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MAN AND THE CHANGING FISH FAUNA OF THE AMERICAN SOUTHWEST[1]

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THE past 100 years have witnessed drastic changes in the rivers of western North America and in their fish faunas. Deterioration of stream flow has greatly shrunk the ranges of many species, and other species have been denied access to large segments of their original distribution by the construction of barrier dams. Profound modification of pristine environments has restricted habitable waters, and the introduction and establishment of a host of exotics have brought about replacement as well as reduction of native forms through competition, predation, and hybridization. Some species and subspecies have become extinct, and many others are endangered (Matthiessen, 1959). These changes have been particularly marked in areas of restricted water supply such as characterize the arid Southwest (Fig. 1). Much of this region is embraced by the Basin and Range Province (Fenneman, 1931, pl. I), including the Great Basin, Sonoran Desert, and the Chihuahuan Desert of northern Mexico.

Only about 100 species of strictly fresh-water fishes are known west of the Rocky Mountains and north of Mexico—a depauperate fauna characterized by relicts, monotypic genera, and much regional

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The following museum abbreviations are used: CAS, California Academy of Sciences; MCZ, Museum of Comparative Zoology, Harvard College; SU, Stanford University Natural History Museum; UMMZ, University of Michigan Museum of Zoology; and USNM, United States National Museum.

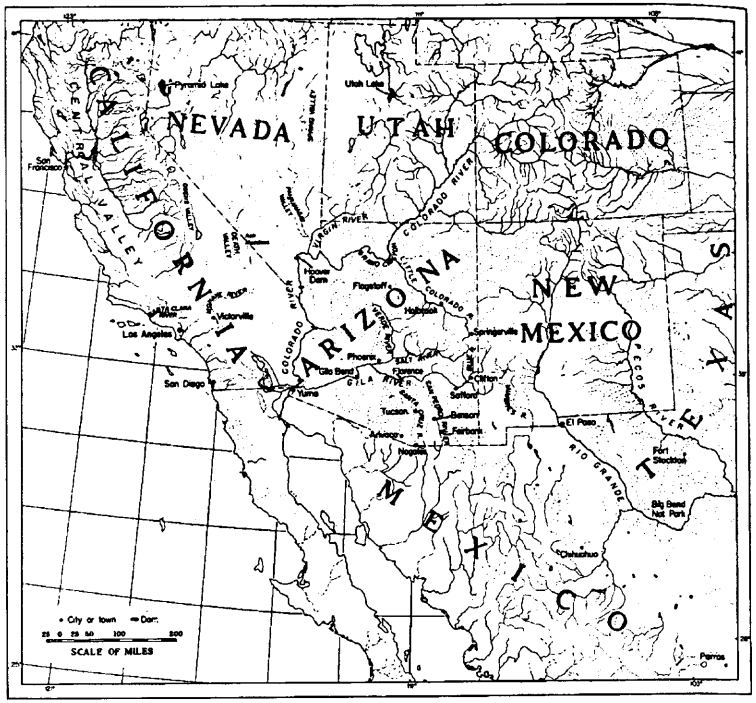

FIG. 1. Drainage map of Southwestern North America, showing localities mentioned in the text.

endemism (Miller, 1959). Many of the species have limited ranges, and some are even confined to habitats that contain only a few thousand gallons of water or cover scarcely an acre. Presumably as a result of greatly reduced competition and little pressure from predation, these isolated populations lack the defense mechanisms that are developed in more nearly saturated faunas, and hence they have been rather easy prey for the typically more aggressive exotic species.

It is the purpose of this contribution to describe some of the environmental modifications that have occurred in the Southwest, to document where possible the changing nature of the fish fauna, and to present evidence that modern man has been the chief architect of these changes.

HABITAT CHANGES

The aboriginal habitats have become modified in various ways. There has been a shift from clear, dependable streams to those of intermittent flow subject to flash floods that carry heavy loads of silt. As a result of loss in volume and destruction of vegetation, there has been a trend toward rising temperatures in the surviving waters. The smaller creeks, springs, marshes, and lagoons have disappeared, due in part to severe lowering of the water table. There has been destruction of trees, grasses, and aquatic plants; pollution from industrial and domestic wastes; deep channeling (arroyo cutting) of stream beds; and gully erosion on bare hillsides. Examples of these types of modifications are considered in this section.

COLORADO RIVER BASIN IN ARIZONA

Lower Colorado River.—The lower Colorado River, from the Lake Mead area to the Gulf of California, flows through a desert region of low plains and narrow valleys broken by short mountain groups. The source of nearly all of its water is in the high mountains of the upper basin. In its natural condition the river was swift, silt-laden, and subject to spectacular fluctuations in volume and turbidity, annually carrying thousands of tons of silt into the Gulf of California. Its maximum flow usually was attained in June, diminished greatly in August, and was very low from September to February. At Yuma, Arizona, a peak flow of 250,000 c.f.s. occurred in 1916 and a minimum daily flow of only 18 c.f.s. was recorded in the drought year of 1934 (Dill, 1944, p. 123). With the completion of Hoover Dam in 1935, control of the river began. The succession of dams lying between Lake Mead and Yuma has transformed the Colorado into a series of deep, placid reservoirs with connecting channels of clear water and regulated volume. The water temperature has been strikingly modified. Originally it varied from about 50° to 90° F. or more annually. Now, below Hoover Dam and Davis Dam the fluctuation is from 54° to 62° F., providing temperatures suitable for the development of an important trout fishery. Below Parker Dam, however, the water is clear but warm. Dredging of the river channel has further modified aquatic habitats by the elimination of marshes, lakes, and sloughs and by producing a straight sluice that is poor in food and cover and with waters of relatively high turbidity (Beland, 1953a). Introduction of a host of exotic species has had a striking effect on the original biota (Tab. I).

Gila River.—This river, rising in western New Mexico and following a westerly course of more than 500 miles to its junction with the Colorado River at Yuma (Fig. 1), has changed drastically since it was first seen by white men. In Arizona, it once was a large, essentially permanent stream of clear to "sea-green" water, with a well-defined, narrow channel flanked by numerous cottonwoods and set off by a dense growth of willows and cane that rendered it difficult of approach. Along its course were numerous lagoons and extensive marshes that abounded in waterfowl, beaver, and fish life (Parke, 1857, pl. IV opp. p. 19; Antisell, 1857, pp. 134–135). On November 17, 1846, Emory (1848, p. 91) wrote of the Gila (when he was perhaps 35 or 40 miles west of Gila Bend): "The bottoms of the river are wide, rich, and thickly overgrown with willow and a tall aromatic weed, and alive with flights of white brant, geese, and ducks, with many signs of deer and beaver." Prior to 1920, these same bottom lands had become "desolate wastes of sand and silt" (Ross, 1923, p. 66). Throughout most of its channel, the river is now largely intermittent, and in its lower 250 miles, from east of Florence to Yuma, it is normally completely dry; its trees and marshes and once abundant aquatic life have long since disappeared. The condition of surface waters in the Gila River basin, Arizona, in 1950 is shown on a map by Miller (1954).

