0
			91.5
Non-native Species			
rainbow trout	X		<0.1
common carp	X	X	0.1
red shiner	X	X	2.2
fathead minnow	X	X	1.1
yellow bullhead	X	X	0.3
channel catfish	X	X	0.8
flathead catfish	X	X	0.1
mosquitofish	X	X	3.2
green sunfish	X	X	0.3
smallmouth bass	X	X	0.1
largemouth bass	X	X	0.3
			8.5

TABLE 11. Fish species recorded (indicated by X) in the Redrock and Virden valleys of the Gila River through 1960. Relative abundance is based on total number of specimens collected in the period.

Native Species	Year of Record 1908	1949	1950	Relative Abundance
longfin dace		X	X	52.9
roundtail chub	X	X	X	1.3
spikedace		X	X	13.6
Sonoran sucker		X	X	27.3
desert sucker	X	X	X	2.6
				97.6
Non-native Species				
black bullhead		X		0.2
yellow bullhead		X		0.1
brown bullhead		X		<0.1
channel catfish		X		1.7
flathead catfish		X		0.3
				2.4

TABLE 12. Fish species recorded (indicated by X) in the Redrock and Virden valleys of the Gila River from 1961 through 1980. Relative abundance is based on total number of specimens collected in the period.

Native Species	Year of Record 1970	1971	1974	1976	1977	1979	Relative Abundance
longfin dace	X	X	X	X	X	X	29.9
roundtail chub						X	0.2
spikedace	X				X	X	24.8
loach minnow	X						0.2
Sonoran sucker	X	X		X	X	X	14.3
desert sucker	X	X		X	X	X	12.9
							82.1
Non-native Species							
common carp	X				X		1.4
fathead minnow	X		X		X		3.5
yellow bullhead					X		0.2
channel catfish	X	X		X	X	X	5.3
flathead catfish					X		0.8
mosquitofish	X		X				6.3
green sunfish			X				0.6
							17.9

Although no native fishes became extirpated, distinct changes occurred in the composition of the fish community between 1961-1980 and 1983-1984 (Table 13). Non-natives became more abundant than native fishes. Red shiner became the most commonly collected fish (47.8%), and it was generally distributed throughout the Redrock and Virden valleys. Other non-natives were less abundant than the red shiner, but all, except the smallmouth and largemouth basses and yellow bullhead, appeared to be well-established. The roundtail chub and loach minnow were extremely rare; neither species had viable populations in the Redrock and Virden valleys. The longfin dace and Sonoran sucker were the most commonly collected native fishes (22.3% and 16.3%, respectively). The desert sucker was found in low numbers, while the spikedace was found almost exclusively at the mouth of the Middle Box (12 collections). In late June 1983, Age 0 (<30 mm TL) spikedace were found at several sites downstream to the Arizona-New Mexico border. Spikedace were, with three exceptions, present in very low numbers. Reasons for the higher numbers at three locations were not immediately apparent, but probably involved some combination of low incidence of predators or competitors, optimal habitat, or vagaries of streamflow. Local landowners informed us that these locations had water in even the driest years. Sampling (excluding the mouth of the Middle Box) between October 1983 and December 1984 yielded spikedace (2 specimens) at two of 19 sites. We believe that the general occurrence of Age 0 spikedace in the Redrock and Virden valleys in June-July 1983 was due to the displacement of larval spikedace from the Cliff-Gila Valley by the high spring runoff in 1983. Thus, while the spikedace might be occasionally found in the Redrock and Virden valleys, viable populations do not persist in this reach. A small population is located at the mouth of the Middle Box, but its future is tenuous.

In addition to the areas discussed above, virtually all other warmwater stream reaches of the Gila-San Francisco basin in New Mexico were sampled to document the fish fauna (see Figure 2). During this survey, seven native and 15 non-native fish species were collected (Table 1). The spikedace was not found in any area other than those reviewed above (Figure 5). The reasons for the absence of the spikedace elsewhere varied, but were related to habitat availability, past and present waterflow regimes, and/or the presence of non-native fishes. For example, the extensive canyon reach of the Gila River between the Forks area and Turkey Creek contained apparently suitable spikedace habitat, yet the species was not found there. Indeed, it is doubtful the species was ever common in this reach. Suitable habitat, while present, is not common there, and occurs only where the canyon floor broadens and the river meanders. Isolating

TABLE 13. Fish species recorded (indicated by X) in the Redrock and Virden valleys of the Gila River from 1983 through 1984. Relative abundance is based on total number of specimens collected in the period.

Native Species	Year of Record 1983	1984	Relative Abundance
longfin dace	X	X	22.3
roundtail chub	X		<0.1
spikedace	X	X	4.1
loach minnow	X		<0.1
Sonoran sucker	X	X	16.3
desert sucker	X	X	2.6
			45.3
Non-native Species			
common carp	X	X	0.3
red shiner	X	X	47.8
fathead minnow	X	X	1.1
yellow bullhead	X	X	0.1
channel catfish	X	X	3.6
flathead catfish	X	X	0.3
mosquitofish	X	X	1.6
smallmouth bass	X		<0.1
largemouth bass	X	X	<0.1
			54.7

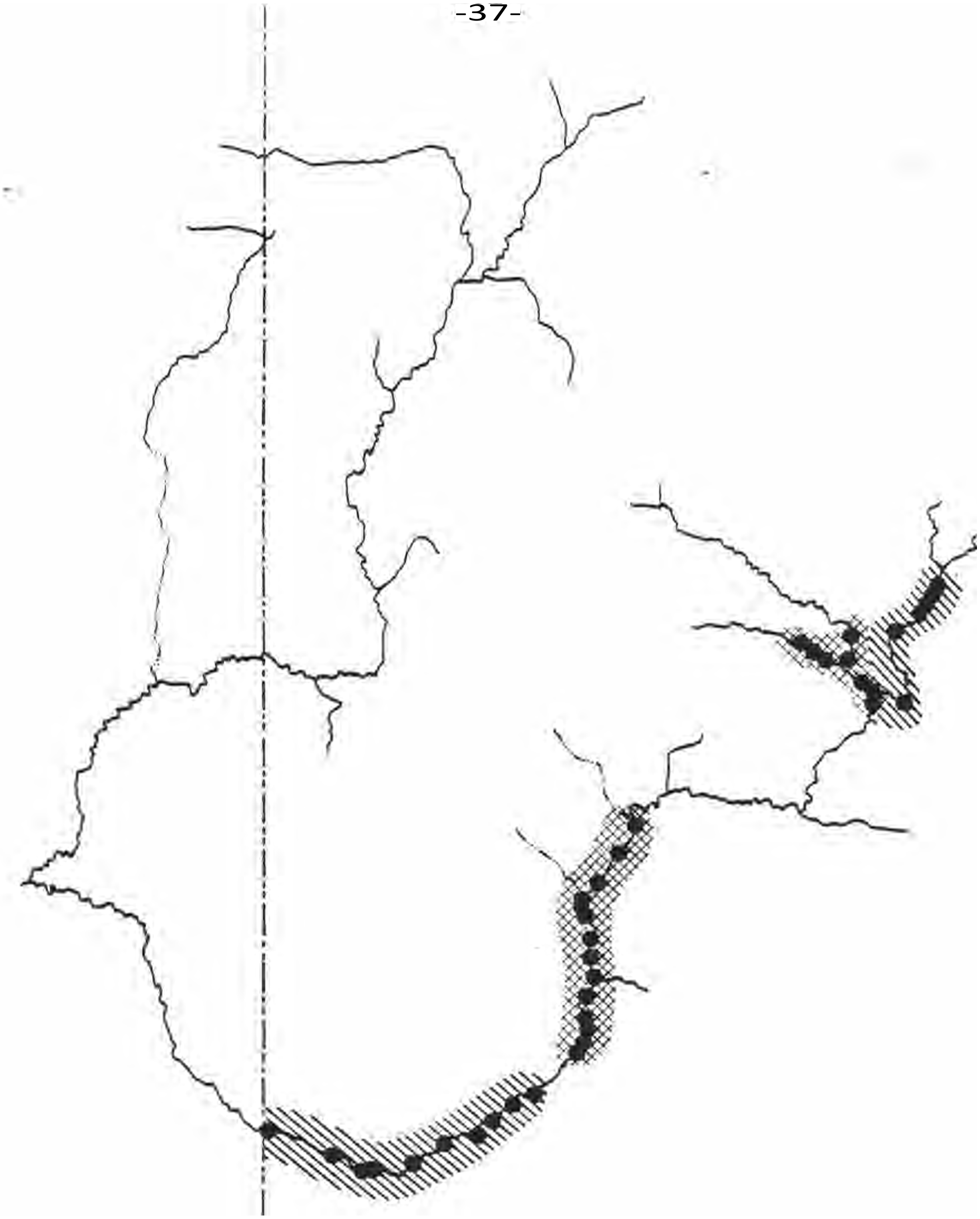


Figure 5. Current distribution of the spikedace in the Gila-San Francisco basin, New Mexico. Solid dots indicate specific collection localities, cross-hatched areas indicate stream reaches of regular occurrence, and hatched areas indicate stream reaches of irregular occurrence.

such stretches are narrow canyon reaches, where the characteristic habitats are runs (> lm), cascading rapids, and deep pools (> 3m). If isolated spikedace populations occurr in the scattered and limited habitat, floods might periodically reduce or eliminate these populations. In such a situation, the reestablishment of the canyon populations is largely dependent upon dispersal from the comparatively small, upstream populations (i.e., the Forks area). The introduction and establishment of non-native predators and/or competitors imposed an additional decimating factor the small, hypothesized spikedace populations evidently could not withstand. Permanent canyon tributaries, such as Turkey Creek, lack suitable spikedace habitat, and it is extremely doubtful the species ever occupied such streams. Floodplain tributaries, such as Duck Creek, may have historically supported small spikedace populations. However, dewatering, erosion, and loss of riparian vegetation have rendered them unsuitable for spikedace and most other fishes.

The present range of the spikedace in New Mexico has been greatly reduced in the past 100 years, primarily by an array of human-induced changes. Whatever the specific causes, the species has been eliminated from the San Francisco River and is much reduced in the Gila River system. If it ever occupied them, the spikedace has been largely, if not completely, eliminated from canyon reaches. Currently, the species persists as seemingly viable populations only in the lowermost reaches of the Middle Fork, the West Fork from about the Gila Cliff Dwellings downstream to the confluence with the East Fork, and the Cliff-Gila Valley from the confluence of the Gila River with Mogollon Creek downstream to the Middle Box.

The great reduction in the range of the spikedace has also meant a concomittant decrease in total population size. Of the surviving populations, only the Cliff-Gila Valley population appears to have remained comparable to that recorded by earlier investigators (i.e., C.L. Hubbs, R.R. Miller, and W.J. Koster). Within the valley, the species was most common downstream of the village of Gila (Figure 6). Upstream of Gila, the density of spikedace decreased and by Mogollon Creek very few were found. The populations in the West and Middle forks of the Gila River were not large and have probably always fluctuated in size. Although the presence of the spikedace in the upper East Fork of the Gila River has been reconfirmed, the species' long-term survival there is not assured. The population at the mouth of the Middle Box is extremely small, and it probably survives mainly by fortuitous augmentation from the Cliff-Gila Valley.

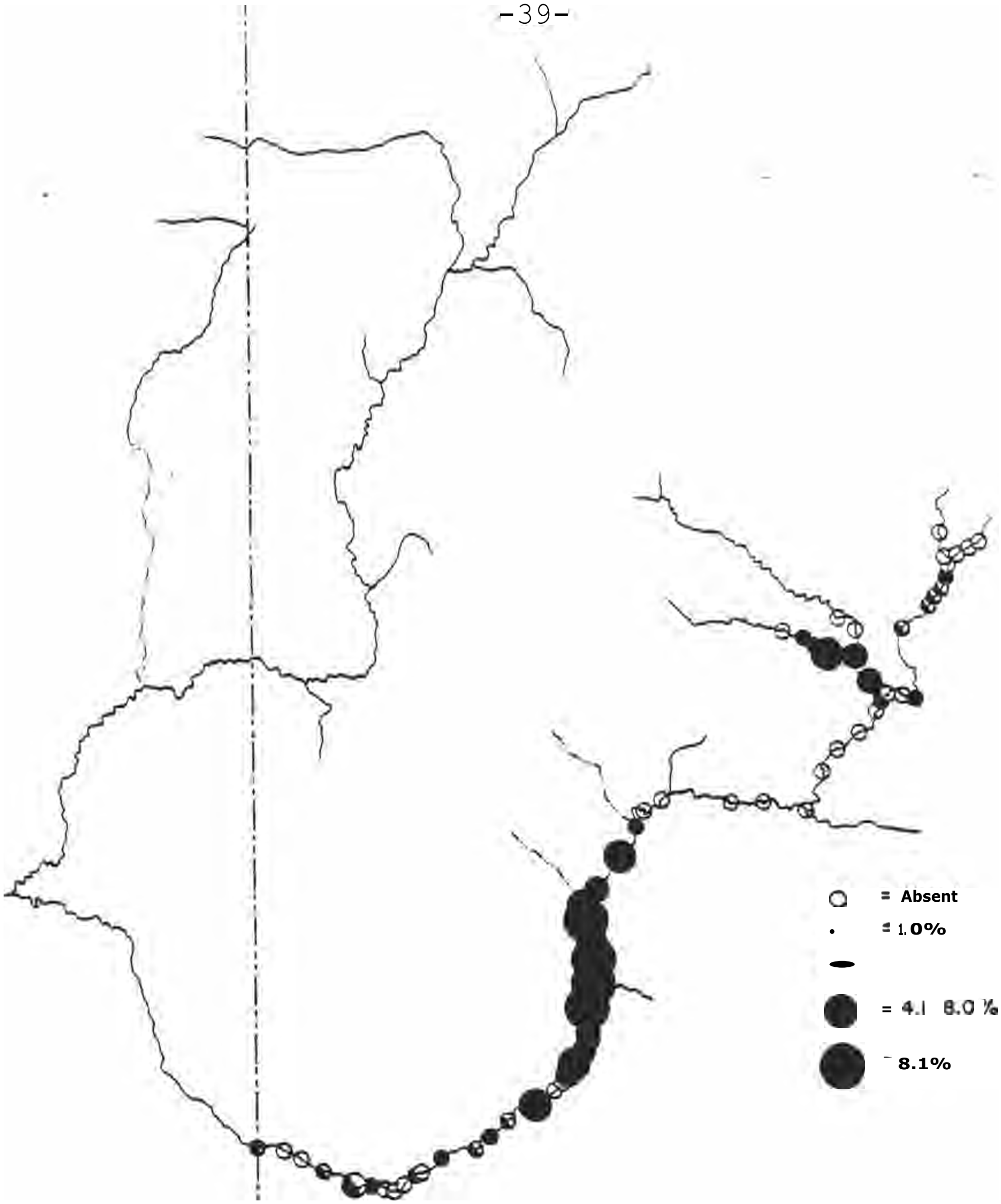


Figure 6. Relative abundance distribution of the spikedace in the Gila-San Francisco basin, New Mexico, 1982-1985. Percentage for each site is based on the total number of spikedace collected during the study. Open circles indicate sites at which the spikedace was never found. Half-solid circles indicate the spikedace was found irregularly at the site. Solid circles indicate the spikedace was found regularly at the site.

Microhabitat Utilization

The spikedace inhabits discrete and definable portions (microhabitats) of the stream reaches in which it occurs. These specific areas of occupancy vary geographically, seasonally, and ontogenetically. For the sake of clarity, each of these foci of variation is treated separately. Throughout this section the expressions "utilized" or "occupied" are used instead of "preferred" microhabitat. The term preferred indicates the species actively seeks out a particular microhabitat whereas utilized or occupied simply indicates where the species was found. Nevertheless, if a species is consistently found in a definable habitat space within a larger available area, it can be assumed a preference is being demonstrated for a particular microhabitat. However, to demonstrate "preference", a quantified comparison of that occupied to that available is required. The following presents the preliminary results of microhabitat studies conducted on the spikedace.

Ontogenetic

During this study, no measurements were made of the spawning microhabitat of the spikedace. However, in Aravaipa Creek in Arizona, Barber et al. (1970) noted that spawning occurs in shallow riffles. Similar habitat is almost certainly utilized for spawning in New Mexico. The eggs of the spikedace are probably demersal and develop among the gravel and cobble of the riffles in which spawning occurs. In such habitat, the eggs are well-oxygenated and are not normally subject to suffocation by sediment deposition or to desiccation by receding water levels.