In October 1849, the river was negotiated from the Pimas Villages (south of Phoenix) to its mouth by a flatboat 16 feet long and 5½ feet wide, carrying a family and 2 other men. During the winter of 1890, Stanley Sykes and a partner, on a dare, attempted to go by boat over this same route. By dragging their flat-bottomed craft over frequent sand bars and across numerous dry stretches (for even then the river had become intermittent in midwinter), they finally reached Yuma after a 30-day struggle—undoubtedly the last men to traverse the lower Gila by boat (Sykes, personal interview, 1950).

Although the pristine watershed of the Gila River did much to regulate the runoff, the Gila, even in its earlier days (1833–69), was not without occasional floods—probably resulting from rains of unusually long duration. The effect of these, however, was to spread out over wide areas rather than to become great detritus-carrying, eroding flood crests such as have occurred subsequent to settlement by the

white man (Olmstead, 1919, p. 9). As the river changed, it entrenched itself in its upper reaches and cut away much of the former flood plain, whereas in its lower course (below the mouth of the Santa Cruz River) the original well-marked channel soon became filled by flood deposits to form a broad, sandy plain (Bryan, 1925, pp. 342–343). In 1875, the well-defined channel of the Gila River near Solomonsville (in T. 7 S., R. 27 E.) had an average width of 138.6 feet and included an area of 103.57 acres, whereas by 1916 the same length of channel averaged more than 1,900 feet wide and occupied an area of 1,503 acres (Olmstead, 1919, p. 11).

San Pedro River.—This stream (Fig. 1) was originally the only permanent southern tributary of the Gila River. In 1870 its nearly level valley had a narrow, grassy bed with banks that were well clothed with vegetation. There was an abundance of willow, cottonwood, sycamore, and ash trees, with excellent growths of grasses (sacatón and grama). Beaver dams retarded the heavy summer rains and prevented channel cutting. Ciénegas, such as the one near the mouth of the then perennial Babocomari River (Dipeso, 1951, p. 3), were common. In the 1600's, more than 2,000 aborigines lived in 15 villages along the lush San Pedro Valley below Fairbank (Dipeso, 1951, p. 7). By 1892 or 1893, however, a gully 3 to 20 feet deep had been cut for 125 miles, and by 1900, the river had entrenched its bed from 10 to 40 feet; trees and underbrush had been destroyed or greatly reduced, the grasses were largely gone, and cattle and horses, moving from feed to water, had cut numerous erosion channels from the hills to the river (Bryan, 1925, p. 342; Thornthwaite et al, 1942, p. 103). In its original condition, the San Pedro was of sufficient size and volume to support a relatively large and varied fish fauna (Tab. II).

San Simon Valley.—This valley is in southeastern Arizona and the adjacent part of New Mexico, and extends north-northwestward for 85 miles from the head of San Bernardino Valley (20 miles north of the International Line) to the Gila River at Solomon (formerly Solomonsville), just east of Safford. The often heavy summer storms were restrained in the valley by the extensive flats of sacatón, and the water sank into the unbroken meadow to furnish an artesian supply near the central part of the valley. According to Olmstead (1919, p. 79) about 1883, "certain settlers near Solomonsville whose lands were along this drainage line were annoyed at finding occasionally after heavy rains that sand and detritus had been washed down on them from the San Simon. They accordingly excavated a small channel, about 4 feet deep and 20 feet wide, for a short distance so that the floods could be discharged in concentrated flow into the Gila. They also built funneling levees so that there would be no question of the water reaching this artificial trough. It worked, and today there is a chasm, in many places 600 to 800 feet wide and from 10 feet to 30 feet deep, for 60 miles, as the indirect result of their effective work to protect their lands from overflow." Efforts by the Soil Conservation Service finally checked the headward erosion of San Simon Creek just short of its drainage of the ciénega that lies along the Arizona-New Mexico line. The erosion has produced deep and wide gullies, permanently changing the surface over most of the length of the valley.

Blue River.—This stream is a mountain tributary of the San Francisco River, which joins the Gila River below Clifton in eastern Arizona (Fig. 1). In 1885 or 1886, the floor of the canyon of Blue River was well sodded and covered with grama grass, hardwoods, and pine. The stream supported many native trout, *Salmo gilae* (Miller, 1950). The valley had an average width of 700 feet, was well settled, and was nearly all under cultivation. In 1900, floods began to incise and widen the channel and a regime of active erosion was well under way by 1906. By 1916, the valley bottom had been converted into a wide wash and was ruined for agriculture as well as for pasturage; less than 8 per cent of the original arable area then remained (Olmstead, 1919, p. 68; Bryan, 1925, p. 342).

Little Colorado River.—This river rises on the northern slopes of the White Mountains of eastern Arizona and flows north and westward to its junction with the Colorado River at the head of Grand Canyon (Fig. 1). In the middle of the sixteenth century, the Little Colorado was described as a "... fine, beautiful, and selected river almost as large as the Del Norte, containing many groves of poplars and willows." It was named the Río Alameda, meaning the river of groves, in reference to the great groves of cottonwoods that lined much of its course (Colton, 1937). In 1851 there were extensive swamps above Winslow (Sitgreaves, 1853, pp. 7–8), and at about the same time Whipple (1856, pp. 30–31) wrote as follows: "The river is about 30 feet wide flowing between alluvial banks eight to ten feet in height.... The banks of the main stream ... are sprinkled with cotton-wood trees ... the river-bottom is in some places marshy, with willow thickets, and in others covered with a loose, pulverized soil." In the 1880's the river, shortly above Grand Falls (about 35 miles northeast of Flagstaff), was a narrow perennial stream, and its banks were bordered by a fine stand of old and young cottonwoods. Many beavers were supported by an ample food supply in the young cottonwood trees. Grama grass covered the adjacent hills. Today, the Little Colorado is normally dry between Grand Falls and Winslow, the trees have long since disappeared, and the fine grass has vanished. When the river does flow between Holbrook and Winslow, it is through a wide, treeless valley, where its bed is broad and sandy, its banks deeply entrenched, and vegetation is scarce. Since around the turn of the century, disastrous floods have converted its sandy bed into a raging, eroding torrent, heavily laden with silt.

OTHER AREAS

Southern California.—The major coastal valley is a complex lowland that lies at the southern base of the San Gabriel and San Bernardino ranges, opens directly westward to the Pacific, and communicates with the Mohave and Colorado deserts via Cajon and San Gorgonio passes. Its total area is about 3,000 square miles. Three major streams traverse this valley, herein called the Los Angeles Plain: the Santa Ana, the San Gabriel, and the Los Angeles. Of these, the Santa Ana River is the largest. It rises high in the San Bernardino Mountains and flows to the Pacific through 2 canyons on the plains, an upper (about 50 miles west of its source) and a lower (through the Santa Ana Mountains); its total length is about 100 miles. The utilization of this river by man is indicated by the following statement: "Probably no other stream of its size in the United States is made to serve greater or more varied uses" (McGlashan, 1930, p. 176). West of the Santa Ana is the San Gabriel River, with a total length of about 70 miles; its headwaters rise on the western flank of Mount San Antonio (Old Baldy) and from the southern slopes of other high peaks. The Los Angeles River originates to the northwest of the city in several small tributaries which normally sink into the sands of San Fernando Valley. Impervious rocks at the lower end of this valley force the underground water to the surface, and the river originally flowed from this point through a valley of low, rolling hills to the

Pacific near Long Beach, although the last 10 miles of its channel were normally dry. The river is joined in Los Angeles by Arroyo Seco, rising on the mountain slopes north of Pasadena.

Utilization of the waters of these rivers for irrigation began as early as 1821 but extensive use for that purpose did not commence until the 1880's. Before the advent of man, the waters of the mountain streams feeding these rivers promptly sank into the alluvial plains, except during periods of unusually great and prolonged rainfall. Below their headwater region, however, the rivers reappeared as perennial surface flows wherever there was an impervious barrier like the bedrock obstructions in the Santa Ana River near Riverside and in Santa Ana Canyon. Between about 1875 and 1905, however, practically all of the normal flow of these streams was appropriated for irrigation purposes. Extensive moist lands about San Bernardino, numerous springs, and large ciénegas also disappeared as the water supply was drained away by pumping plants and artesian wells. At a time preceding the settlement of San Jose Valley (near Pomona), San Jose Creek was a summer stream fed by waters rising as springs in the old Palomares Ciénega; after settlement the ciénega disappeared and the valley was deprived of its normal water source (Mendenhall, 1908, p. 55). In aboriginal times probably 50 to 75 per cent of the stream courses within the basins of the 3 major rivers afforded permanent habitats for aquatic organisms; very probably the lower parts of all 3 rivers were normally dry or intermittent most of the year. At present, the perennial surface flow of these streams has been reduced to a fraction of what it was in 1850.

Upper Río Grande.—In the early 1900's the Río Grande had a rather small but permanent flow in its upper part, southward about to the vicinity of Albuquerque; but from there to the Texas border it often went dry in years of below normal rainfall or toward the close of the dry season. The river was described as "essentially a storm-water stream, subject to great and sudden floods" (Lee, 1907, p. 7). Río Puerco, an important tributary from the west, already had developed local gullies during the period from 1846 to 1877, with trenches up to 30 feet deep and 100 feet wide (Antevs, 1952, p. 379). That the upper Río Grande was once a larger river of more reliable flow is indicated by the record of a sturgeon taken near Albuquerque in the 1870's and the identification of remains of the blue sucker (*Cycleptus elongatus*) from an Indian site west of Santa Fe which

dates from about 1500 (Cope and Yarrow, 1875, p. 639; Gehlbach and Miller, 1961; see also Henderson and Robbins, 1913).

Fish Faunal Changes

Fish faunas have undergone considerable alteration in the American Southwest but documentary evidence of these changes has not heretofore been available. Depletion has been widespread, many species are threatened with extermination, and others have already become extinct. The introduction of a large number of alien species into a generally depauperate fauna has resulted in species replacement in many waters, especially in the larger impoundments.

DOCUMENTARY EVIDENCE FOR COLORADO RIVER SYSTEM

The most impressive documentation for a changing fish fauna pertains to southern Arizona, where repeated collections spanning a century provide a progressive record of the change (Tab. I–III). This record dramatically demonstrates the sharp decline in native fishes. In many places, notably the lower Colorado River, introduced kinds are now flourishing. The data are taken from the observations and records of the explorations during the middle of the nineteenth century (principally from the Pacific Railroad Survey reports), the accounts by Gilbert and Scofield (1898) and Snyder (1915), the unpublished data (1904) of F. M. Chamberlain,[2] the records and specimens (accumulated since 1926) in the Museum of Zoology, University of Michigan, and the data presented by Dill (1944). In addition to the progressive change shown for single stations, there is also the picture obtained from the testimony of old-timers as to the former occurrence, distribution, and abundance of fishes now nearing extinction. Testimony of this nature was particularly sought by me during a 2½-month survey of Arizona in the spring of 1950.

COLORADO AND GILA RIVERS, YUMA (TABLE I)

The primitive fish fauna of the Colorado River near Yuma evidently comprised very few species. The huge Colorado squawfish, *Ptychocheilus lucius* Girard, the bonytail, *Gila robusta elegans* Baird and Girard, and the humpback sucker, *Xyrauchen texanus* (Abbott), are the only fishes mentioned in the early surveys, and they are the

[2] Deposited in the Division of Fishes, U. S. National Museum, Washington, D. C.

TABLE I

A Century of the Fish Fauna in the Colorado and Gila Rivers Near Yuma, Arizona

Parentheses around a cross indicate that the species, although not reported or taken, was probably present. R = rare. Collections from Gila River were made at its mouth and 8 to 10 miles above (at or near Dome).

Species	1854	1890–95	1904	1926	1940–42	1950–55
Native species:						
Elops affinis	—	—	—	—	×	×
*Gila robusta elegans**	×	×	×	×	R	—
Ptychocheilus lucius	×	×	×	×	R	—
Plagopterus argentissimus	(×)	×	—	—	—	—
Catostomus latipinnis	(×)	—	—	—	—	—
Xyrauchen texanus	×	×	×	×	R	—
Cyprinodon macularius	(×)	×	(×)	×	—	—
Poeciliopsis occidentalis	(×)	×	(×)	×	—	—
Mugil cephalus	—	—	—	—	×	×
Introduced species:						
Dorosoma petenense	—	—	—	—	—	×
Cyprinus carpio	—	×	×	×	×	×
Notropis lutrensis	—	—	—	—	—	×
Ictalurus punctatus	—	—	—	—	×	×
I. melas	—	—	×	×	×	×
I. natalis	—	—	—	—	×	×
Gambusia a. affinis	—	—	—	×	×	×
Micropterus salmoides	—	—	—	—	×	×
Lepomis cyanellus	—	—	—	×	×	×
L. macrochirus	—	—	—	—	×	×
Pomoxis spp. (2)	—	—	—	—	×	×
Total species:						
Native	7	6	5	5	5	2
Exotic	0	1	2	4	10	12

* *Gila r. robusta* was taken at Dome (Gila River) during 1892–94.

only ones that have been collected from the river at Yuma. However, the flannelmouth sucker, *Catostomus latipinnis* Baird and Girard, must have once inhabited the main river since it occurs in both the Gila River drainage and in the middle and upper parts of the Colorado River basin; hence I have added it to the list. The fate of the squawfish is discussed later (p. 392).

Between 1890 and 1895 the woundfin, *Plagopterus argentissimus* Cope (Miller and Hubbs, 1960), was present in the Gila River at its mouth (Gilbert and Scofield, 1898, p. 496). Other species listed in Table I that were taken only in the lower Gila include the desert pupfish, *Cyprinodon macularius* Baird and Girard, and the Gila topminnow, *Poeciliopsis occidentalis* (Baird and Girard). That the habitat in the lower Gila River was very favorable for these quiet-water species is indicated in the report by Antisell (1857, p. 133), which describes how the river spread broadly and was in places swampy and overgrown with willows. The appearance of the euryhaline striped mullet, *Mugil cephalus* Linnaeus, around 1934–35, and of the machete or ten-pounder, *Elops affinis* Regan, in 1941 (Glidden, 1941), is plausibly attributed to the disappearance of the predatory Colorado squawfish and likely also to other ecological changes, such as the advent of clear water and a relatively stable flow. A number of the exotic species represent intentional introductions or bait releases (Miller, 1952; Hubbs, 1954; Kimsey, Hagy, and McCammon, 1957; Shapovalov, Dill, and Cordone, 1959, p. 166), and still other introduced forms may now occur in the Colorado around Yuma (Beland, 1953b; St. Amant, 1959). The recent record (Hubbs, 1953) of *Eleotris picta* Kner and Steindachner from a canal spillway north of Yuma is not included in the tabulation since this specimen obviously represents a rare straggler; the species has not been taken from the Colorado River, and there have been no subsequent records from the lower Colorado River basin.