Spikedace larvae (< 25 mm TL) were most commonly associated with slow-velocity water near stream margins (Table 14). The larvae were found in water up to 62.5 cm deep, but they were most common where depths were less than 32.0 cm (Figure 7). Most larvae (60%) were found over sand-dominated substrates, and roughly equal numbers (18%) were found over gravel or cobble-dominated substrates.

As the spikedace developed and attained greater size, shifts in microhabitat utilization were detected. Juvenile spikedace (26-35 mm TL) were found to occur over a greater range of water velocities than larvae (Figure 7). However, both larvae and juveniles were most common in water depths of 32.0 cm or less. Juveniles were most commonly found over gravel (46%) and sand-dominated (45%) substrates, but some (9%) were associated with cobble-dominated substrates.

TABLE 14. Microhabitats occupied by larva, juvenile, and adult spikedace in the Cliff-Gila Valley, New Mexico. Chi-square values are at 0.95 probability level. An asterisk indicates a significant difference in the comparison.

Comparison	N	Mean	Range	S.D.	df	Chi-square
		Water Velocity (cm/sec)				
Larva	224	8.4	0.0-27.4	5.8		
vs					3	74.5*
Juvenile	219	16.8	0.0-57.9	9.7		
Juvenile	219	16.8	0.0-57.9	9.7		
vs					4	316.5*
Adult	189	49.1	0.0-74.7	21.3		
		Water Depth (cm)				
Larva	224	8.4	3.0-48.8	7.4		
vs					3	26.5*
Juvenile	219	16.1	3.0-45.7	5.1		
Juvenile	219	16.1	3.0-45.7	5.1		
vs					2	2.4
Adult	189	19.3	6.1-42.7	6.4		

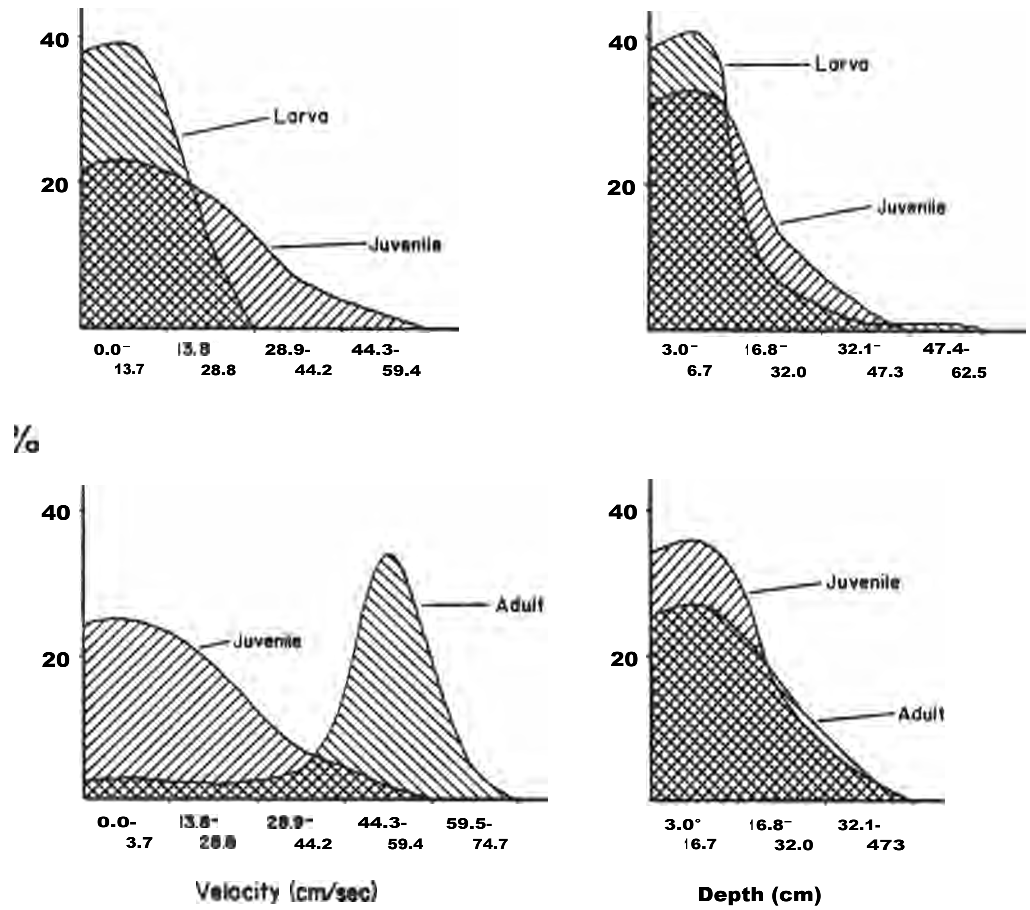


Figure 7. Microhabitat utilized by larva, juvenile, and adult spikedace in the Cliff-Gila Valley, New Mexico. **Percent (%) indicates proportion of specimens.**

As adults (> 36 mm TL), the species was found over a rather wide **range** of water velocities (0.0-74.7 cm/sec). Mean velocity at which adults were found was 29.6 cm/sec (Table 14). Like larvae and juveniles, adults were found most frequently in fairly shallow water (Figure 7). Mean depth occupied was 19.5 cm, and most individuals were found in water less than 32.0 cm deep. Adults were most commonly found over gravel-dominated substrates (47%), but they were also common over cobble (32%) and sand-dominated (19%) substrates.

Geographical

Over the range of a species, some differences in the microhabitat utilized might be expected. To test this supposition as regards the spikedace, comparisons were made between microhabitat utilization in the Forks area and the Cliff-Gila Valley. Because few larva and juvenile data points were obtained from the Forks area, only adults are considered in this comparison.

In the Forks area, the spikedace was most common throughout the year in water flowing less than 29.0 cm/sec. In contrast, water velocities between 29.0 and 59.5 cm/sec were most frequently utilized by the spikedace in the Cliff-Gila Valley (Figure 8). In the Forks area, the spikedace tended to occupy slightly deeper water than it did in the Cliff-Gila Valley (Table 15).

The foregoing suggests that geographic differences exist in spikedace microhabitat utilization. However, this comparison did not account for several pertinent differences between the study areas. The streams in the Forks area are near the upstream distributional limits of the spikedace, and have cooler thermal regimes than does the Gila River in the Cliff-Gila Valley. The West and Middle Forks are comparatively narrow streams (5-10 m wide), with a roughly even mix of cobble and rubble-dominated riffles and runs, whereas the river in the Cliff-Gila Valley is typically 15-30 m wide, and the habitat is predominately shallow, sand-bottomed runs. The much greater abundance of spikedace in the Cliff-Gila Valley reach is assumed to be the result of the greater availability of optimal spikedace habitat in this area. Thus, the apparent geographic differences in microhabitat utilization may actually be differences caused largely by habitat availability. For example, if the habitats occupied by the spikedace in the Cliff-Gila Valley are assumed to be inclusive of the entire spectrum in which the species can survive, then the range of habitats occupied in the Forks area might be considered a subset of what it can actually occupy. Figure 9 diagrammatically illustrates this

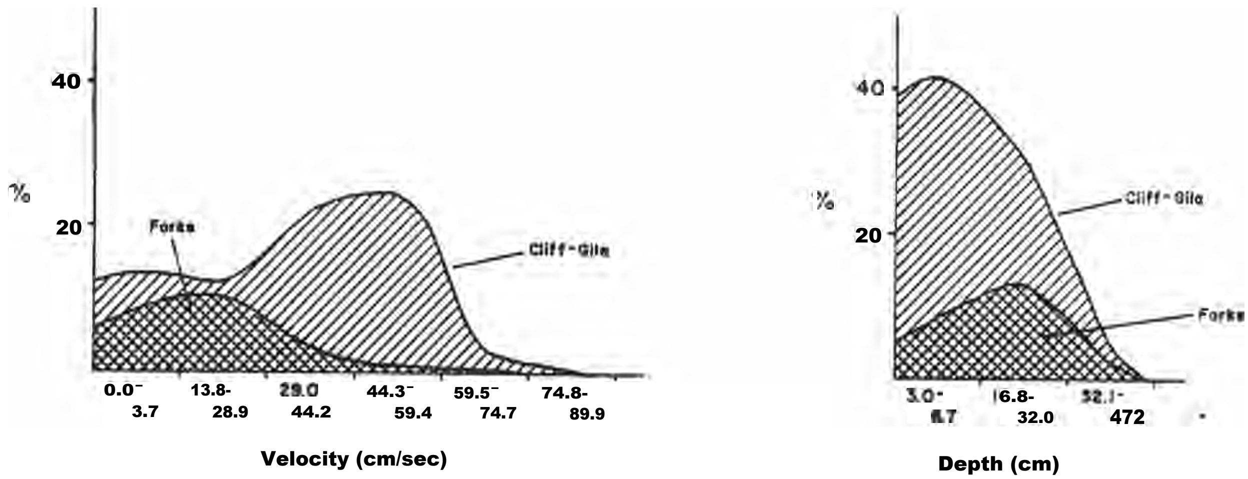


Figure 8. Microhabitat utilized by adult spikedace in the Forks area and the Cliff-Gila Valley, New Mexico. Percent (%) indicates the proportion of specimens.

TABLE 15. Microhabitats occupied by adult spikedace in the Cliff-Gila Valley and Forks area, New Mexico. Chi-square values are at 0.95 probability level. An asterisk indicates a significant difference.

Comparison	N	Mean	Range	S.D.	df	Chi-square
		Water Velocity (cm/sec)				
Cliff-Gila	504	36.3	0.0-79.2	13.5		
vs					5	549.7*
Forks	154	21.0	0.0-67.1	11.7		
		Water Depth (cm)				
Cliff-Gila	504	19.2	3.0-48.8	6.1		
vs					2	22.2*
Forks	154	21.3	3.0-36.6	6.9		

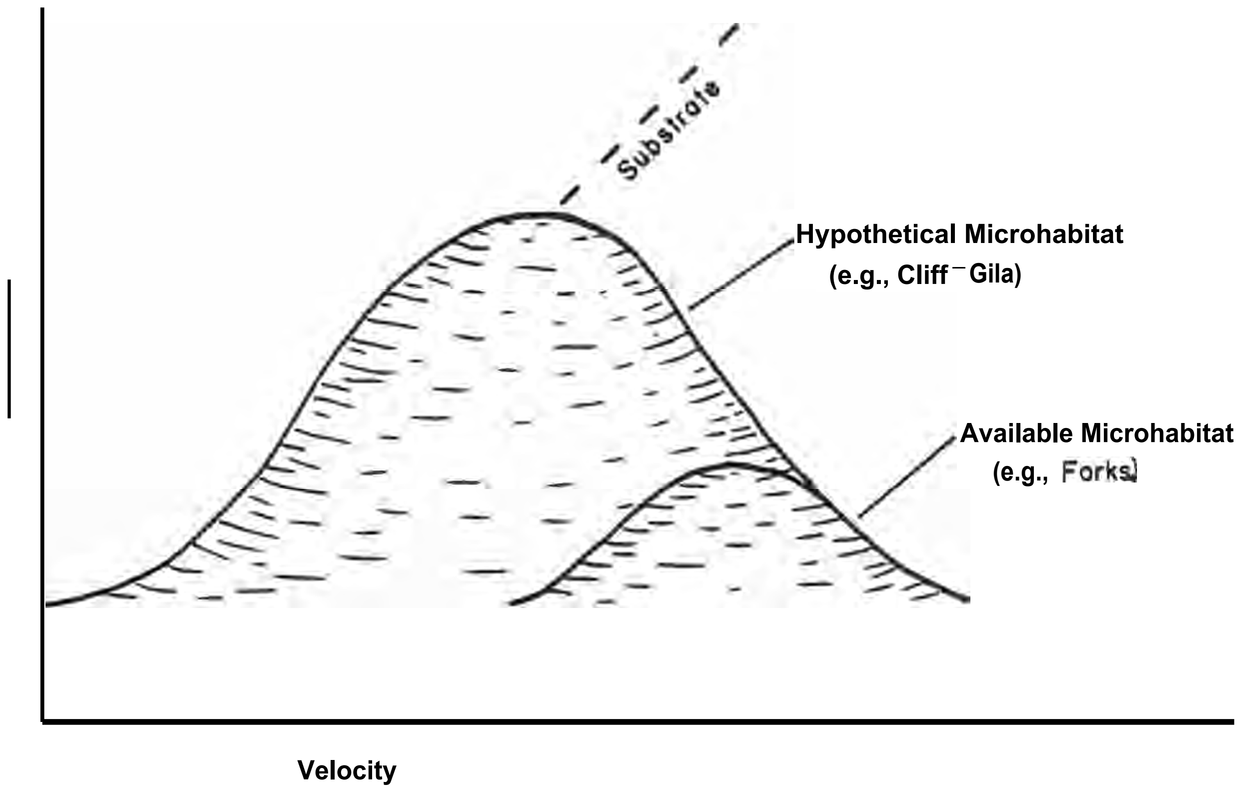


Figure 9. A diagramatic illustration of the hypothetical microhabitat space in which the spikedace can survive (e.g., Cliff-Gila), and the hypothetical space available to it (e.g., Forks).

concept. A cursory examination of the habitat utilization patterns in the Forks area and Cliff-Gila Valley lends some credence to the hypothesis (Figure 8).

Given the above considerations, additional analyses are necessary to determine if the observed differences are real, or are merely artifacts of differences in habitat availability.

Seasonal

Comparisons to determine if seasonal differences existed in microhabitat utilization patterns were made in each study area. In the warm season (June through November), water temperatures were 13.3-26.7 C (mean 19.3) in the Forks area, and 18.3-23.3 C (mean 20.8) in the Cliff-Gila Valley. Cold season (December through May) water temperatures were 5.6-12.2 C (mean 7.8) in the Forks area, and 9.0-17.8 C (mean 11.7) in the Cliff-Gila Valley.

Within the Forks area, seasonal microhabitat shifts were detected for depth but not velocity. In both seasons, the spikedace was most common in water flowing less than 29.0 cm/sec (Table 16). In contrast, there was a significant shift to deeper water in the warm season. During the cold season, the spikedace was most frequently found in water less than 16.8 cm deep; in the warm season, it was most common in water 16.8-32.1 cm deep (Figure 10).

In the Cliff-Gila Valley, seasonal shifts in habitat utilization were opposite those detected in the Forks area. Water depths occupied by the species remained essentially the same throughout the year in the Cliff-Gila Valley. However, distinct seasonal shifts occurred in the water velocity occupied by the species. In the cold season, the spikedace was most frequently found in water velocities less than 44.2 cm/sec. In the warm season it was most common in water velocities between 44.3 and 59.5 cm/sec.

We believe that the seasonal shifts in spikedace microhabitat utilization in both study areas reflected selection by the species for particular microhabitats. For example, the metabolic rate of the spikedace decreases in the cold season, and the fish therefore seeks protected areas. In the Forks area, such habitat is found among the cobble of stream channel margins. There, water depths are comparatively shallow, but velocities are not noticeably different from those occupied in the warm season. As the water warms and the metabolic rate of the fish increases, the spikedace leaves the protection of the cobbled stream

TABLE 16. Microhabitats occupied by adult spikedace in warm (June-November) and cold (December-May) seasons in the Cliff-Gila Valley and Forks area, New Mexico. Chi-square values are at 0.95 probability level. An asterisk indicates a significant'difference.