San Pedro River (Table II)

In 1846 the Colorado squawfish was reported to have run up the San Pedro River to about Fairbank (Fig. 1), and remains of this species have been recovered from an archaeological site along this river at nearby Quiburi (Miller, 1955, pp. 133–134); the trash heap containing the fishbones was dated as A.D. 1704–63. Humpback suckers also once inhabited the San Pedro for they were reported by Chamberlain to have been marketed at Tombstone as "buffalo," probably prior to the 1880's (Miller, 1955, p. 134). The desert pupfish, described from the San Pedro River near Benson, evidently inhabited the then marshy canyon just below (Leopold, 1951, p. 310), but has not since been collected from the Arizona part of that river. The species was taken, however, 100 years after its original capture, in

TABLE II

CHANGING FISH FAUNA OF SAN PEDRO RIVER, BETWEEN BENSON AND FAIRBANK, ARIZONA, 1846–1950*

R = rare.

Species	1846–1854	1904	1939	1950
Native species:				
Gila robusta	×	×	—	—
Ptychocheilus lucius	×	—	—	—
Rhinichthys osculus	×	R	—	—
Agosia chrysogaster	×	×	×	×
Tiaroga cobitis	×	×	×	×
Meda fulgida	×	×	×	×
Catostomus insignis	×	×	×	—
C. latipinnis	×	—	—	—
Pantosteus clarki	×	×	×	—
Xyrauchen texanus	×	—	—	—
Cyprinodon macularius	×	—	—	—
Introduced species:				
Ictalurus melas	—	—	×	—
Lepomis cyanellus	—	—	×	—
Total species:				
Native	11	7	5	3
Exotic	0	0	2	0

* In 1959 (June) the river was dry, or damp only, in this section but it was flowing farther upstream at Charleston (about 10 miles above Fairbank); here the river contained all the native fishes listed for 1939.

the Mexican part of the San Pedro in the spring of 1950 (UMMZ 162680).

It is noteworthy that the species of Arizona that persists longest in the dwindling waters of sandy streams, the longfin dace (*Agosia chrysogaster* Girard), still survives in the many shallow, intermittent Arizona streams, and was by far the commonest fish in the upper San Pedro River in June 1959. The fishes that have disappeared from the lower part of the stream are those that either require pools (*Gila, Catostomus, Pantosteus)*, long since filled with sand, or a sizable, permanent river with strong current (*Ptychocheilus, Xyrauchen*); the desert pupfish presumably utilized marshy areas that must have been drained rapidly with the onset of arroyo cutting in 1883 (Bryan, 1925, p. 342). The speckled dace, *Rhinichthys osculus* (Girard), was perhaps eliminated chiefly by rising water temperatures as the river became deeply entrenched, the vegetation was destroyed, and the water supply shrank. The flow diminished so markedly between 1939 and 1950 that even the two exotic species, the black bullhead (*Ictalurus melas* Rafinesque) and the green sunfish (*Lepomis cyanellus* Rafinesque), had disappeared here, presumably because of insufficient cover. On June 22, 1959, the river was dry at Benson, and only damp at St. David and Fairbank.

SALT RIVER (TABLE III)

The shift from 11 native species to 5 exotic species in the Salt River south of Phoenix, during approximately a half century, reflects changing water conditions upstream (dam construction, irrigation) and the establishment of exotics. Before the turn of the century the river was of sufficient size and flow to support such big-river or current-loving fishes as the roundtail (*Gila r. robusta* Baird and Girard), bonytail (*G. r. elegans*), woundfin (*Plagopterus*), flannelmouth sucker (*Catostomus latipinnis)*, and humpback sucker (*Xyrauchen*); overflow, marshlike areas presumably provided habitats for the pupfish and topminnow (*Cyprinodon* and *Poeciliopsis*). As the river dwindled in volume and depth to a comparatively shallow stream dominated by shifting sand, longfin dace (*Agosia*) appeared and attained numerical superiority, and *Gila robusta intermedia* Girard, a headwater and small-creek ecotype, appeared in place of the bonytail. With the desiccation of the river at this point by 1943, only predatory introduced species remained.

Farther upstream in Salt River, at and near the present site of Roosevelt Dam, there were, in 1904, only 1 exotic species (the carp), and 10 native species including Colorado squawfish, spikedace (*Meda fulgida* Girard), flannelmouth and humpback suckers, and the Gila topminnow. By 1937, *Meda* had disappeared, the last adult squawfish was captured, the humpback sucker had vanished, and *Poeciliopsis* had been eliminated. The bigmouth buffalo (*Ictiobus cyprinellus*), yellow bullheads, bluegills, yellow perch, and yellow bass had become established—a total of 7 native and 6 exotic species. In 1950, the reservoir contained only 8 introduced fishes, although near its head Salt River still supported 6 native species, including roundtails,

TABLE III

MODIFICATION OF THE FISH FAUNA IN THE SALT RIVER NEAR TEMPE, ARIZONA, 1890–1944

Parentheses indicate probable occurrence.

Species	April–May 1890	Sept. 11 1926	1943–44*
Native species:			
Agosia chrysogaster	—	×	—
Gila robusta robusta	×	×	—
G. robusta intermedia	—	×	—
G. robusta elegans	×	—	—
Rhinichthys osculus	×	—	—
Meda fulgida	×	—	—
Plagopterus argentissimus	×	—	—
Catostomus insignis	×	—	—
C. latipinnis	×	—	—
Pantosteus clarki	×	—	—
Xyrauchen texanus	×	—	—
Cyprinodon macularius	(×)	×	—
Poeciliopsis occidentalis	×	×	—
Introduced species:			
Cyprinus carpio	—	—	×
Ictalurus melas	—	—	×
Gambusia a. affinis	—	×	×
Lepomis macrochirus	—	—	×
L. cyanellus	—	×	—
Pomoxis nigromaculatus	—	—	×
Total species:			
Native	11	5	0
Exotic	0	2	5

* These collections were made on December 1 and March 23, respectively, from a series of gravel pits in the river bed, which was otherwise dry.

speckled dace, *Castomus insignis, C. latipinnis,* and *Pantosteus clarki* (Baird and Girard).

SANTA CRUZ RIVER BASIN

In Sonoita Creek, the only important eastern tributary of the Santz Cruz River between Tucson and Nogales, Arizona, Chamberlain collected, in April 1904, near Patagonia, *Agosia, Catostomus insignis, Pantosteus,* and *Poeciliopsis.* Joseph Mailliard obtained 2 specimens of *Cyprinodon macularius* there on September 20, 1927 (CAS 18561). In July 1928, C. E. Burt sampled the fishes at the same place and obtained all but *C. insignis* and *C. macularius* plus an additional species, the speckled dace. In September 1938, Carl L. Hubbs secured the same species taken by Burt. In April 1959, our party found the stream almost fishless, and took only *Agosia.* The creek exhibited obvious signs of severe erosion, and the area between Patagonia and Nogales showed clearly the effects of serious overgrazing, with impoverished and badly eroding soil. Many of the great cottonwoods along Sonoita Creek, and in the Santa Cruz River valley, above and below the mouth of that creek, had died—probably as a result of the drastic lowering of the water table that has been accelerated since 1950 by the swelling population in southern Arizona. The original stands of tall grass had long since been replaced by mesquite, cholla, prickly pear, and burroweed.

For many years the Santa Cruz River, intermittent from near Nogales almost to Tucson, rose to the surface shortly above San Xavier Mission, about 8 miles south of Tucson. Here, on March 29, 1904, Chamberlain obtained 5 species: *Agosia chrysogaster, Gila robusta intermedia, Catostomus insignis, Pantosteus clarki,* and *Poeciliopsis occidentalis.* By April 25, 1937, when Allan R. Phillips sampled this perennial flow, only the resistant *Agosia* remained, and this is the only species that I found there on July 12, 1939. By April 13, 1950, the flow had disappeared, and I was informed by Raymond Hock (then of the University of Arizona) that it went dry for the first time during the previous winter. Even in early historic time, the Santa Cruz ordinarily had no surface flow from some distance below Tucson to its confluence with Gila River. It formerly maintained a permanent flow in the headwaters, near Lochiel (Schwalen, 1942, pl. II), but pumping in the San Rafael Valley eliminated this surface water and its fishes (*Gila, Agosia, Poeciliopsis*) between 1950 and 1956 (C. H. Lowe, Jr., personal communication).

EXTINCT AND ENDANGERED SPECIES

Since the close of the nineteenth century, no fewer than 6 species, and probably 7, have become extinct in the American Southwest. At least 13 additional forms have either been locally exterminated or are threatened with depletion to levels from which they might not be able to recover. In the following discussion, extinct species are treated first; some of the endangered forms are covered elsewhere in this report.

Stypodon signifer Garman, stumptooth minnow.—This unique genus and species was described from 2 specimens collected in 1880 in a spring on the Chihuahuan Desert near Parras, Coahuila, Mexico (Fig. 1). It is characterized by having distinctively shaped pharyngeal arches with the teeth molariform to bluntly pointed and reduced to only 3 on each arch. Aside from the types, I am aware of only one collection (USNM 50971, 4 poorly preserved specimens) taken by George Hochderfer in 1903, presumably from the type locality. In May 1953, Carl L. and Laura C. Hubbs made a determined effort to obtain the species but were unsuccessful. All testimony they obtained indicated that there no longer are any natural springs in the immediate vicinity of Parras or anywhere in the Parras basin or in the great desert basin to the north. The flow of the springs has been increased or maintained by tunneling into the lava hill from which they issue, but the flow is concentrated into a reservoir, from which it is diverted through ditches into a cotton mill and onto fields. The reservoir contains carp. The reduced flow in the stream bed is affected by industrial and domestic sewage. These modifications of the habitat have probably been responsible for the elimination of this species, as well as *Dionda episcopa punctifer* and *Cyprinodon latifasciatus* (see below).

Dionda episcopa punctifer (Garman), Parras roundnose minnow. —This fish was described, as *Hybognathus* (*Dionda*) *punctifer*, from material collected at Parras and in a spring near Saltillo, Coahuila, Mexico; the latter lies in the basin of the Río San Juan, a tributary of the lower Río Grande. As determined by Carl L. and Laura C. Hubbs, the Parras population is extinct. It may have represented a local form belonging to the *D. episcopa* complex. A plausible explanation for the disappearance of this fish from Parras is given above.

Lepidomeda altivelis Miller and Hubbs, Pahranagat spinedace.—This recently described species inhabited the outflow of Ash Spring and the chain of lakes in Pahranagat Valley, Nevada, into which these waters flow. The species was first collected in 1891 and became extinct between 1938 and 1959. Modification of its habitat and competition with introduced species are believed to have been responsible for its extermination (Miller and Hubbs, 1960, pp. 27–28).

Lepidomeda mollispinis pratensis Miller and Hubbs, Big Spring spinedace.—This subspecies was endemic to a single spring-fed marsh near Panaca, Lincoln County, Nevada, in the basin of Meadow Valley Wash, a flood tributary to the Virgin River (Hubbs and Miller, 1948, pp. 98–100, map 1, no. 65). Recent agricultural modifications of the area and the introduction of exotics, especially *Gambusia a. affinis*, are held to be important factors that led to the extermination of this localized population, sometime between 1938 and 1959 (Miller and Hubbs, 1960, pp. 21–23).

Pantosteus species.—This sucker has been collected only once, in 1938, at the northern end of Spring Valley, eastern Nevada (Fig. 1). In an effort to obtain further specimens, Carl L. Hubbs and I revisited Spring Valley in 1959 and thoroughly worked the same stream where the species was collected 21 years earlier. No specimens were secured. Other waters in the valley bottom were either fishless or contained only a small minnow; mountain streams have only planted trout. Deterioration of stream flow is a plausible explanation for the extinction of this endemic sucker.

Cyprinodon radiosus Miller, Owens Valley pupfish.—This species, restricted to the northern part of Owens Valley, California, was formerly abundant in ditches, sloughs, swamps, and bog pastures that featured this part of the valley in the early 1900's. The population was then sufficiently large to serve as an effective means of mosquito control. As its habitat suffered through tapping of the water supply and drainage of the swamps, the species began to decline; introduction of exotics, particularly largemouth bass, presumably hastened its disappearance (Miller, 1948, pp. 94–95). The species has not been taken since 1939 and in all probability is now extinct.

Cyprinodon bovinus Baird and Girard, Leon Springs pupfish.—This species is known only from Leon Springs (Clark Hubbs, 1957, p. 101), about 8 miles west of Fort Stockton (Fig. 1), Pecos County, Texas. It was described from 16 specimens taken in 1851 and, to my knowledge, has not been collected since then. In 1938, Carl L. Hubbs attempted to secure material and in 1950 Howard E. Winn and I worked the spring sources and their outlets exhaustively but to no avail. Local testimony in 1950 asserted that the spring heads had been treated with rotenone ("about 4 or 5 years ago") for the purpose of eliminating the hordes of carp. The Leon Springs pupfish probably disappeared through the combined attack of habitat restriction, modification of the source springs it lived in, and the introduction of such exotics as *Gambusia a. affinis, Micropterus salmoides*, and the still persistent carp.

Cyprinodon latifasciatus Garman, Parras pupfish.—This distinctive species, like *Stypodon signifer*, once inhabited a spring or springs near Parras, Coahuila, Mexico. It occurred there in 1880 and at least until 1903, when George Hochderfer obtained 9 specimens (USNM 50970). It has not been taken since and is very likely extinct. The probable causes of its extermination are given above under the account of *Stypodon signifer*.