Locale	Comparison	N	Mean	Range	S.D.	df	Chi-square
			Water Velocity (cm/sec)				
Cliff-	warm	189	49.1	3.0-70.1	21.3	5	29.1*
	vs						
Gila	cold	315	39.4	0.0-79.2	13.0		
	warm	101	18.8	0.0-67.1	12.2		
Forks	vs					4	7.4
	cold	57	21.4	0.0-48.8	15.2		
			Water Depth (cm)				
Cliff-	warm	189	19.3	6.1-42.7	6.4	3	4.9
	vs						
Gila	cold	315	18.2	3.0-48.8	6.1		
	warm	101	23.1	12.2-36.6	6.4		
Forks	vs					2	29.4*
	cold	57	17.3	9.1-33.5	6.9		

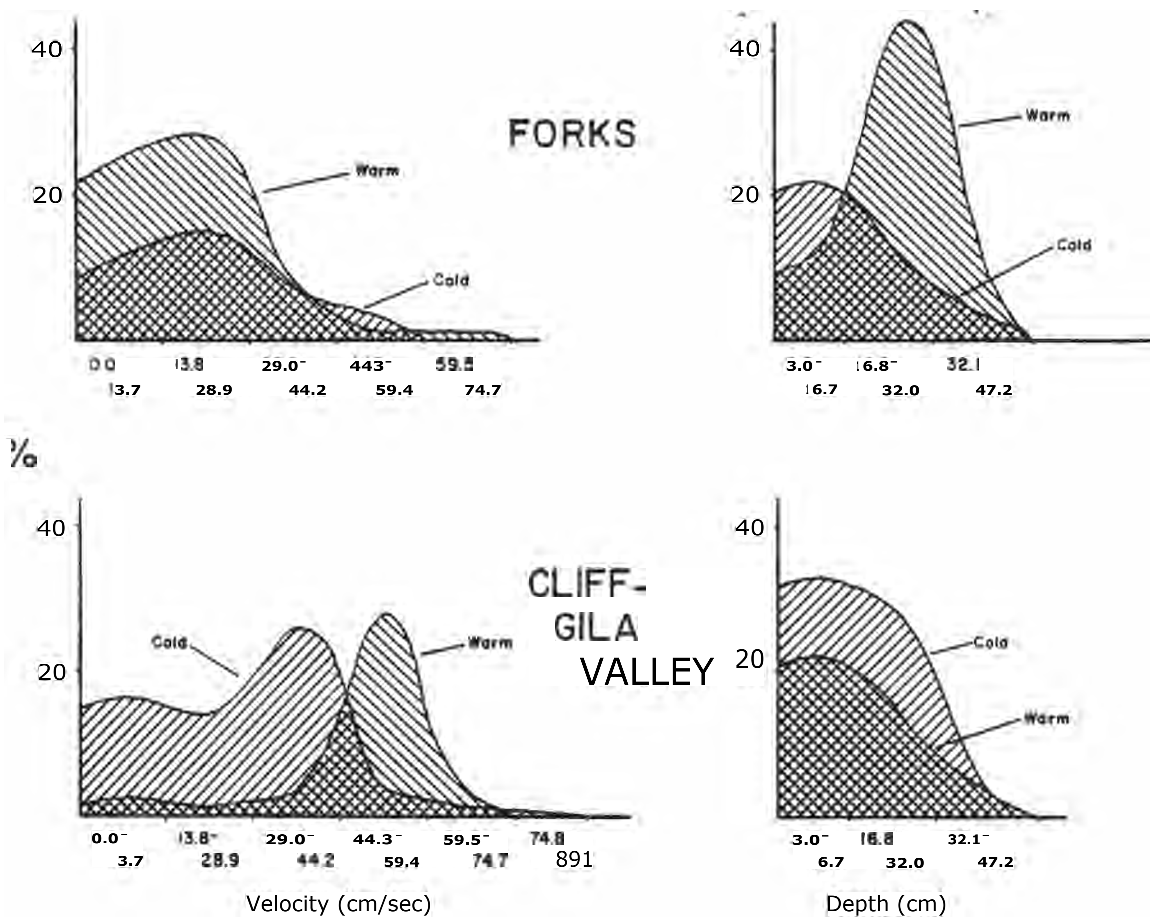


Figure 10. Microhabitat utilized by adult spikedace during the warm season (June-November) and cold season (December-May) in the Forks area and the Cliff-Gila Valley, New Mexico. Percent (%) indicates proportion of specimens.

margins. In the Cliff-Gila Valley, differences in habitat availability resulted in a different response to cold season water temperatures. There, cobbled banks for protection were generally not available. However, slow-velocity areas in the lee of gravel bars and riffles were common. Thus, during the cold season, spikedace in the Cliff-Gila Valley found protected habitat in slow-velocity water. The shift in winter to slower velocity water did not involve a change in water depth. The spatial distribution of the spikedace in each study area during both seasons reflected the above scenarios. However, more detailed study and comparison of utilization patterns to habitat availability are necessary to demonstrate active selection.

Life History and Biology

Reproduction

Spikedace specimens collected in the Cliff-Gila Valley from June 1983 through July 1984 were used to describe the reproductive cycle of the species in New Mexico. Other spikedace populations (Cliff Dwellings, Trailhead, and Conner sites) were too small to provide sufficient specimens for such determination. Because the Cliff-Gila Valley is the populational center of the species in New Mexico, the reproductive cycle of the species there should represent the norm for the spikedace in New Mexico.

Two age classes (I and II) comprised the spikedace reproductive population, although Age I fish were evidently responsible for most of the reproductive effort. Age II spikedace were very uncommon in all collections.

Ovarian development began at 5-6 months, and small (<0.3mm), nucleated ova were present in females by September of their first year (Age 0). By November, the egg mass of Age 0 females was comprised only of small (mean 0.53 mm, range 0.44-0.88 mm) ova, and averaged less than 3.4% of total body weight (range 2.3-4.6%). The one Age I female collected in November had a gonadal-somatic-index (GSI) of 5.8, and the mean ovum diameter was 0.73 mm (range 0.55-0.88 mm). During December and January, ovarian development was rather slow (Figure 11). By early February, mean GSI for Age I and II females had increased only slightly (8.8 and 10.0, respectively) over November values. In late February, mean GSI (9.7) of Age I females (no Age II females were present in this collection) had not increased noticeably over early February. However, the range of GSI values was greater (6.8-10.2 in early February and 5.5-14.3 in late February). Ovum diameter also increased slightly from early to late February. Mean ovum diameter in early February was 0.83 mm

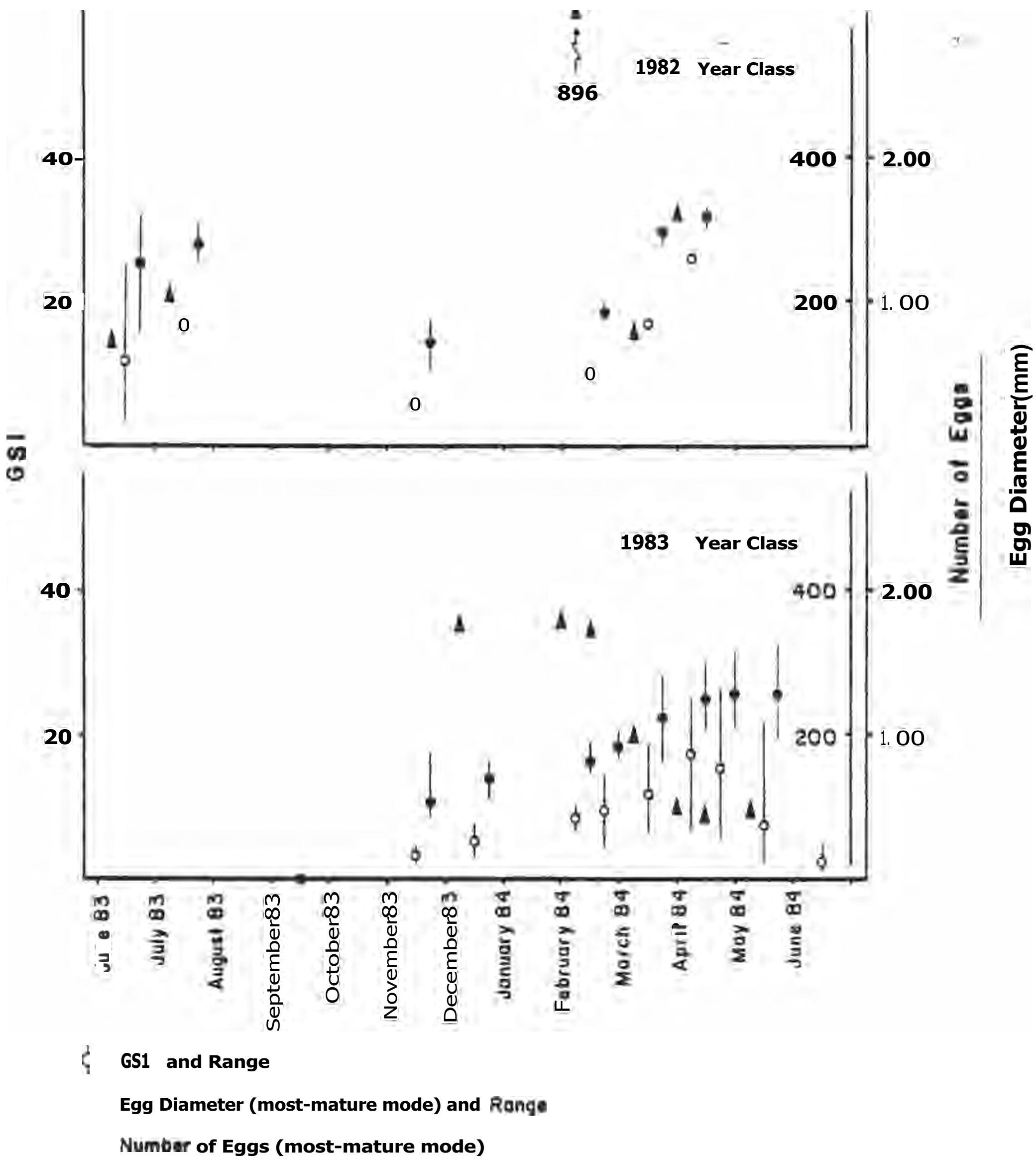


Figure 11. **Gonadal-Somatic-Index** (GSI), egg diameter, and number of eggs for the spikedace in the Cliff-Gila Valley, New Mexico, June 1983 through July 1984.

(range 0.73-0.96 mm), versus 0.92 mm (range 0.84-1.04 mm) in late February. An Age II specimen collected in early February contained 896 ova, but Age I females averaged only 358 (range 259-440) and 343 (range 263-475) ova on the two February sampling dates. All females, except one, examined in February contained ova in only one mode of development. Based upon these ovum diameters, this stage corresponds to the pre-recruitment mode of Barber et al. (1970). The one exception, a 41 mm SL specimen, contained ova in three distinct size classes (0.90-0.98, 0.39-0.48, and 0.14-0.21 mm).

Ovarian development accelerated in March. The one Age II specimen had a GSI of 17.0, a mean ovum diameter of 1.47 mm (range 1.39-1.53 mm), and 157 ova in the most mature mode (i.e., the recruitment mode of Barber et al. [1970]). Age I females had a mean GSI of 11.9 (range 6.4-18.8), averaged 196 ova (range 86-315) in the most mature mode, and diameter of these ova averaged 1.12 mm (range 0.80-1.40 mm). Of the females examined, only three had more than one mode of ova present.

Ovarian development peaked in early April for many spikedace. The one Age II specimen (55 mm SL) collected in April had a GSI of 26.0, and ova in the most mature mode averaged 1.56 mm in diameter. This size corresponds to the mature (i.e., ripe) mode of Barber et al. (1970). This female had 319 ova in the mature mode. Age I females collected at the same time had GSI's ranging from 6.7 to 25.0 (mean 17.6). However, none of these individuals had ova large enough to be considered mature by the standards of Barber et al. (1970). Average ovum diameter was 1.26 mm, and the range was 1.05-1.50 mm. Age I females had distinctly fewer ova in the most mature mode than the one Age II female. Among the 14 Age I specimens examined, the number of ova in the most mature mode ranged from 35 to 149 (mean 101).

On 13 April, another collection was made that contained only Age I specimens. Range and mean values for GSI, ovum diameter, and number of ova in the most mature mode were similar to those (i.e., recruitment mode) for Age I females on 4 April. The only exception, a 38 mm SL specimen, had a GSI of 26.2, a mean ovum diameter of 1.52 mm, and contained 81 ova in the mature mode.

Collections made on 14 May indicated that spawning was largely completed. Most specimens in this sample had a GSI of 10.0 or less. One specimen had a GSI of 21.4, contained 109 ova that were nearly mature or mature (average diameter 1.48 mm). Among the remaining females (12 Age I specimens), three had a few large (ca. 1.50 mm diameter), dark yellow ova, but no other ova were visible. The other nine specimens had ova in various stages of development; however, based on their GSI values, all appeared to have already spawned.

Thirteen Age I females collected on 8 June were examined; none had a GSI greater than 5.1, and most had a GSI of 2.4 or less. The slightly higher GSI's of two specimens were attributable to the presence of a few large, non-viable ova in each.

In summary, spikedace spawning in 1984 was initiated in early April, continued through that month, and probably ceased by late May. This estimated time-span may, however, be longer than actually occurs. Barber et al. (1970) described mature ova as being 1.50 mm or greater in diameter and dark yellow in color. Very few of the preserved females that we examined contained such ova. However, females examined in the field on 10 April released large, yellow ova when slight pressure was applied to the abdomen. We suspect that the ova of most females are in the mature mode for only a few days before they are spawned. After a female spawns, any mature ova not released deteriorate and/or are reabsorbed. The remaining egg mass constitutes a small percentage of total body mass. In the Cliff-Gila Valley spikedace population, a female may be involved in several spawning episodes within a few days (fractional spawning). We found no evidence to suggest a greater delay between spawning episodes, as Anderson (1978) speculated might occur and Barber et al. (1970) believed occurred with Age II fish.

Based upon the few Age II females that we examined, it appears that older females spawned earlier than Age I females. In addition, the former tended to have more ova in the most-mature state than did Age I fish. However, given their very low numbers, Age II fish did not contribute significantly to the total reproductive effort in the Cliff-Gila Valley.

Over the course of the reproductive study, the sex ratio shifted from a close equilibrium in the autumn of 1983 to a preponderance of females in February and March 1984. No consistent pattern was detected through the spawning season. The greater number of females in the February and March collections may indicate that males have a higher winter mortality than do females, although spawning does not appear to cause differential mortality.

The onset of the spawning season was not consistent from year to year. Spring runoff in 1984 was quite low, and spikedace spawning was initiated by early April. By early

May, it had largely ceased. In 1983, however, spring runoff was very high. Based upon the collection of small (6-7 mm TL) spikedace on 7 June of that year, it appeared that at least some spawning continued until late May or early June. It is virtually impossible to segregate the relative effects of water discharge from those of water temperature upon the initiation of spikedace spawning. However, it was apparent that the combined effect of these factors influenced the onset and perhaps the duration of the spawning season. Low spring-runoff resulted in the water warming more rapidly than occurred when such runoff was high and sustained.

Barber et al. (1970) reported that spawning occurred in shallow, sand and gravel-bottomed riffles. Females staged in slow-velocity water below riffles occupied by males, moved into these riffles, and there, each female was joined by several males as she moved upstream through the riffle. Spawning occurred in a brief flurry of activity, ova were released in midwater, and presumably drifted to the bottom. After spawning, the female moved upstream to a slow-velocity area, while males remained in the riffle. Although we did not observe spawning, we found the distribution of male and female spikedace at the Cottonwood site on 10 April 1984 to be very similar to that described above.

Larval Drift

The propensity of larval spikedace to drift appeared to be largely dependent upon stream discharge volumes. In 1983, when spring runoff was high and prolonged, Age 0 (larvae) spikedace were found in June at several locations from the mouth of the Middle Box (Conner site) downstream to the Arizona-New Mexico border (Figures 1 and 5). No Age I or older fish (adults) were present in any of these collections. Subsequent collections in the Redrock and Virden valleys yielded very few Age 0 spikedace. By spring 1984, no spikedace was found from the upper end of the Redrock Valley downstream to the Arizona-New Mexico border. A small population, however, appeared to be surviving at the Conner site.

Additional data to ascertain the causative factors controlling the likelihood and amount of larval spikedace drift were obtained from March through early June 1984. However, most of these data remain to be analyzed, and the following dicussion represents only a preliminary assessment.

In 1984, spring runoff was low, and much lower than that of 1983 (USGS unpublished Gila and Redrock station records 09430500 and 09431500, respectively). Larval drift net sampling encompassed the entire spring runoff period, and spikedace larvae were rarely found in any drift collection. The species was typically represented by only one or two specimens among several hundred of other species obtained in most collections. During the latter portion of the drift study, spikedace larvae were common in stream margin nursery areas, but very few were entrained in the current.

Periodic sampling following the 1984 spawning season at several sites in the Redrock and Virden valleys yielded only one spikedace (Age 0). Differences in reproductive effort between the two years did not appear to be a plausible explanation for the presence of spikedace in the Redrock and Virden valleys in 1983 and its absence in 1984.

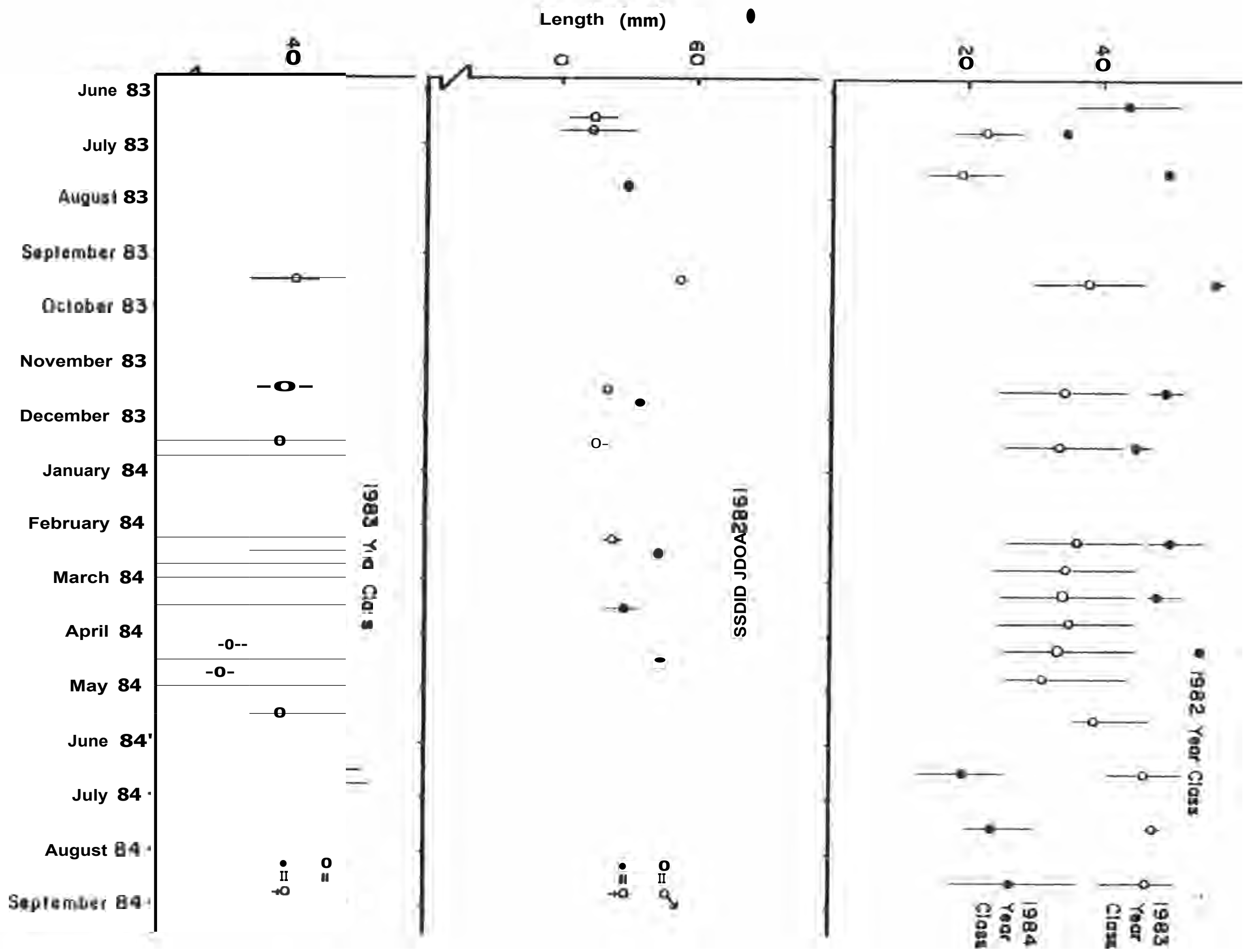
Given the above, we believe that downstream displacement of the spikedace occurs mainly as a result of entrainment and subsequent transport by high discharge volumes. If the Conner population were the source of the spikedace found in the Redrock and Virden valleys in 1983, larvae may drift as much as 45 km and survive, at least for a short time. If, however, the Cliff-Gila Valley were the source of the Redrock and Virden valleys spikedace, transport distances were greater (>60 km). The distance transported, site of deposition, and survival are not only dependent upon discharge volume, but also on such factors as predation and permanence of water in downstream areas.

Growth

Incubation time for spikedace ova is unknown, but is presumed to be similar to the 4-7 days of other western cyprinids (Snyder 1981 and citations therein). Upon emergence from the gravel of the spawning riffles, 5-7 mm TL spikedace dispersed to stream margins where water velocity was very slow or still. In these nursery areas (see Microhabitat section), growth was quite rapid through early September. Based upon spikedace collected in early and late June 1983, growth was about 1 mm/day for 15 days after emergence. By early July, Age 0 spikedace averaged 19.8 mm SL, and by September average length was 38.4 mm SL.

Between autumn and late spring, very little growth occurred in spikedace of any age-class (Figure 12). After spawning in 1984, the 1983 year-class (Age I) had comparatively rapid growth from April through June. Mean SL in Age I specimens increased from 33.9 mm to 48.0 in this period. At the end of its first year (Age 0), average spikedace length was 38 mm SL and 50 mm SL at the end of the second year (Age I).

Figure 12


Length (mm)
June 83
July 83
August 83
September 83
October 83
November 83
December 83
January 84
February 84
March 84
April 84
May 84
June 84
July 84
August 84
September 84
1983 Year Class
1982 Year Class
1984 Year Class

Some differences in growth were detected between the sexes. Very few 1982 year-class specimens were collected during the study, but when both sexes were present in a collection, females were larger (Figure 12). Sufficient numbers of fish in the 1983 year-class were collected to describe growth, but no consistent pattern was evident. From September 1983 through early February 1984 males were, on the average, larger than females (Figure 12). In late February 1984, females were larger than males and this pattern persisted through May. In June 1984, Age I males averaged slightly greater size than females. The largest sexed specimen obtained in this study was a 55 mm SL (Age II) female collected in early February 1984 at the Riverside site. A 58 mm SL (Age II) unsexed specimen was collected from the West Fork of the Gila River at the Cliff Dwellings site in early November 1983.

Population Age Structure

Length-frequency histograms were utilized to estimate the age structure of the Gila-Cliff Valley spikedace population. Although divisions between age classes on any particular sampling date were not always distinct, the method provided results that were generally in agreement with those presented by Barber et al. (1970) and Anderson (1978).

The Cliff-Gila spikedace population was usually comprised of only one age class. When two age classes were present, the older class was represented by few individuals. In early June 1983, the entire collection consisted of Age I fish (1982 year-class). However, from late June through the end of the year, Age 0 (1983 year-class) spikedace dominated the collections (Figure 13). By spring 1984, Age II (1982 year-class) individuals were extremely rare in the collections and absent after April. During this period, Age I fishes (1983 year-class) predominated, and then they declined rapidly in abundance after the completion of spawning in 1984.

Based upon length-frequency analyses, the maximum longevity for the spikedace in the Cliff-Gila Valley is about 24 months, although few survive more than 13 months. Anderson (1978) and Barber et al. (1970) reported a similar lifespan. However, both found a greater proportion of Age II fish than we did. Because the length-ranges given by Barber et al. and Anderson were comparable to those that we assigned each age class, it is unlikely that apparent differences in survivorship are due to investigator judgement. Rather, it is more likely that some undetected factor caused a higher mortality among older spikedace in the Cliff-Gila Valley during our study than occurred when Anderson (1978) did his

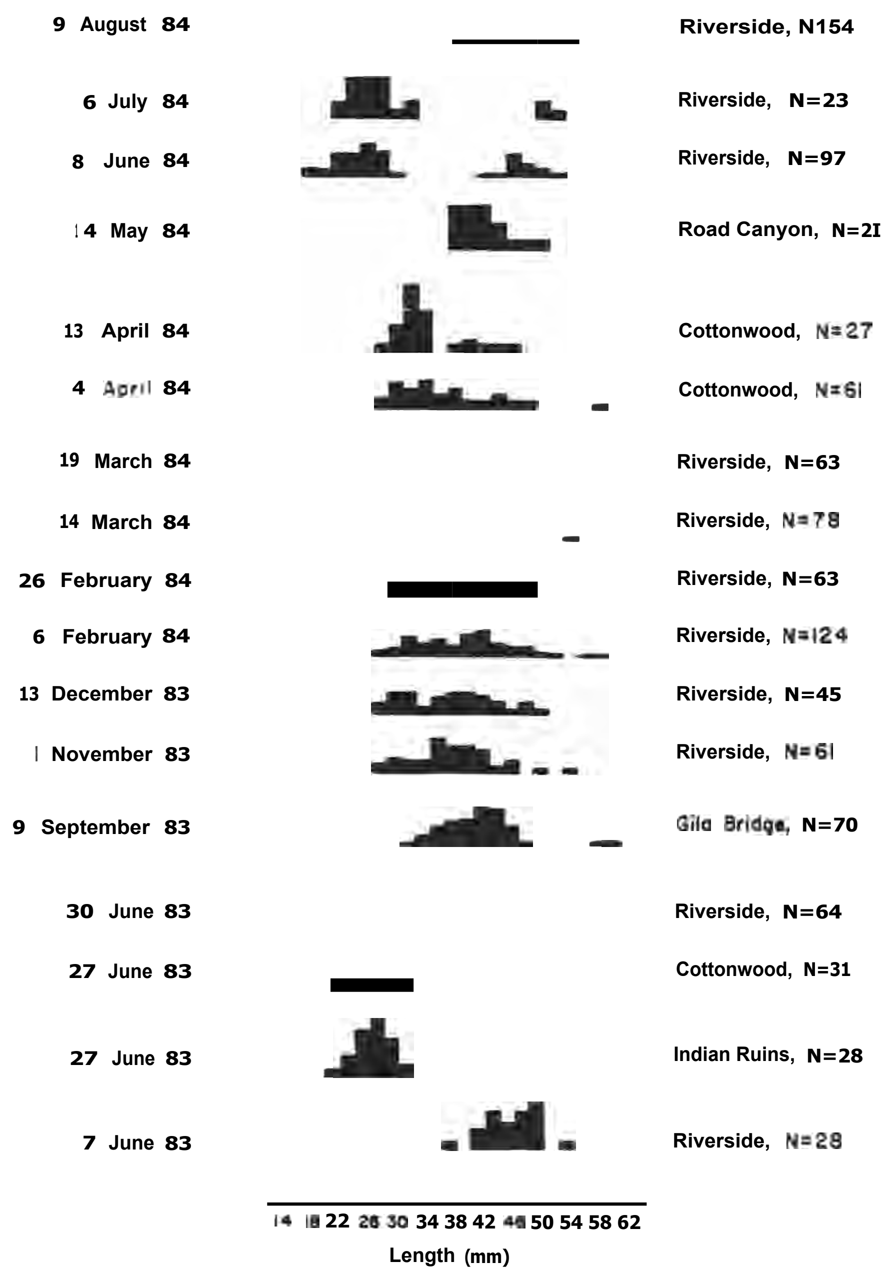


Figure 13. Length-frequency (2 mm length classes) of the spikedace in the Cliff-Gila Valley, New Mexico.

study in the Gila basin or Barber et al. (1970) did their work in Aravaipa Creek, Arizona.

Food Habits

Between June 1983 and June 1984, 88 spikedace from the Cliff-Gila Valley were examined to characterize the food habits of the species. Mayflies (Ephemeroptera) were the most common food item, but caddisflies (Trichoptera), true flies (Diptera), stoneflies (Plecoptera), and dragonflies (Odonata) were also found in spikedace stomachs. All stomachs examined and containing food (76) had a large amount of unidentifiable insect parts.

In descending order, the frequency of occurrence of major food groups in 76 spikedace stomachs was mayflies (71%), true flies (34%), and caddisflies (25%). Because of their larger size, caddisflies constituted a greater proportion of food volume than trueflies. Anderson (1978), Schrieber and Minckley (1981), and Barber and Minckley (1983) also found mayfly nymphs and adults to be the most common food item.

Ontogenic changes in food habits were not quantitatively determined for spikedace in our study. However, smaller individuals tended to ingest smaller food items, particularly true fly larvae. Seasonal trends in feeding were not quantitatively examined. However, between December and March, 40% of the spikedace examined (N = 24) contained no food items. In contrast, only 8% of the 64 spikedace examined between April and November had empty stomachs.

The general absence of terrestrial invertebrate remains in spikedace stomachs indicated that the species is very dependent upon aquatic insects for sustenance. Production of aquatic insects consumed by the spikedace occurs mainly in riffle habitats (Hynes 1970). Maintenance of riffles in relatively pristine condition is thus essential to the survival of the spikedace.

Ecological Considerations

Community Structure and Dynamics

In New Mexico, spikedace occurred from the upper reaches of the East Fork of the Gila River downstream to the mouth of the Middle Box. Within these stream reaches, the distribution of the fish was not continuous, nor was its abundance similar among the occupied areas. The reasons for the distributional and abundance patterns varied among the areas, and were dependent upon an array of biotic and abiotic factors. Minimally, a potential area of occupancy must have certain environmental features that permit the species to maintain viable populations. In addition to preferring particular ranges of water velocity and depth (see Microhabitat section), the spikedace has optimal temperature ranges and regimes, water flow requirements (seasonal and annual), and presumably chemical and other tolerances. Provided the spikedace had access, it might be expected to occupy an area if the above abiotic elements occurred in the requisite mix. If the spikedace was present, the size and stability of its population was also influenced by the structure and dynamics of the associated fish community. The degree to which other species populations influenced spikedace populations was governed, to a certain extent, by the species present and their habits.

Historically, 13 native fish species may have had ranges that partially, or completely, overlapped that of the spikedace in New Mexico (LaBounty and Minckley 1972). Some *(e.g.,* Colorado squawfish and razorback sucker) are only hypothesized natives, others have evidently been extirpated (Gila chub and Gila topminnow), and the Gila trout is now limited to streams outside the current range of the spikedace. Six species (longfin dace, roundtail chub, speckled dace, **loach** minnow, desert sucker, and Sonoran sucker) were found within the present New Mexico range of the spikedace. Each of these was at least an occasional associate of the spikedace, and undoubtedly had some influence upon the dynamics of spikedace populations. In addition to the native fishes, several non-native species occur or have occurred within portions of the spikedace's range (Table 1). Where established, these non-natives have no doubt imposed varying impacts upon spikedace populations. To provide some insights into the dynamics of spikedace and associated species populations under various abiotic and biotic conditions, a review of each of the regularly studied stream reaches is presented in the following section.

Cliff Dwellings Site

Habitat at this site during our study was a roughly even mix of riffles and runs, with several pools (Figure 14). Stream width varied from 5 to 20 in (mean 10), and depths were usually less than 40 cm. Substrate varied from cobble and rubble in riffles to sand and gravel in slow-velocity runs and pools. Within the site, the stream did not meander and was confined to one channel. Stream banks were vegetated with grasses, forbs, and willow (<u>Salix</u> sp.). During the study, flooding caused some realignment of pool, riffle, and run habitats, but such changes were typically slight. The integrity of the stream at this site was enhanced by it being a short distance

Figure 14. The West Fork of the Gila River at the Cliff Dwelling Site, New Mexico.

downstream from the Gila Wilderness, where land management practices have largely eliminated human-caused habitat modification. Within the site, optimal spikedace habitat was limited in extent.

The fish community at this site was comprised almost exclusively of native fishes. Non-native species (rainbow trout, yellow bullhead, and mosquitofish) were irregularly collected, and they never represented more than a small fraction of the community. Because of their very low numbers, non-native species were discounted as a factor influencing the dynamics of the fish community at this site. Similarly, the rarity of the roundtail chub excluded it from consideration as an important component of the Cliff Dwelling site community.

The speckled dace numerically dominated the community on most sampling dates, while the longfin dace was usually the second most common species. The spikedace, desert sucker, and Sonoran sucker were typically moderately common, and the loach minnow was usually uncommon (Figure 15).

Over the two years of sampling, sucker and loach minnow abundance remained fairly constant, with little seasonal change evident. Slight peaks in abundance of suckers occurred in autumn and/or early winter, when Age 0 fish were susceptible to capture. The loach minnow occurred in such low numbers that recruitment to the population was very low and not evidenced by distinct peaking patterns.