Gambusia gaigei Hubbs, Big Bend gambusia.—This species was first discovered at Boquillas Spring, near the Río Grande, Texas, in 1928, but became extinct there by 1954. It was more recently collected at Graham Ranch Warm Springs. There, in 1954, nearly 95 per cent of the population of *Gambusia* was *G. gaigei*, the remainder *G. affinis*; in 1956, however, the proportions were reversed, so that the known population of *G. gaigei* sank to a very low level. The more widespread and aggressive mosquitofish, *G. affinis*, had probably been introduced (Clark Hubbs and Springer, 1957, p. 305). The imminent danger of extinction of the Big Bend gambusia was subsequently relieved by action of the National Park Service, which eliminated the introduced species and stocked the native one in other springs. However, on April 16, 1960, Clark Hubbs (*in litt.*) found the surviving population of *G. gaigei* to be very small since Río Grande species, including *G. affinis*, had penetrated the waters reserved for the native species, which is unable to compete successfully with them. In a last-ditch attempt to save the Big Bend gambusia, Dr. Hubbs carried back to Austin more than half of the population. It was estimated by him that fewer than 24 individuals of the species existed and that the wild population would become extinct by midsummer, 1960. It is hoped that several hundred individuals may be reared from the brood stock returned to Austin and that Big Bend National Park may successfully be restocked. The species was prematurely reported to be extinct by Matthiessen (1959, p. 271).

Gila crassicauda (Baird and Girard), thicktail chub.—This species, which reached a length of about 1 foot, formerly was common in lowland waters of the Central Valley of California (including Clear Lake and Coyote Creek, a southern tributary to San Francisco Bay[3]); it evidently preferred the sluggish parts of streams, sloughlike channels, and marshy or lacustrine conditions. From the 1850's to about 1880, it was sufficiently abundant to be marketed at San Francisco (Rutter, 1908, pp. 112, 117). In October, 1872, the Hassler Expedition obtained 43 specimens (MCZ 18372, 18743–746) from the Sacramento River, and Gustav Eisen collected 5 from Fresno in 1881 (USNM 30226, 107752). Midden material from an Indian mound near Oakley, Contra Costa County (close to the junction of the Sacramento and San Joaquin rivers), collected by Sherburne F. Cook, includes pharyngeal bones and teeth of the thicktail chub (W. I. Follett, letter of April 7, 1960).

[3] The supposed occurrence of the species in Salinas River, tributary to Monterey Bay, is questionable (Clark Hubbs, 1947, p. 148).

Reduction of its habitat through drainage, dam building, and diversion of water for irrigation, coupled with competition from numerous exotic species, are believed to have been important factors in its impending demise. On August 29, 1926, Carl L. Hubbs and Leonard P. Schultz collected 3 hybrids between *Gila crassicauda* and *Lavinia exilicauda* (UMMZ 94166) in Putah Creek, 4 miles west of Davis, California. A hybrid between these 2 species occurred in 1872 among specimens collected by the Hassler Expedition (MCZ 35692). The thicktail chub was seldom taken after the early 1900's and, to my knowledge, only 5 specimens have been obtained since 1936: 3 from Putah Creek, 3 air miles southeast of Davis (Sacramento State Coll. Mus. No. 112) on June 26, 1936; 1 from Clear Lake, caught on May 18, 1938 (SU 37361); and another from the vicinity of Río Vista on the Sacramento River, taken on August 7, 1950 (CAS 20456). By the late 1940's the species no longer survived in Clear Lake (Murphy, 1951). This chub now is obviously on the brink of extinction, but perhaps is surviving locally. W. I. Follett made several trips since 1950 to the Río Vista region but failed to capture the species.

Gila nigrescens (Girard), Chihuahua chub.—This species, collected in 1851 from the Mimbres River north of Deming, New Mexico, is restricted to streams of interior drainage that flow into several isolated basins of northern Chihuahua, Mexico (Miller and Uyeno, MS). Its extermination from the United States has been noted by Koster (1957, p. 57), who thought its disappearance was probably due to the introduction of the longfin dace, *Agosia chrysogaster*, from the Gila River basin. However, the chub was gone when Carl L. Hubbs collected in the Mimbres on June 30, 1938, prior to the establishment of the dace. I think its disappearance is likely due to the elimination of deep holes in the Mimbres River; a local informant told Dr. Hubbs that in the 1880's such holes (frequented elsewhere by this species) were numerous, that the stream had a more reliable and constant flow, and that he caught many 6-inch "Gila trout," the local name of this species. The terminus of the Mimbres was described in the 1850's as comprising pools or lagoons, surrounded by willow thickets, and 4 to 6 miles above it was up to 2½ feet deep and flowing at (during summer) 2½ miles per hour (Antisell, 1857, p. 176).

Gila[4] *mohavensis* (Snyder), Mohave chub.—This fish is endangered because its numbers, over almost all of its natural range in the Mohave River, California (Fig. 1), have been severely reduced by hybridization and competition with an introduced minnow, *G. orcutti* (Hubbs and Miller, 1943, 1948, p. 41). The species forms a pure and large population at only one locality in the basin, a spring-fed artificial pond, the site of a health resort, on the western side of Soda (Dry) Lake; it was abundant there on July 1, 1959. An attempt to establish this fish in other suitable but fishless waters was made in 1939 and 1940, and although the introduction was initially a success in Sentenac Canyon (San Diego County, California) the population died out there between 1957 and 1959. How long it will continue to persist in the Mohave River basin is problematical.

Lepidomeda vittata Cope, Little Colorado spinedace.—This species, endemic to the upper part of the Little Colorado River, Arizona, has been collected only 3 times since 1873—once in 1938 and twice in 1939. It belongs to a unique, small group of New World minnows, confined to the Colorado River system, that are peculiar in having spinose dorsal and pelvic rays (Miller and Hubbs, 1960). Whether the species still persists, in the face of competition with introduced species and modification of its environment, is questionable (reservoirs have been built and fish toxin used in the main river since 1939; see Hemphill, 1954). Since this statement was written, extensive efforts to collect this fish during August 1960 resulted in the capture of but a single specimen in Clear Creek, a tributary of the Little Colorado River.

Catostomus microps Rutter, Modoc sucker.—This species was described from Rush Creek, a small tributary of Ash Creek, near Adin, Modoc County, California, in the upper basin of Pit River, a part of the Sacramento River system. Three specimens were collected there on September 1, 1898 (Rutter, 1908, pp. 120–121, fig. 1). So far as I am aware, this sucker was not taken again until August 16, 1934, when Carl L. Hubbs secured 27 specimens (UMMZ 130643) from Rush Creek about 6 miles above Adin; no additional collections have come to my attention. In response to my request for information on the status of this species, J. B. Kimsey (letter of May 4, 1960) wrote that the California Department of Fish and Game failed to take any suckers in the 3.7 mile section of lower Rush Creek that was used as a test stream from 1947 to 1951. This, however, is not the part of the stream from which the Modoc sucker has been collected. An effort should be made to determine whether this extremely localized fish still survives and, if so, to provide the means for its protection.

[4] The reference of this species to *Gila* rather than to *Siphateles* results from unpublished studies of the comparative osteology of the genus *Gila* and its relatives by Teruya Uyeno (Ph.D. thesis, 1960, Univ. of Mich.). He regards *Siphateles* as a synonym of *Gila*, a viewpoint with which I agree.

Chasmistes liorus Jordan, June sucker.—The status of this species, known only from Utah Lake, Utah, is not clear. Tanner (1936, p. 166) tentatively synonymized it with *Catostomus fecundus* Cope and Yarrow, but these 2 suckers, as well as *C. ardens* Jordan and Gilbert, are best regarded as valid, pending critical study of the types and all available material. The species was formerly common, as was the trout of Utah Lake. The severe drought of the mid-1930's, coupled with domestic use of the waters of Provo River (the principal source of Utah Lake), so severely reduced the sucker population of the lake that in 1935 commercial fishing was abandoned, and, according to Tanner (1936, p. 167), there was no spring spawning migration up Provo River for the first time in history. However, a few fish of this type, or possibly hybrids, were collected in this stream by Carl L. Hubbs in 1942, and an adult was captured in Utah Lake by B. Arnold (Utah Dept. of Fish and Game) on March 21, 1959. If not yet extinct, this species is certainly seriously threatened.

Chasmistes cujus Cope, cui-ui.—This species formerly spawned in the lower Truckee River, Nevada, and was abundant in deep water in the two lakes—Pyramid and Winnemucca—at the terminus of the river. During the spectacular spawning run, this large sucker provided a major source of food for the Indians and was of great importance in their tribal economy. Snyder (1917, p. 53) wrote: "The flesh of this species is highly prized by the Indians. In former times the coming of the 'cui-ui' was a great event, not only for the Pyramid Lake tribe but also for other Piutes from far to the south, who sometimes reached the fishing grounds in such a starved condition that many were unable to survive the first feast. At present numerous little camps may be seen along the river during the spawning period. The fishes are caught in large numbers and tons of them are dried for later use. They are taken most easily when the river is roily, the fishermen hooking them with an improvised gaff which is drawn quickly through the muddy water. Knowing the 'cui-ui' habit of resting in schools in quiet water, the Indian establishes his camp accordingly, and the willows, wire fence, or hastily constructed rack are soon covered with unsalted drying fish, which attract numbers of flies and send characteristic odors a long distance down the wind."

With the development of dams, irrigation, and reclamation projects during the past half century, the lowered water level of the Truckee River and the complete desiccation of Winnemucca Lake have restricted the cui-ui to Pyramid Lake where, fortunately, the species has been able to spawn successfully along the shoreline. Unlike the native cutthroat trout (see elsewhere), this sucker is maintaining a sizable population in Pyramid Lake at the present time (1958), and thus is surviving despite the environmental disturbance wrought by man. The early life history is unknown, since specimens smaller than a foot in length have never been captured.

Empetrichthys merriami Gilbert, Ash Meadows killifish.—This and the following species of the relict genus *Empetrichthys* are confined to isolated waters of the Death Valley system in southern Nevada (Miller, 1948, pp. 99–105, pls. 10–11). *E. merriami*, rare 20 years ago, may now be extinct; it has not been taken in Ash Meadows since 1942 and, during the period from 1936 to 1942, only 22 specimens were secured by myself and others.

Empetrichthys latos Miller, Pahrump killifish.—This species was locally abundant at 3 places in Pahrump Valley in 1942. However, Ira La Rivers has written (February 2, 1960) that many changes have taken place in the valley since then and that a couple of years ago only 1 of the 3 localities was still relatively undisturbed by man's activities. Although all 3 populations were then extant, the abundance of carp and bullfrogs and the pumping dry of the spring sources and ponds render it unlikely that this killifish can survive indefinitely without protection.

Cyprinodon diabolis Wales, Devils Hole pupfish.—This extraordinary fish is confined to a single cave-spring hole in Ash Meadows, Nevada. In its small population size it is nearly unique among vertebrates (matched only by the whooping crane) and is peculiar in lacking pelvic fins, in the small size attained (mature at 15–20 mm., standard length), and in its coloration and life colors. The temperature of its restricted habitat fluctuates narrowly between 91° and 93° F., and the tiny fish occur only rarely to a depth of 50 feet, although the pool is more than 150 feet deep. The total population of this species probably varies between 100 and 300 individuals; a rather accurate estimate of a total population of 160 fish, of which approximately 100 were adults representing the effective breeding population, was made recently (Miller, in press).

This species has been able to maintain itself over many thousands of years because of the isolation of its habitat in a rather remote desert area. However, in order to prevent a man-made catastrophe from eliminating the species, the Devil's Hole area (40 acres) was added to Death Valley National Monument early in 1952. Even so, a species with a home range much smaller than that of a backyard swimming pool must be considered endangered.

Cyprinodon elegans Baird and Girard, Comanche Springs pupfish.—This distinctive species was based on a series of both sexes taken in 1851 from Comanche Springs at Fort Stockton, Texas. Although the type locality of *C. bovinus* (Leon Springs) is less than 10 miles distant, the 2 species are remarkably different. *C. elegans* was common in Comanche Springs on September 15, 1938, when Carl L. Hubbs and party collected 110 specimens. Although the springs stopped flowing during the summer of 1951, after a prolonged period of drought, *Cyprinodon* still persisted in pools in the outlet ditch in April 1952 (observation by Earl S. Herald), and specimens were collected at Comanche Springs by Frank T. Knapp and class on July 30, 1952 (material at Texas A & M College). However, by October, 1956, Clark Hubbs found the springs and outlet to be completely dry, with no trace of fish life. The largest of the spring pools was about 100 by 400 feet in major dimensions and the total spring flow, in 1938, was stated to be 35 million gallons daily, which is approximately 54 second-feet, since a second foot of water is equal to about 646,000 gallons per day (Meinzer, 1927, p. 3). The discharge, in second feet, was 66 in the summer of 1899, 64 on July 26, 1904, and 44 on August 21, 1919 (Meinzer, 1927, p. 41).

Although the Comanche Springs population of *Cyprinodon elegans* appears to have become extinct, the species still persists in Phantom Lake and its outlet near Toyahvale, Texas.

Characodon lateralis Günther.—This species was recorded from Parras, Coahuila, before the turn of the century, but has not been taken there since (Hubbs and Turner, 1939, p. 57). Like *Stypodon signifer* and *Cyprinodon latifasciatus,* it has probably been exterminated from Coahuila, for reasons given under the account of *Stypodon.* The only member of an endemic Mexican family otherwise living farther to the south, this fish still persists in the headwaters of the Río Mezquital around Durango City, Durango.

Archoplites interruptus (Girard), Sacramento perch.—This, the only native sunfish west of the Rocky Mountains (Miller, 1959, p. 199, figs. 8–9), is an interesting relict endemic to the Central Valley and neighboring coastal streams of California. It was very abundant in early days, inhabiting sloughs and sluggish channels as well as lakes.[5] Its numbers have been greatly reduced, presumably by the establishment of exotic species and changing ecological conditions, so that it has become scarce over its native range except in a few isolated localities. Its spawning habits are unique for the family since no nest is built and the eggs are unguarded (Murphy, 1948). Jordan and Gilbert (1894) wrote of the species in Clear Lake: "Formerly very common, but now becoming scarcer as its spawning grounds are devastated by the carp.... The destruction of this valuable fish is one of the most unfortunate results of the ill-advised introduction of the carp into California waters." Failure of the adults to guard the eggs was not serious in aboriginal times but has subsequently made the species vulnerable to predation by such introduced species as the bluegill. Although endangered in its natural habitat, the species has become successfully established elsewhere, for example in Walker Lake, Nevada.