No pattern was discerned in the abundance fluctuations of the longfin dace over the course of the study. The decline in abundance in June 1984 may have been a reflection of spawning mortality, while the subsequent increase may have been a reflection of recruitment. Both the spikedace and speckled dace had distinct patterns of seasonal abundance. The spikedace was least common in June-September and most common in November-February. Conversely, speckled dace abundance peaked in summer months and was lowest in winter. The low abundance of the spikedace in summer was probably a reflection of high mortality among spawning adults. By late autumn-early winter, Age 0 spikedace had attained sufficient size to be susceptible to capture, which probably produced the peak in abundance. Winter mortality also reduced spikedace numbers, as evidenced by the decline of the species through the spring. Speckled dace abundance peaked in June of both years, which suggests it spawned at least one and, more likely, two months earlier. The peak in June reflected Age 0 recruitment. The decline in abundance of speckled dace through winter probably reflected the high mortality suffered by Age 0 individuals.

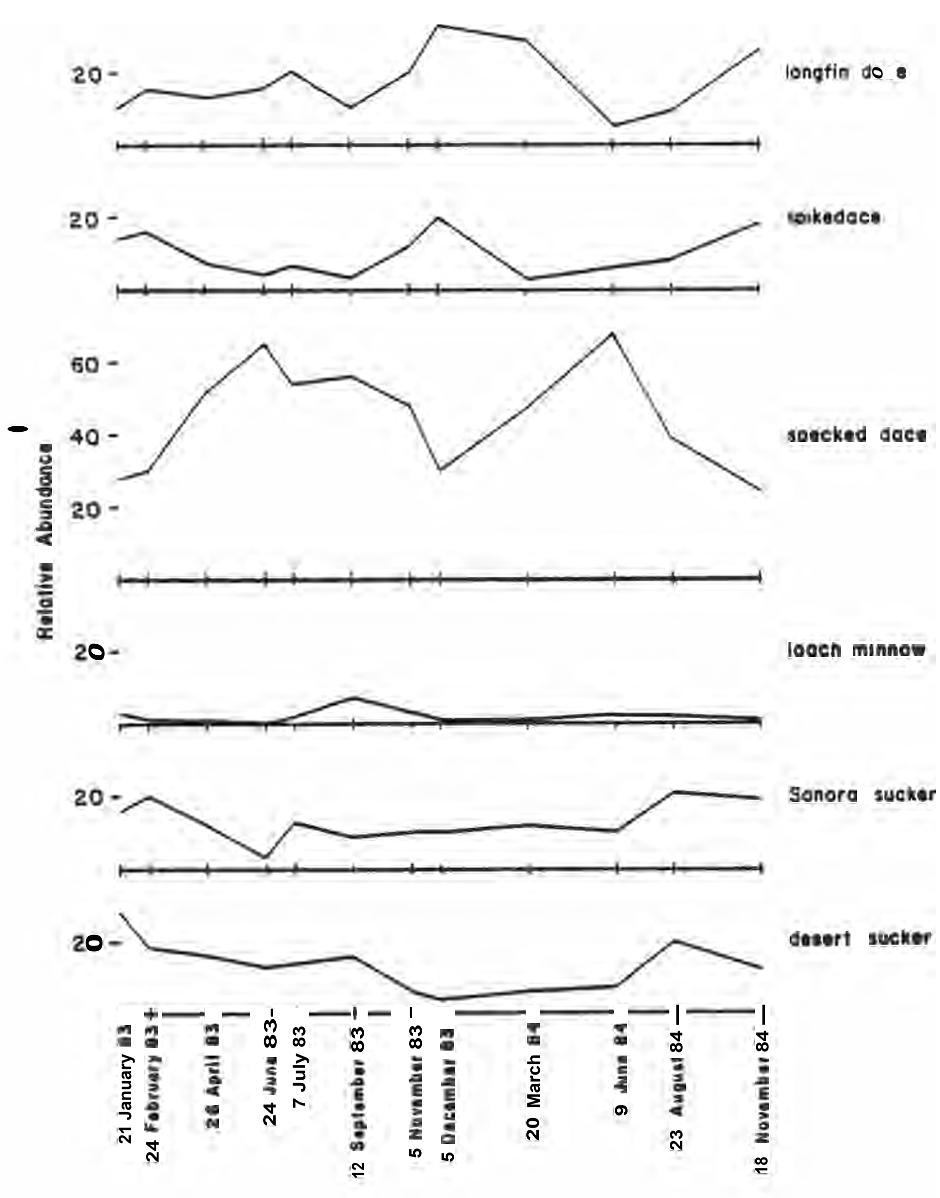


Figure 15 Relative abundance of the primary elements of

The relative commonness of each species was also a function of the availability of preferred habitats. Seasonal changes in availability of preferred habitats affected the relative abundance of all species, but it was most noticeable in the roundtail chub and adult suckers. If deep pools with cover were present, a few roundtail chub and many adult suckers were present. However, if flow patterns shifted and eliminated much of the pool habitat, adult suckers were rare and roundtail chub absent. Generally, the habitat for speckled dace (riffles and cobbled banks), longfin dace (quiet backwaters and eddy pools), and spikedace (shallow, gravel-bottomed runs and lees of riffles) were moderately common. Consequently, these species were usually moderately common. The low abundance of the loach minnow did not appear to be due to a lack of suitable habitat (riffles). Instead its numbers may have been limited by its thermal tolerances or by competition with the speckled dace, which utilized similar habitat.

At the Cliff Dwelling site, near the upstream limits of its range, the spikedace maintained a moderately abundant population. Suitable habitat was available, though limited. Each species present, in moderate to high numbers, occupied different microhabitats within the site. The use of different microhabitats throughout the year suggested little direct competition existed for food or any other potentially limiting resource among the species. The general absence of predatory fishes (native or non-native) excluded them as a factor controlling community structure.

Trailhead Site

Riffles and runs were the main habitat at this site on the Middle Fork of the Gila River, although debris-choked pools were also present (Figure 16). Stream width ranged from 6 to 22 in (mean 16), and depths averaged about 40 cm. Rubble and cobble dominated the substrates of riffles and runs, while sand dominated pool substrates. In the vicinity of the site, the stream meandered slightly within a rather narrow floodplain. A braided riffle was present at the upstream terminus of the site throughout the study. Although stream banks were vegetated with grasses, forbs, willow, and cottonwood (*Populus* sp.), unstable and eroded areas were common within the site. Major flooding caused dramatic channel realignment of the stream channel on two occasions. Between flood events, lesser degrees of habitat alteration occurred. Spikedace habitat was present, but not common within the site.

Population dynamics and community structure at this site varied throughout the study and did not demonstrate

Figure 16. The Middle Fork of the Gila River at the Trailhead Site, New Mexico.

predictable patterns. Seven native fishes were present, and most were found on each of the 12 visits to the site (Figure 17). Five non-native fishes were found, but only the yellow bullhead was regularly collected. As a group, natives numerically dominated the community, but no single native was consistently the most common. While most natives had abundance patterns that roughly tracked expected seasonal changes, the degree of change was greater than would be expected in a relatively stable community.

The longfin dace demonstrated the most dramatic fluctuations in abundance. Early in the study, it was relatively uncommon, increased to comparatively high numbers, and was then absent in July 1983. After July, it was relatively common for several months, crashed in June 1984, after which its abundance increased to moderate levels. Post-spawning mortality certainly contributed to the two population crashes, and the subsequent increase in abundance was due partly to recruitment of Age 0 fish. The degree of change in abundance was, however, too severe to be explained completely by spawning mortality and recruitment.

The roundtail chub had a very different pattern of abundance. Early in the study it was either absent or rare. By the middle of the study it had increased to moderate levels, but again declined at the end of the study. High spring runoff in 1983 created several debris-choked pools within the site. These pools persisted for much of the study, but by late 1984 much of this pool habitat had been lost because of channel and flow changes. Recruitment, as evidenced by the collection of Age 0 fish in each summer, contributed to the maintenance of the population at moderate levels for much of the study. Nonetheless, availability of suitable habitat appeared to be the primary factor influencing roundtail chub abundance (Bestgen 1985).

Early in the study, the speckled dace was moderately common. The absence of the species in July 1983 may have been due to post-spawning mortality. Thereafter, it remained relatively common. Interestingly, its abundance declined only slightly in the summer of 1984, suggesting there was comparatively little post-spawning mortality.

The Trailhead site supported a small population of loach minnow. The species was most common in late summer-autumn 1983 and June 1984. Assuming these peaks were due to recruitment, spawning apparently occurred earlier in 1984 than 1983. Mortality within this small population appeared to be most pronounced in the winter.

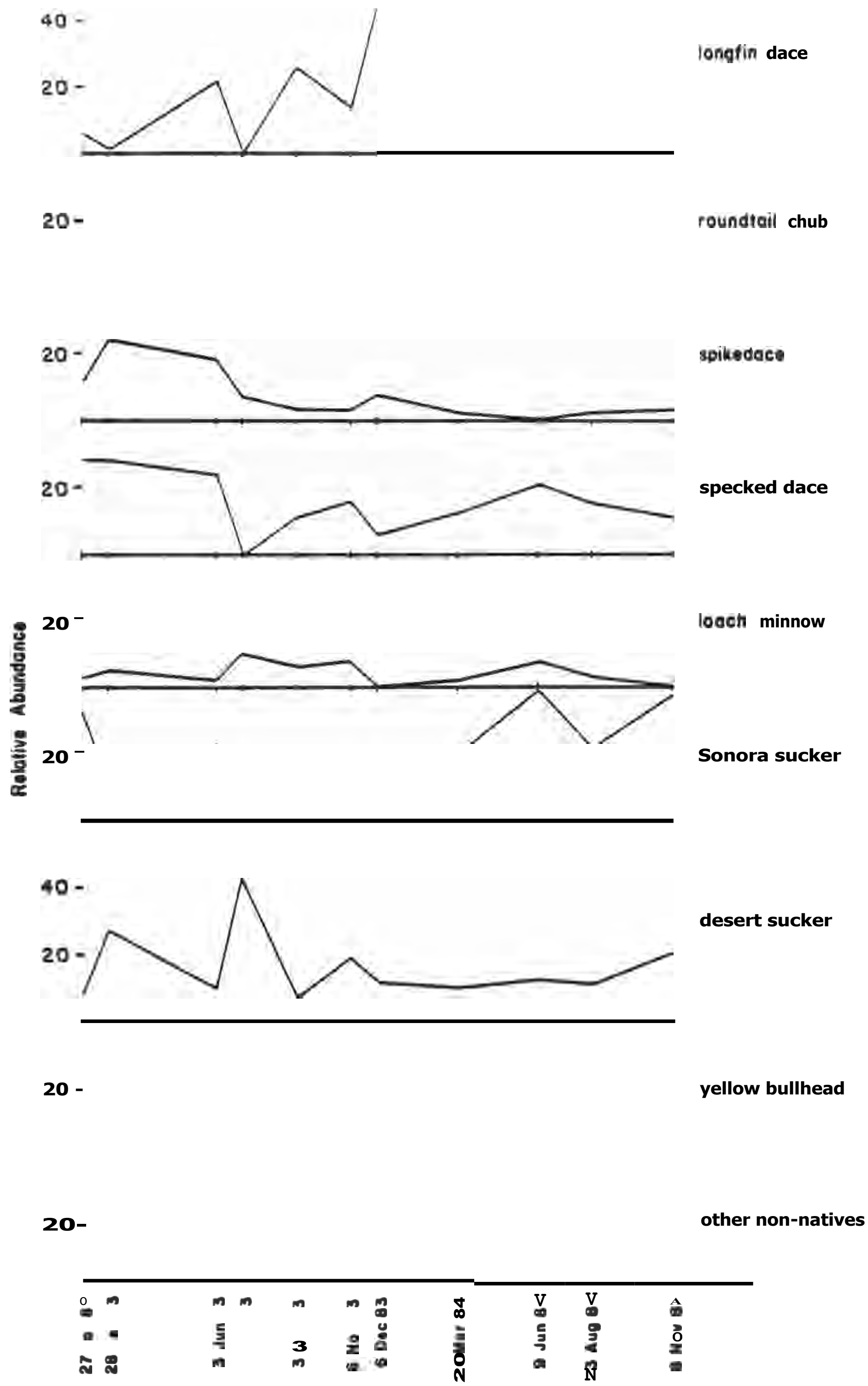


Figure 17. Relative abundance of the primary elements of the Trailhead fish community, New Mexico.

Neither sucker species evidenced a consistent annual cycle of abundance at the site. Sonoran sucker abundance was moderately high in January 1983, declined and remained fairly constant until June 1984, when it rose appreciably. In 1983, there was a slight abundance increase in June, but the increase in June 1984 was quite pronounced. In contrast, desert sucker abundance increased greatly in July 1983, declined thereafter, and remained fairly constant until November 1984, when it increased slightly. Thus, it appears that the desert sucker spawned quite successfully in 1983, while the Sonoran sucker was less successful. In 1984, the opposite occurred.

The spikedace was moderately common in early 1983, but it generally declined throughout the remainder of the study. The slight increase in abundance in December 1983 probably resulted from recruitment, but this was insufficient to sustain the population at even moderate levels.

Non-native fishes usually comprised less than 10% of the fish fauna at this site. Of the non-natives, the yellow bullhead was most consistently present. The two peaks in its abundance reflected spawning success. However, mortality among Age 0 yellow bullheads was evidently high, but not sufficient to completely eliminate the species from the area.

Other than the roundtail chub, the availability of seemingly suitable habitat did not appear to be a paramount factor influencing the abundance of native species on a given sampling date. For example, longfin dace abundance fluctuated considerably during the study, yet apparently suitable habitat was always available. Other native fishes also exhibited patterns for which the obvious factors did not provide a complete or satisfactory explanation.

The instability of the native fish community at Trailhead was probably caused by the combination of habitat instability and the non-native fishes. While this site did not experience flows that were more devastating than those that occurred elsewhere in the basin, the channel there tended to shift readily with only moderate flow increases. Such channel movement, and the resultant habitat instability, probably caused the abundance of many species to change abnormally. In addition, the non-native fish community adversely affected, through predation and/or competition, some species populations. Another non-native that might have adversely affected native fishes was the bullfrog (*Rana catesbiana*). In August 1984, large numbers of this species, particularly tadpoles, were present at the site. Fish were rather uncommon at this time, and remained so through November. The specific interaction by which the bullfrog may have caused the decline in fish numbers was not apparent.

However, elsewhere in the basin, we noted a similar negative correlation between bullfrog numbers and fish abundance.

Riverside Site

This site was located in a broad floodplain reach of the Gila River, where the stream was characterized by broad meanders (Figure 18). Stream width averaged 36 m, and ranged from 22 to 76 m. Water depths were usually less than 50 cm, but some pool depths exceeded 1.5 m. Long sand and gravel-dominated runs separated cobble and rubble-bottomed riffles. Pools were scattered and mainly located around eroded trees. Braided channels and gravel-sand bars were fairly common. In many reaches, including those of the study site, banks were unstable and eroding.

The Riverside site supported six native species. Five native fishes dominated the community. The roundtail chub was rare at this site, and was uncommon throughout the valley. The speckled dace was not found at the site, nor was it more than a rare vagrant in the Cliff-Gila Valley. During the study nine non-native fishes were found at the site, but none comprised more than a fraction of the community.

The abundance of the longfin dace followed a seasonal cycle, with greatest numbers occurring in autumn-early winter and lowest in late spring-early summer. Overall, the species was moderately common during the study (Figure 19).

The spikedace was usually the most common species at Riverside. Its abundance peaked in late autumn-early winter and declined through mid-summer. Winter mortality was responsible for the early decline, but post-spawning mortality contributed significantly to overall mortality.

No obvious reasons for the abundance pattern of the loach minnow were discerned. In 1983 and 1984 gravid females were found in late spring, and ova were found deposited on rocks in April 1984. A chronology such as this would suggest that spawning mortality should be reflected by June or July. However, loach minnow abundance was lowest in December 1983 and November 1984. Resolution of this apparent anomaly will require additional investigation.

The fluctuations in abundance of the two sucker species followed similar patterns at this site. Greatest abundance was in the summer months, and lowest numbers were found in late autumn-early winter. Each sucker species is relatively long-lived (5+ years). Therefore, spawning mortality was not nearly as obvious a factor in seasonal abundance cycles as it

Figure 18. The Gila River at the Riverside Site, New Mexico.

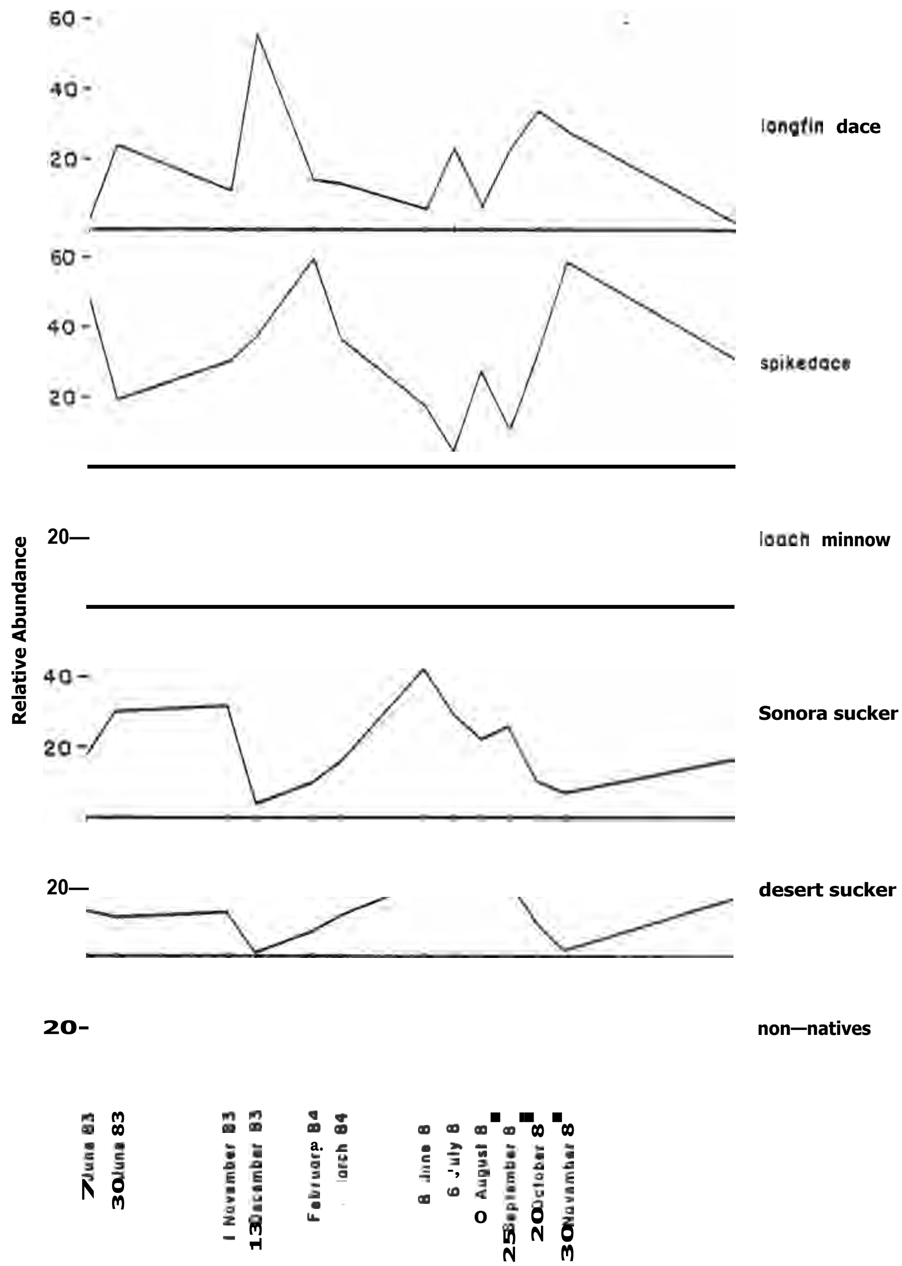


Figure 19. Relative abundance of the primary elements of the Riverside fish community, New Mexico.

was for shorter-lived species, such as spikedace and loach minnow. Rather, the decline in sucker abundance was probably due to high mortality among Age 0 suckers.

No non-native fish species was consistently found at the Riverside site, but two or three were usually present in each sample. Usually non-native fishes numerically comprised less than 5% of the community. Given this irregularity of occurrence and their low numbers, non-natives played a comparatively minor role in community structure at the site.

The Riverside site supported a rather large and apparently stable native fish community. Suitable habitat was common for most natives within the area, hence their relatively high numbers. The consistently high abundance of spikedace reflected the presence of extensive amounts of optimal habitat for this species in the Cliff-Gila Valley. Because of high habitat quality, the species apparently maintained sufficient numbers to negate the detrimental effects of non-native fishes. The rarity of the roundtail chub was due, in part, to the scarcity of its preferred habitat. Although some non-native species maintained viable populations within the valley, all were probably supplemented to varying degrees by dispersal from elsewhere in the drainage.

Conner Site

This site was located where the Gila River emerges from the Middle Box. At this point, the floodplain broadens greatly (Figure 20). Runs were the predominant flow pattern within the site, and pools were limited. Substrates varied from sand in pools and runs to cobble and rubble in the few riffles. Stream width varied from 20 to 85 m and averaged 30 m. Depths were usually about 35 cm in runs, but exceeded 1.5 m in some pools. Banks were unstable and eroded throughout much of the site.

The native fish community of the Conner site was usually comprised of the spikedace, longfin dace, and the desert and Sonoran suckers. The speckled dace was never found at this site, while one loach minnow and several roundtail chub were found on one occasion. Of the natives present, all were a minor to moderate component of the community on most sampling dates. The abundance of each native fish fluctuated in patterns that were not obviously linked to normal factors. Species diversity of the non-native fish community was greater than the native, and the former usually numerically dominated the community. Among the non-native fishes, the channel catfish and red shiner were most common.

Figure 20. The Gila River at the Conner Site, New Mexico.

The abundance of the longfin dace at this site was highly variable. Early in the study, it was moderately common, then fluctuated greatly for about 7-8 months, and finally increased to a very high level in December 1984 (Figure 21). Such a pattern is not reflective of natural variation, in which numbers peak with recruitment of Age 0 fish and then decline through the winter to reach a low shortly after spawning in the spring. The observed pattern was indicative of "unnatural" forces causing a constant fluctuation, with no apparent longterm stability. Suitable longfin dace habitat was present at the site throughout the study.

From June 1983 through March 1984, the spikedace was moderately common at the site. The decline from late 1983 through February 1984 was due to winter mortality. The increase in March 1984 may have been the result of augmentation by displacement from upstream reaches. However, discharge volume was low at this time and displacement from upstream habitats does not seem likely. Conversely, it is more probable that the slight rise in abundance was an artifact of sampling. After March, spikedace abundance declined sharply in April and remained quite low for the duration of the study.

Although the Sonoran sucker was abundant (38%) and the desert sucker moderately common (12%) in June 1983, both declined in abundance and were usually uncommon for the remainder of the study. The low abundance of adult suckers at the Conner site, as well as elsewhere in the Redrock and Virden valleys, suggested that maintenance of these species in this area is largely dependent upon displacement from upstream reaches.

At the outset of the study, channel catfish was not particularly common at the site. After an increase in September 1983, its abundance declined and remained low until May 1984, when numbers increased greatly. However, by December 1984, the species was absent at the site. Channel catfish was represented by juveniles and adults (Age I +) in May, but most specimens in August were Age 0. Given the commonness of Age 0 channel catfish in August, its absence in December is an enigma.

The red shiner was usually the most common fish at the Conner site. It was most numerous from autumn 1983 through the spring of 1984. Such a pattern suggested spawning occurred in late summer and that recruitment was rather high, although winter mortality diminished the population.

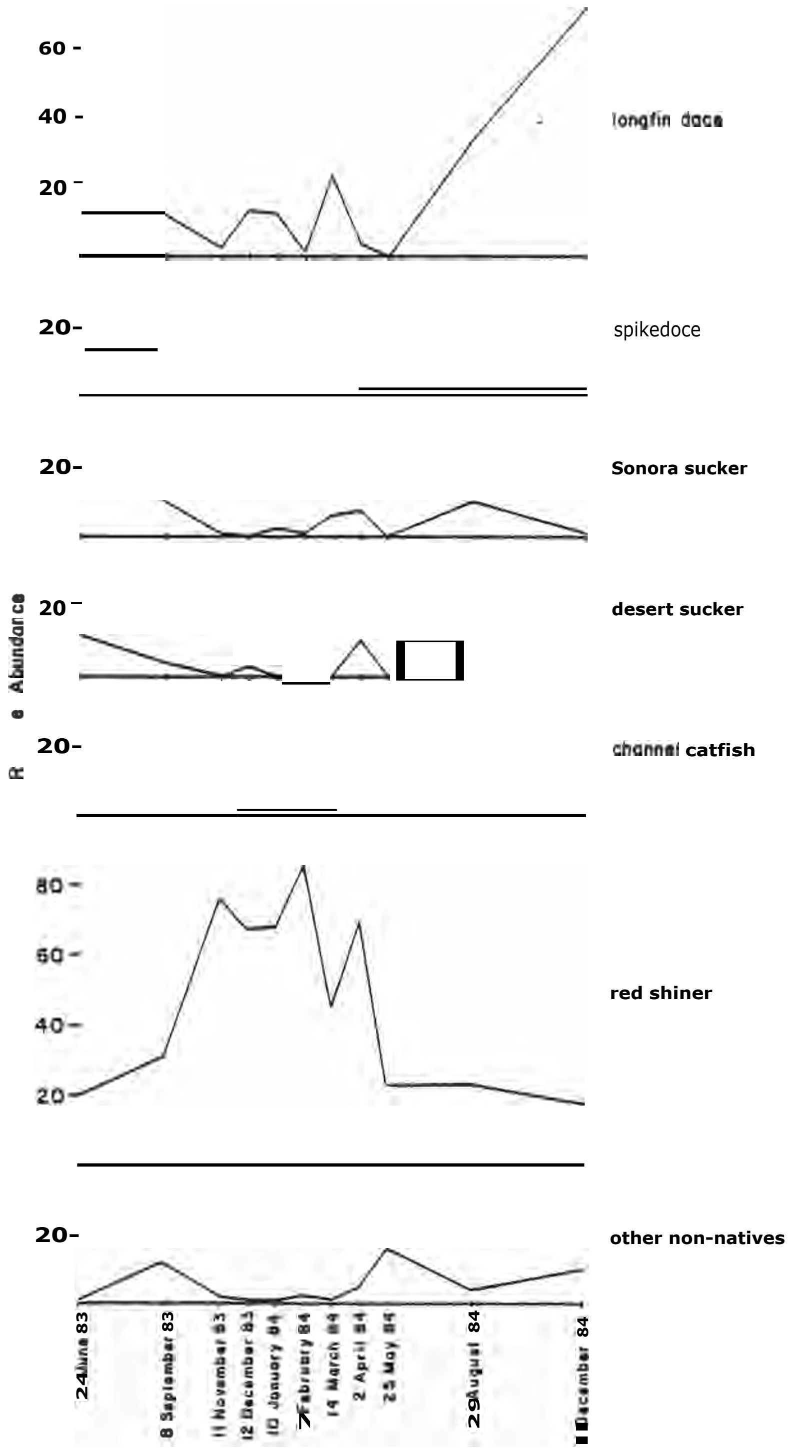


Figure 21. Relative abundance of the primary elements of the Conner fish community, New Mexico.

Both the fathead minnow and the flathead catfish were frequently found in low numbers. All other non-native fishes were irregularly collected in low numbers.

The highly variable species and age composition of the community, and the degree and unpredictability of abundance shifts were indicative of the instability of the fish community at the Conner site. Shifts in availability of preferred habitats may have caused some of the shifts, but the domination of the community by non-native fishes (particularly channel catfish and red shiner) was more likely the primary reason for the observed instability of the native fish community. For example, the crash in spikedace abundance was preceded by a period of high red shiner abundance and coincided with an increase in channel catfish numbers. Both sucker species declined in abundance during a period when red shiner numbers were high. The resurgence of longfin dace may have initially been enhanced by the drop in red shiner abundance, and then accelerated by the absence of the channel catfish.

Floods

In late September and early October 1983, a prolonged rain in the Gila watershed caused a flood that crested at 237.6 cu. m/sec (8,390 cu. ft/sec) near the village of Gila (USGS Station No. 09430500) and 356.8 cu. m/sec (12,600 cu. ft/sec) near Redrock (USGS Station No. 09431500). By 16 October, flows were less than 5.7 cu. m/sec (200 cu. ft/sec) at both stations (USGS unpublished data). As soon as flow levels had receded enough to allow access, we sampled the river at several pre-flood sites. The collections made in the shortest interval before and after the flood were on the West Fork (Cliff Dwelling site), the Middle Fork (Trailhead site), and the Conner site. Each of these was visited the month before and after the flood. At the Gila River Riverside and Cottonwood sites, collections were 3 months before and 1 month after the flood. At the Gila River Indian Ruins site (Figure 1), the pre-flood collection was in June and the post-flood collection was in December. At all sites except Indian Ruins and Cottonwood, more than one collection had been made prior to the flood. After the flood each site was sampled at least twice.

Because of the variability in sampling, it is appropriate to consider each site separately. The following discussion deals primarily with the spikedace, but it also applies generally to other native fishes.

Cliff Dwellings Site

The fish fauna at this site was composed almost exclusively of native species prior to and after the flood (Figure 22). Changes in the relative abundance of native species were generally small enough to be within normal sampling variability. The increase in spikedace relative abundance (and absolute abundance), from 2.7% of the community before the flood to 12.2% after the flood, was most likely due to recruitment of Age 0 fish to the population. The location of this site at or near the upstream distributional limits of the species precludes displacement as an explanation for the greater abundance of spikedace after the flood.

Trailhead Site

The most obvious impact of the flood upon the fish community at this site was the reduction in the abundance of non-native fishes (Figure 22). The relative abundance of the spikedace after the flood (5.2%) was quite similar to what it was before (4.2%). The failure of spikedace to increase in abundance as it had at the Cliff Dwelling site was probably caused by the instability of the river channel and associated habitats in the Trailhead area. Any increase in abundance due to recruitment was offset by downstream displacement caused by habitat degradation. Augmentation by displacement from upstream populations was not a factor because this site was near the upper limits of the range of the spikedace in the Middle Fork.

Indian Ruins Site

In late June 1983, the fish community at this site was largely composed of native fishes, although non-natives represented 8.5% of the total (Figure 22). On 15 December 1983, non-natives were 19.5% of the fishes present. However, non-natives declined to only 0.3% of the community by 22 March 1984. In addition to the above changes in community composition, the number of specimens obtained during each site visit changed dramatically; despite comparable sampling efforts. In the June sample, 490 (native and non-native) specimens were collected, but in December only 75 (native and non-native) specimens were obtained. In March, 172 specimens were collected.

Some changes in numbers and community composition are typically associated with flood events, but the patterns discerned at the Indian Ruins site did not occur within a

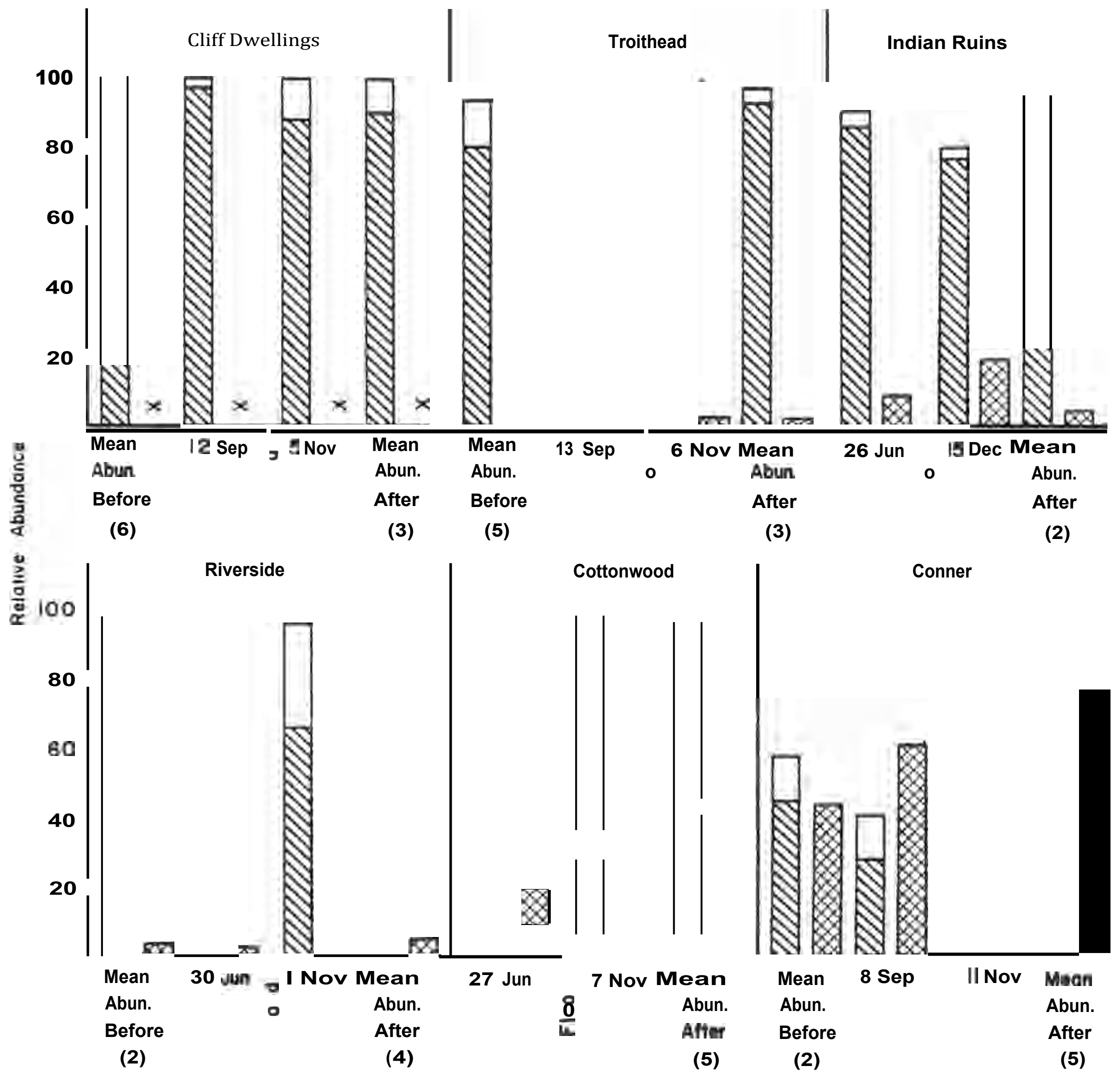


Figure 22. Relative abundance of the spikedace and other fishes at six locations in the Gila River drainage, New Mexico, before and after the October 1983 flood. Open portions of a bar represent spikedace relative abundance, hatched areas indicate the relative of other native fish species, and cross-hatched bars indicate the relative abundance of non-native fish species. Parenthetical values indicate the number of samples for each period. An X indicates non-natives comprised less than 1.0% of a sample or group of samples.

natural framework. In this stretch of the river, levees have been constructed to contain floods. In the October 1983 flood, the levees performed as intended. The river was constrained, and as a result it deeply incised the channel. After water levels receded, the only habitat remaining consisted of deep, rapid-velocity runs. Such habitat was unsuitable for most native fishes, particularly the spikedace. By March 1984, the river had re-established some meanders and gravel bars, and native fish abundance increased as the habitat evolved to a more natural state. Thus, native species suffered at this site apparently because of man-induced habitat modifications, not because of the flood itself.

Riverside Site

The structure of the fish community at this site did not change appreciably as a result of the flood. In a sample made prior to the flood (30 June), native fishes comprised 97.9% of the community and the spikedace represented 18.8% of the fishes present (Figure 22). After the flood (November), native fishes accounted for 95.1% of the community, and the spikedace constituted 30.2%. The comparatively low abundance of spikedace in June reflected post-spawning mortality (See Life History section), while the increase in abundance in November resulted mainly from recruitment of Age 0 fish.

Cottonwood Site

Changes caused by the flood in the fish community at this site were very pronounced. In late June 1983, natives comprised 73.0% of the community, with the spikedace representing 11.0% (Figure 22). After the flood, on 7 November, natives constituted 97.3% of the community, and the spikedace was numerically the dominant species (63.2%). The magnitude of increase in spikedace abundance could not be solely attributed to in situ recruitment of Age 0 fish. Rather, displacement of spikedace from upstream habitats probably augmented numbers at this site. Six non-native fishes (yellow bullhead, channel catfish, common carp, red shiner, mosquitofish, and smallmouth bass) were present before the flood, but only channel catfish, red shiner, and green sunfish were present afterward. The flood was at least partially responsible for the shifts in non-native abundance and diversity.

Conner Site

Other than the Indian Ruins site, this site was the only one that did not evidence neutral or positive effects of flooding upon native fishes. In early September 1983, five native species comprised 39.6% of the community, with the spikedace representing 12.4% (Figure 22). Of the six non-natives present, the channel catfish, red shiner, and mosquitofish were most common (16.4%, 31.1%, and 7.8%, respectively). After the flood, in mid-November, the spikedace and longfin dace were the only natives present (19.2 and 1.5%, respectively). The non-native fish assemblage was still comprised of six species, and the red shiner had increased to 74.8% of the community. Although the increase in spikedace abundance might be largely attributed to recruitment of Age 0 fish, the degree of change in red shiner abundance indicated a source in addition to recruitment. The decline of the red shiner at the Cottonwood site (from 19.9% of the community before the flood to 0.5% after) indicated considerable displacement of the species from the Cliff-Gila Valley, and thus, a source for the large numbers found at the Conner site following the flood.

After the flood, neither desert nor Sonoran suckers were found at the Conner site. A reconstruction of the size-class (age-class) pre-flood distribution of both species from the Conner site upstream to the Cliff-Gila Valley provides a probable explanation for their observed decline. At the Conner site, the small pre-flood sucker community was composed largely of juveniles and younger individuals (< 150 mm TL). In the Middle Box, only adult suckers (> 150 mm TL) were present. Upstream of the Middle Box, all size-classes of suckers were present. Above the Middle Box, suckers generally avoided entrainment (discussed below), and in the Middle Box most were of sufficient size to maintain position. Although the force of the current was diminished at the Conner site, some displacement of all species probably occurred. The congruence of comparatively high flows, small size of the fish, and low numbers there may have resulted in the reduction of suckers to such low numbers that they were not obtained in the post-flood Conner collection.

In assessing the changes discerned in the Conner site fish community caused by the flood, it is important to understand the nature of the Gila River upstream of the site. In this reach (Middle Box), the stream is narrow and tightly constrained by canyon walls. During a flood, such a reach is best described as a sluiceway through which water rushes, and little or no refuge from the force of the current is available to most fishes. Once the water is released from the sluiceway and spills out over the floodplain, its force rapidly abates. Fish that are entrained by flood waters are swept through the sluiceway and "pile up" at the downstream terminus of the sluice. The increased abundance of spikedace and, particularly, red shiner at the Conner site might have occurred via the foregoing scenario. Above the Middle Box, the sucker species generally avoided entrainment and those within the box were of sufficient size to maintain position.

The preceding discussion presents evidence that native fishes were able to survive the October 1983 Gila Basin flood well in most instances. When they did not, exogenous factors diminished their tenacity. Quite likely, native fishes avoided displacement during the flood by moving with the stream margin as flood waters rose. Such a strategy enabled them to avoid the most forceful flows. As flood waters receded, most retreated back to the main channel. By so responding, native fishes tended to avoid entrapment in isolated sloughs and backwaters left by a flood. Indeed, it might be argued that native fishes were in a constant state of readiness for floods. Throughout our study, and particularly during the microhabitat investigations, we noted that most native fishes were found near the shore. Very few ventured into the main channel, even when frightened. Adult Sonoran and desert suckers were the exception; they were occasionally observed cruising main channels and often taken in rapid velocity runs. Non-native fish, however, did not appear to exhibit a behavioral trait that signaled them to vacate pools and backwaters before such areas became completely isolated from the main channel. After the October 1983 flood receded, we found that most isolated habitats were occupied primarily, if not exclusively, by non-native fishes. Water persisted in these areas for a time, but decreasing dissolved oxygen concentrations and/or desiccation caused the eventual demise of even the hardiest non-native. Non-native fishes, if not eliminated, were at least checked in their expansion and increase by floods. The foregoing does not imply that native fishes completely avoid displacement. Rather, non-native fishes are more susceptable to displacement by flooding than native fishes.

Drought

The opportunity to study the response of spikedace and other native fishes to drought did not occur during our study. However, based upon aspects of the study, several comments regarding drought survival strategies of the spikedace are appropriate. As previously discussed, the species mainly inhabits floodplain reaches where shallow, gravel and cobble-bottomed riffles and runs are common (Barber and Minckley 1966; Barber et al. 1970; Anderson 1978; this study). During droughts, these areas may be largely desiccated and therefore uninhabitable by the spikedace. In such an environment, the spikedace may have to survive in the reduced lotic habitats of the floodplain and/or retreat to canyon reaches, where the effects of droughts are less pronounced. In either case, mortality would be expected to be high. The result would be scattered and isolated populations. Once drought conditions abated, depopulated stream reaches might be reinhabited by dispersing adults and/or larvae displaced by high discharge volumes (or behavioral drift). Support for the latter scenario was provided by our finding Age 0 spikedace at several locations in the Redrock and Virden valleys following the high spring runoff of 1983. Obviously, the success of such "transplants" is dependent upon the numbers displaced, the suitability of the available habitat, and the composition of the indigenous fish community. In 1983 one (or any combination) of the above factors prevented the successful re-establishment of the spikedace in the Redrock and Virden valleys.

Predation and Competition

Most evidence for competition and predation among native and non-native fishes in the Gila River basin of New Mexico is circumstantial or anecdotal. However, sufficient observational and tangible data are available from the area to support the contention that both interactions exert negative influences on the stability and persistence of native fish communities in the study area. In the following discussion several examples are presented as evidence of the deleterious impacts of non-native upon native fishes.

Predation

Evidence of predation by non-native fishes *(e.g.,* channel and flathead catfishes and smallmouth bass) upon native fishes in the Gila River basin, New Mexico is largely circumstantial at this time. However, several salient facts indicate that such predation occurs, and in several instances has probably had major adverse impacts upon native fish communities. Each of the aforementioned non-natives is piscivorous (Carlander 1969 and 1977; Becker 1983), and native fish remains have been found in stomachs of specimens of each of these species in the Gila River basin, New Mexico (James M. Montgomery, Inc. 1985; this study). A thorough examination of all predator viscera preserved in our study will be presented as a separate report.

Circumstantial evidence for the negative impact non-native predators have upon native fishes exists for several stream reaches. In areas such as the Middle Box and the reach between the Forks area and Mogollon Creek, where high predator loads have been documented, native fishes are uncommon. In addition, the native fish assemblage in these reaches is comprised almost completely of large (> 150 mm TL) individuals. Such fish, by virtue of size alone, largely escape predation. Another example is the upper reaches of the East Fork of the Gila River. Prior to the 1983 and 1984 floods, this area had a depauperate native fish community composed mainly of adult desert and Sonoran suckers and roundtail chub. Channel catfish and smallmouth bass (particularly adults) were moderately common. When the area was again sampled in September 1985, adult non-native predators were generally absent. It is surmised that the severe flooding of the East Fork greatly reduced non-native predators in this area (see Floods section). Longfin dace and spikedace, which had been rare or absent in much of the area in 1983, were collected in moderate numbers in 1985. In addition, juvenile suckers (and adults) of both species were common in 1985.

Competition

Although the threat posed by the non-native red shiner to native southwestern fishes has been the subject of considerable discussion (Minckley and Deacon 1968; Minckley 1973; Deacon et al. 1964; W. L. Minckley pers. comm.), the specific mode(s) of interaction has not been delineated. However, the relationship between the establishment of the red shiner and the concomitant decline of certain native fishes, including the spikedace, is sufficiently well-documented (Minckley and Deacon 1968) to suggest there is causality.

In the Gila Basin of New Mexico, the red shiner has recently become established. The species was first reported (1951) in the basin in Taylor Creek in the vicinity of Wall Lake (Huntington 1955), where it apparently did not become established. It was not found elsewhere in the Gila River system of New Mexico prior to 1978 (e.g., Anderson 1978), but in 1979 the species was found in the Gila River near the Arizona-New Mexico border (B.L. Jenson pers. comm.). Since then, the species has occupied and has become quite common in the Redrock and Virden valleys of the Gila River (Schmitt 1980; this study). Above the Middle Box, red shiner has been irregularly collected since 1981 (Mueller and Delamore, 1981; James M. Montgomery, Inc. 1985; this study).

The current numerical dominance, or near-dominance, of the red shiner of the fish communities in the Redrock and Virden valleys has probably resulted either from displacement of native fishes (e.g., spikedace) or occupancy of altered habitats that are sub-optimal for natives. Alternatively, the red shiner may have been able to successfully invade the lower Gila River of New Mexico by exploiting unoccupied habitat. Support for utilization of "unoccupied niche(s)" by the red shiner is derived from the fact that a depauperate native fish fauna existed in the Redrock and Virden valleys prior to the establishment of the red shiner. For example, the collecting record revealed that only four native fishes (i.e., longfin dace, spikedace, Sonoran sucker, and desert sucker) were regular inhabitants of the valleys, and the abundance of the spikedace was inconsistent. Conversely, the native fish fauna of the area had already been subjected to a variety of human-imposed stresses by the time most ichthyological inventories were made (1949 and thereafter). These environmental traumas included periodic (and unseasonal) dewatering of streams in the area. Although native fishes would be expected to survive some human-caused stresses, respite was infrequent in the Redrock and Virden valleys. When the red shiner invaded the area, available habitats included ones similar to those occupied by the species in its native range (Matthews and Hill 1979). Presented with such habitats, and encountering a limited native fish fauna, the range and numbers of the red shiner rapidly increased.

Support for the hypothesis of competition among native fishes and the red shiner was provided by observations made on several occasions in the Redrock and Virden valleys. Juvenile suckers (mainly Sonoran) were observed moving about, feeding on the bottom in shallow water near the stream margin. At intervals of 1-3 minutes, a red shiner would swim through the aggregation of feeding suckers, hitting and scattering them. After a disruptive foray, the red shiner would return to a protected area behind a large boulder. We watched repetitions of the above activity for over 1 hour. Gradually, individual suckers would move upstream, away from the "terrritory" of the red shiner. As these suckers moved upstream, they were replaced by others from downstream. A similar behavioral sequence between a red shiner and several spikedace was observed in the Verde River, Arizona (James Brooks pers. comm.).

SUMMARY AND CONCLUSIONS

In New Mexico, the spikedace is currently limited to the lowermost reaches of the West and Middle forks of the Gila River and the Gila River between its confluence with Mogollon Creek and the upper end of the Middle Box (Cliff-Gila Valley). The populations in the East Fork of the Gila River and at the mouth of the Middle Box (Conner site) are small and perhaps ephemeral. In 1983-1984, no spikedace were located in the East Fork of the Gila River; however, in 1985, the species was found there at several sites. Such a pattern (and that revealed in the historic record) suggests that this population is now unstable. Consequently, it should not be considered a viable population until monitoring for several years has documented its persistence. The survivability of the small Conner population is problematic. For much of our study, we believed it to be viable, but its precipitous decline in late 1984 was sufficient reason to question this premise. Vagrant spikedace were occasionally found downstream of the Conner site, but these fish did not survive. Given the dominance of non-native fishes and degraded habitat in the Redrock and Virden valley reaches, it is extremely unlikely that viable spikedace populations will be established there.

The general absence of the spikedace in canyon reaches of the Gila River basin in New Mexico is due primarily to the paucity of its preferred habitat. In addition, its hypothesized survival strategy of retreating to stream margins to avoid the main force of flood waters is negated by the proximity of canyon walls. The establishment of non-native fishes in the canyon reaches has further diminished the suitability of these areas for spikedace.

The Cliff-Gila population of the spikedace is the largest in New Mexico, and very likely the largest surviving population anywhere in the species' range. Although the species has been found throughout the Cliff-Gila Valley, in 1983-1985 it was most common in the lower portion. Optimal habitat and the relatively low incidence of non-native fishes were the major reasons for the species' observed abundance in the valley. Elsewhere in the Gila basin, surviving spikedace populations are rather small, some appear to be unstable, and the survival of each is uncertain. Given the tenuous prospects for these populations, the maintenance of the Cliff-Gila population is of utmost importance to the survival of the species.

The spikedace rarely survives as long as 24 months, and most individuals live no more than 13 months. The reproductive season is limited to a brief period in the spring, when water temperature and discharge volume reach optimal spawning levels. Ambient temperatures influence gonadal development and thus the time of spawning. Females spawn in shallow, sand and gravel-bottomed riffles. Age I females may produce as many as 200 ova and Age II females 300, but average fecundity for each age class is lower. Upon hatching, the larvae move to nursery areas along stream margins. Most growth is attained in the first 3-5 months of life. From September through April, spikedace grow little, if any. After spawning, Age I fish experience a second period of growth in June and July. Thereafter, growth is slight. Age 0 fish averaged 38 mm SL at the end of their first summer, and Age I fish averaged 50 mm SL at the end of their second summer. Maximum size recorded in spikedace in New Mexico is about 58 mm SL. Food consists mainly of mayflies.

Seasonal, geographical, and ontogenic differences were detected in microhabitat utilization by the spikedace in New Mexico. Larval spikedace are most commonly found in water velocities of less than 15.2 cm/sec, depths of less than 32.0 cm deep, and over sand-dominated substrates. Juveniles move to faster velocity and deeper water, over sand-and gravel-dominated substrates. Adults are found over a rather wide range of water velocities (up to 74.7 cm/sec); however, as in larvae and juveniles, they tend to stay in shallow water. Adults range over sand, gravel, and cobble substrates. Geographic differences in habitat utilization are probably more a function of habitat availability than of intrinsic "preferences". However, seasonal differences in microhabitat utilization reflect real shifts. In the Forks area there were significant differences in water depths occupied between cold and warm seasons, but none were detected in water velocity. Conversely, the spikedace in the Cliff-Gila Valley, moved to slower velocity water in the cold season, but water depth utilization did not change.

Many biotic and abiotic factors interact to influence the abundance and distribution of the surviving spikedace populations in New Mexico. Within a community composed mainly of native fishes, the spikedace appears to be able to maintain itself even in areas with suboptimal spikedace habitat. However, when non-native fishes become established, the equilibrium that historically existed among the native fishes and their environment is disrupted. This instability is exacerbated by anthropogenic modifications of the river systems. Singly, or in tandem, these two factors have been responsible for the elimination of the spikedace from much of its native range. If the spikedace is to be maintained in New Mexico, survival of the Cliff-Gila Valley population is critical. If the Cliff-Gila Valley population of the spikedace is lost or diminished, the overall survival of the species is doubtful.

RECOMMENDATIONS

1. List the spikedace as a federally threatened species as proposed (U.S. Dept. Interior 1985).

2. In New Mexico, designate critical habitat in the Gila River in the Cliff-Gila Valley and the lower reaches of the West and Middle forks of the Gila River as proposed (U.S. Dept. Interior 1985).

3. Maintain endangered listing of the spikedace in New Mexico under the New Mexico Wildlife Conservation Act.

4. Develop cooperative agreements among private landowners, state and federal agencies, and others as necessary to protect and enhance the occupied or potential habitat of the spikedace in New Mexico and Arizona.

5. Develop a recovery or management plan, as appropriate, to provide strategies for the conservation of the spikedace in New Mexico and Arizona.

6. Introduction of non-native warmwater fish species to the Gila-San Francisco Basin of New Mexico should be discontinued. Any human activities which disturb, modify, or destroy occupied or potential spikedace habitat should be carefully evaluated. Where or when such activities are determined to be detrimental to the spikedace, they should be halted.

7. Continue and expand spikedace studies to provide the information necessary for development and implementation of appropriate management strategies. Of particular need are studies to delineate and mitigate the effects of human-induced modifications of streams upon native fish communities. Integral to the above are investigations of the impacts that introduced fishes have on native fish communities. These studies should be holistic in overall design, yet sufficiently specific to provide baseline data on all components.

8. Secure areas for management to ensure survival of the species, including the Cliff-Gila Valley, East Fork of the Gila River, and the Redrock Valley in New Mexico.

9. Evaluate the feasibility of reintroductions of the spikedace into areas of historic range. Considerations should include availability of spikedace stock, habitat suitability in proposed reintroduction sites, and the non-native predator/competitor load of such areas. Any major reclamation effort would require the development of hatchery stocks, for which Dexter National Fish Hatchery would be an appropriate facility.

10. Establish guidelines and a federal-state-local agency infrastructure to provide advice and assistance to entities (private or public) that propose instream or riparian modifications that might damage existing spikedace habitat.

ACKNOWLEDGEMENTS

In the three years we spent studying the fishes of the Gila Basin, we have become indebted to many people for their assistance, advice, and encouragement. Foremost is John P. Hubbard of the New Mexico Department of Game and Fish, who conceived the study, and through his efforts funding for the study was made available. His advice, assistance, and editorial comments are greatly appreciated. Bruce J. Hayward, Western New Mexico University; Carl L. Couret, U. S. Fish and Wildlife Service; Michael D. Hatch, New Mexico Department of Game and Fish; and Paul R. Turner, New Mexico State University, provided assistance in a variety of ways and helped make the study successful. James E. Johnson, U. S. Fish and Wildlife Service, aided in obtaining funds for the study. W. L. Minckley, Arizona State University, shared his knowledge and insights on the biota of the southwest. Dean Hendrickson and Dennis Kubly deserve a special thanks for their assistance, advice, and shared knowledge of southwestern fishes and their habitats.

Private landowners throughout the region graciously allowed us access to study sites. In particular, we appreciate the consideration given by Brook and Jamie Stillman of the Diamond-Heart Ranch, Wolford and Marlene Kelly of the Kelly Ranch, and Tony Conner of the Conner Ranch. Dustin Hunt was a source of much interesting, local information. Joan Ulibarri patiently typed the report. Chris Altenbach, Marilyn Altenbach, William Baltosser, Sherry Barrett, Richard Baumann, Scott Belfit, Gerald Burton, Steven Carothers, J. William Eley, Jennifer Fowler-Propst, Bryan Hanson, Roy Hayes, Steven Henry, William Liebfried, Robert Minckley, Tim Mitchusson, John Rinne, and C. Gregory Schmitt provided needed assistance.

LITERATURE CITED

Anderson, R. M. 1978. The distribution and aspects of the life history of Meda fulgida in New Mexico. Unpubl. M.S. thesis, New Mexico State Univ., Las Cruces, NM. 62pp.

Anderson, R. M. and P. R. Turner. 1977. Stream survey of the San Francisco River. New Mexico Dept. Game and Fish (Final Rept., Contract No. 516-65-24). 19pp.

Barber, W. E. and W. L. Minckley. 1966. Fishes of Aravaipa Creek, Graham and Pinal counties, Arizona. Southwest. Natur. 11:313-324.

Barber, W. E. and W. L. Minckley. 1983. Feeding ecology of a southwestern cyprinid fish, the spikedace, Meda fulgida Girard. Southwest. Natur. 28:33-40.

Barber, W. E., D. C. Williams, and W. L. Minckley. 1970. Biology of the spikedace, Meda fulgida, in Arizona. Copeia 1970:9-18.

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

Becker, G.C. 1983. Fishes of Wisconsin. The University of Wisconsin Press, Madison, WI.

Bestgen, K. R. 1985. Distribution, biology, and status of the roundtail chub, Gila robusta, in the Gila River basin, New Mexico. Unpubl. M.S. thesis, Colorado State Univ. Fort Collins, CO. 104pp.

Carlander, K. A. 1969. Handbook of freshwater fishery biology, Vol. I. Iowa State Univ. Press, Ames, IA. 752pp.

Carlander, K. A. 1977. Handbook of freshwater fishery biology, Vol. II. Iowa State Univ. Press, Ames, IA. 431pp.

Cope, E. D. 1874. On the Plagopterinae and the ichthyology of Utah. Proc. Amer. Philosoph. Soc. 14:129-139.

Cope, E. D. and H. C. Yarrow. 1875. Report upon the collections of fishes made in portions of Nevada, Utah, California, Colorado, New Mexico, and Arizona during the years 1871, 1872, 1873, and 1874. Rept. Geog. and Geol., Expl. and Surv. W. 100th Merid. (Wheeler Survey) 5:635-703, pls. 26-32.

Cross, J. N. 1975. Ecological distribution of the fishes of the Virgin River (Utah, Arizona, Nevada). Unpubl. M.S. thesis, Univ. of Nevada, Las Vegas, NV. 187pp.

Deacon, J. E. and W. G. Bradley. 1972. Ecological distribution of fishes of Moapa (Muddy) River in Clark County, Nevada. Trans. Amer. Fish. Soc. 101:408-419.

Deacon, J. E., C. Hubbs, and B. J. Zahurancek. 1964. Some effects of introduced fishes on the native fish fauna of southern Nevada. Copeia 1964:384-388.

Everhart, W. H., A. W. Eipper, and W. A. Youngs. 1975. Principles of fishery science. Cornell University Press, Ithaca, NY. 288pp.

Fowler, H. W. 1925. Notes on North American cyprinoid fishes. Proc. Acad. Nat. Sci., Phila. 76:389-416.

Gilbert, C. H. and N. B. Scofield. 1898. Notes on a collection of fishes from the Colorado basin in Arizona. Proc. U. S. Nat. Mus. 20:487-499.

Girard, C. 1856. Researches upon the cyprinoid fishes inhabiting the freshwaters of the United States of America, west of the Mississippi Valley, from specimens in the museum of the Smithsonian Institution. Proc. Acad. Nat. Sci., Phila. 8:165-213.

Girard, C. 1859. Ichthyology of the boundary. United States and Mexican Boundary Survey 2:1-85, pls. 1-41.

Hendrickson, D. L. and W. L. Minckley. 1984. Cienegas - Vanishing climax communities of the American Southwest. Desert Plants 6:130-175.

Hubbs, C. L. 1955. Hybridization between fish species in nature. Syst. Zool. 4:1-20.

Huntington, E. H. 1955. Fisheries survey of the Gila and Mimbres rivers drainages. New Mexico Dept. Game and Fish, Santa Fe, NM. 56pp.

Hynes, H. B. N. 1970. The ecology of running waters. Univ. Toronto Press, Toronto, Ontario. 555pp.

James M. Montgomery. 1985. Wildlife and fishery studies, Upper Gila Water Supply Project. Part 2: Fisheries. Prepared for U. S. Bureau of Reclamation, Boulder City, NV. Final Draft Rept. 127pp.

Kirsch, P. H. 1888. Notes on a collection of fishes obtained in the Gila River, at Fort Thomas, Arizona, by Lt. W. L. Carpenter, U. S. Army. Proc. U. S. Nat. Mus. 11:555-558.

Koster, W. J. 1957. Guide to the fishes of New Mexico. Univ. New Mexico Press, Albuquerque, NM. 116pp.

LaBounty, J. F. and W. L. Minckley. 1972. Native fishes of the upper Gila River system, New Mexico. pp. 134-146. In. Symposium on rare and endangered wildlife of the southwestern United States. New Mexico Dept. Game and Fish, Santa Fe, NM.

Lagler, K. F. 1956. Freshwater fishery biology. 2nd ed. Wm. C. Brown Company Publishers, Dubuque, IA. 421pp.

Marsh, P. C. and W. L. Minckley. 1982. Fishes of the Phoenix metropolitan area in central Arizona. N. Amer. J. Fish. Mgmt. 2:395-402.

Matthews, W. J. and L. G. Hill. 1979. Habitat partitioning in the fish community of a southwestern river. Southwest. Natur. 25:51-66.

Meffe, G. K. 1985. Predation and species replacement in American southwestern fishes: A case study. Southwest. Natur. 30:173-187.

Miller, R. R. 1961. Man and the changing fish fauna of the American Southwest. Pap. Mich. Acad. Sci., Arts, Lett. 46:365-404.

Miller, R. R. 1963. Distribution, variation, and ecology of Lepidomeda vittata, a rare cyprinid fish endemic to eastern Arizona. Copeia 1963:1-5.

Miller, R. R. 1964. Extinct, rare, and endangered American freshwater fishes. Proc. XVI Internat. Cong. Zool. 8:4-16.

Miller, R. R. and C. L. Hubbs. 1960. The spiney-rayed cyprinid fishes (Plagopterini) of the Colorado River system. Misc. Publ. Mus. Zool. Univ. Mich. 115:1-43.

Miller, R. R. and H. E. Winn. 1951. Additions to the known fish fauna of Mexico: three species and one subspecies from Sonora. J. Wash. Acad. Sci. 41:83-84.

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

Minckley, W. L. 1980. Plagopterus argentissimus Cope, woundfin. p. 344. In D. S. Lee, et al. Atlas of North American freshwater fishes. N.C. St. Mus. Nat. Hist.

Minckley, W. L. and L. H. Carufel. 1967. The Little Colorado River spinedace, Lepidomeda vittata, in Arizona. Southwest. Natur. 12:291-302.

Minckley, W. L. and J. E. Deacon. 1968. Southwestern fishes and the enigma of "Endangered Species". Science 159:1424-1432.

Minckley, W. L. and G. K. Meffe. in press. Differential selection for native fishes by flooding in streams of the arid American Southwest. In. W. J. Matthews and D. C. Heins (eds.) Ecology and evolution of North American stream fish communities. Univ. Oklahoma Press, Norman, OK.

Mueller, G., and M. Delamore. 1981. U. S. Bureau of Reclamation memorandum, 6 October 1981.

Nielson, L. A. and D. L. Johnson (eds.). 1983. Fisheries techniques. American Fisheries Society, Bethesda, MD. 468pp.

Pister, E. P. 1974. Desert fishes and their habitats. Trans. Amer. Fish. Soc. 103:531-540.

Propst, D. L., P. C. Marsh, and W. L. Minckley. 1985. Arizona survey for spikedace (Meda fulgida) and loach minnow (Tiaroga cobitis): Fort Apache and San Carlos Indian Reservations and Eagle Creek, 1985. U. S. Fish and Wildlife Service, Office of Endangered Species, Albuquerque, NM. Rept. 8pp.

Rinne, W. E. 1971. The life history of Lepidomeda albivallis mollispinis (Virgin River spinedace), a unique western cyprinid. Unpubl. M.S. thesis, Univ. of Nevada, Las Vegas, NV.

Rinne, W. E. 1980. Lepidomeda albivallis Miller and Hubbs, Pahranagat spinedace. p. 202. In D. S. Lee et al. Atlas of North American Freshwater Fishes. N.C. St. Mus. Nat. Hist.

Schmitt, C. G. 1980. New Mexico Department of Game and Fish memorandum, 24 November 1980.

Schoenherr, A. A. 1981. The role of competition in the replacement of native fishes by introduced species. pp. 173-203. In. R. J. Naiman and D. L. Soltz (eds.). Fishes in North American deserts. John Wiley and Sons, New York, NY. 552pp.

Schreiber, D. C. and W. L. Minckley. 1981. Feeding interrelationships of native fishes in a Sonoran Desert stream. Great Basin Natur. 41:409-426.

Snyder, D. E. 1981. Contributions to a guide to the cypriniform fish larvae of the upper Colorado River system in Colorado. No. 3. U. S. Bureau of Land Management, Denver, CO, Biological Sciences Series, No. 3. 81pp.

U. S. Department of Interior. 1985. Endangered and threatened wildlife and plants; proposal to determine the spikedace to be a threatened species and to determine its critical habitat. Fed. Regist. 50:25390-25398.

U. S. Geological Survey. Published periodically. Water-supply records for New Mexico. U. S. Geol. Surv., Santa Fe, NM.

Uyeno, T. and R. R. Miller. 1963. Summary of Late Cenozoic freshwater fish records for North America. Occ. Pap. Univ. Mich. Mus. Zool. 631:1-34.

Ward, J.V. 1982. Ecological aspects of stream regulation: Responses of downstream lotic reaches. Wat. Poll. Mgmt. Rev. 2:1-26.

Ward, J. V. and J. A. Stanford (eds.). 1979. The ecology of regulated streams. Plenum Press, New York, NY. 398pp.

APPENDIX I

Museums at which spikedace, Meda fulgida, specimens are curated.

AMNH	American Museum of Natural History
ANSP	Academy of Natural Sciences, Philadelpia
ASU	Arizona State University
CORU	Cornell University
ENMU	Eastern New Mexico University
HSU	Humbolt State University
KU	Kansas University
NMSU	New Mexico State University
OSU	Oklahoma State University
TU	Tulane University
UBC	University of British Columbia
UMMZ	University of Michigan, Museum of Zoology
UNLV	University of Nevada, Las Vegas
UNM	University of New Mexico