Gasterosteus aculeatus williamsoni Girard, unarmored threespine stickleback.—This freshwater stickleback was based on 8 specimens collected in 1853 in "Williamson's Pass," California, which is in the headwaters of Santa Clara River (Fig. 1), Los Angeles County (Miller, 1961). It has apparently always been restricted in the Santa

[5] In 1849, for example, it was abundant and grew to be 15 to 20 inches long in lakes in the San Joaquin and Tulare valleys (Harris, 1960, p. 106, as "black perch").

Clara to its upper part and has, at times, been very difficult to find there. On the other hand it was "abundant everywhere" in 1912–13 in the then flowing streams of the Los Angeles Plain, just to the south (Culver and Hubbs, 1917). It still occurred in the Los Angeles River as late as 1929 (USNM 94343), but disappeared there within the next decade; it was probably during this same period that it vanished from the Santa Ana River, for the last record there of which I am aware is for 1923 (CAS 18558), and none was found during careful investigation along the river in the late 1930's. By 1939, this stickleback occurred on the Los Angeles Plain apparently only in the San Gabriel River system near Whittier, where it was last taken in April 1942 (UMMZ 139009).

Changing water conditions, especially the disappearance of former perennial flows (see p. 371), and competition with introduced fishes have evidently brought about the extinction or near extinction of this fish over that part of its range where it once was most abundant. *Gambusia affinis affinis* has very likely been the principal exotic responsible for the disappearance of the stickleback; the mosquitofish was introduced and widely established in California in 1922 (Dill, 1944, p. 162), and was common in the Los Angeles area by 1930. Whether *G. a. williamsoni* still survives on the Los Angeles Plain is questionable; it was still present in the upper part of Santa Clara River in 1951 and probably persists also in the Mohave River at Victorville (where it has been introduced, and was last collected in 1955).

DEPLETION AND SPECIES REPLACEMENT

The Arizona native trout, which I have tentatively referred to *Salmo gilae* (Miller, 1950, p. 34), once inhabited suitable tributaries of Salt River, Gila River (in New Mexico as well as Arizona), and the headwaters of the Little Colorado River (Fig. 1). It is the only trout indigenous to Arizona.[6] Testimony from old-timers and records

[6] I have examined specimens of the trout recorded by Jordan and Evermann (1896, p. 496) as *Salmo clarki pleuriticus* from the Little Colorado River and identify them as the Arizona native trout. The occurrence of the latter in the Little Colorado drainage is the result of introduction by way of an 1897 canal diversion (from a tributary of White River), or by transplanting activities of early stockmen, or both (letter from Jack E. Hemphill, November 10, 1960). This fish is well portrayed in color on the cover of the pamphlet by Mulch and Gamble (1954).

kept by F. M. Chamberlain (see p. 373) have shown how the range of *S. gilae* has dwindled since around the turn of the century (Miller, 1950, pp. 18–20, 27–29). Additional information on its former distribution and abundance in Oak Creek, south of Flagstaff, was obtained from Stanley Sykes in Flagstaff on May 25, 1950. He came to Arizona from Kansas in 1886, and first went down into Oak Creek Canyon in 1888, by a very rough trail. Native trout, as long as 16 inches, were then abundant as far downstream as the small falls (now just above the first highway crossing north of Sedona), and were easily caught. Before 1900, however, Sykes observed that introduced rainbow trout had already started to displace the native trout through competition and hybridization (see also Miller, 1950, p. 28), and it is doubtful whether a remnant of the pure stock still persists anywhere in the Verde River drainage. Dan A. Purtyman, Superintendent of the Page Springs Fish Hatchery on Oak Creek, testified that he helped stock the first rainbow trout in the creek when he was a boy (shortly before 1900). The last native trout he saw in Oak Creek was in 1915 or thereabouts; these trout were yellowish and spotted and lacked the "rainbow" band and the "cutthroat" mark.

In his letter of June 30, 1939, to Carl L. Hubbs, E. C. Becker, of Springerville, related information obtained from his father, Gustav Becker, who came to Arizona in 1876. This testimony is concerned with the native trout—"yellow bellies," as they were called—of the White Mountains, in both the headwaters of the Little Colorado and Salt rivers, and with the early history of trout stocking in the Little Colorado River. Such documentation is difficult to find in print and much valuable information has disappeared with the passing of old-timers. No exotic species were planted between 1876 and 1917, for the streams were apparently always stocked to capacity from natural reproduction. From 1898 to 1916, E. C. Becker stated that the native trout "were so plentiful that it was no trick for a boy to catch 100 in a few hours or 200 in a full afternoon." Because of ancient taboos against eating fish, the trout were not eaten by the Apache Indians and so survived until the white man began to exploit them. In 1917, brook trout (*Salvelinus fontinalis*) were brought from Holbrook and planted above Greer. A short time later, the rainbow trout (*Salmo gairdneri*) was introduced. When the South Fork Hatchery was built 10 miles from Springerville, in 1921, rainbow and "Wyoming natives" (*S. clarki lewisi*) "were distributed to practically all the accessible streams." Since then the Loch Leven or brown trout (*S. trutta*) has been added. Whether there are still uncontaminated stocks of native Arizona trout in the headwaters of the Little Colorado River I am not sure, but a sample collected by E. C. Becker at about 11,000 feet (near the summit of Mt. Ord) in 1938 represents the original form (UMMZ 157653).

A native cutthroat trout, *Salmo clarki* Richardson, was once common in Pine Valley and Grass Valley, southwestern Utah, at the head of Santa Clara River. It may have inhabited upper tributaries of the North Fork of the Virgin River, above Zion National Park, according to Vere Beckstrom whom I contacted in 1950 at the Pine Valley store. In 1907, he caught 350 native trout in Pine Valley in one day. I also talked to M. E. Bracken of Central, Utah, then 93 years old. He came to St. George in 1861 and to Pine Valley in 1863, when he first saw the trout. Most individuals did not exceed 12 inches and were "better tasting than rainbow or brown." The "mountain trout" did not come far down the streams, not much beyond the junction of the "Middle Fork and Left Fork" in Pine Valley. Mr. Bracken believed that trout were planted in the region shortly after 1900. Native trout still persisted in the headwaters of Pine Valley as late as 1934, when Arthur Paxman and V. M. Tanner collected 7 specimens (deposited at Brigham Young University). All informants were in accord, in 1950, that the only native stock still persisting is confined to the upper part of Main Canyon Creek in Grass Valley. Kumen Gardner, owner of Gardner Ranch near the mouth of Main Canyon, informed me that the creek was planted with rainbow trout during the period from 1915 to 1920, but not since then. It is now necessary to hike several miles up above the ranch to Reservoir Canyon to obtain the native trout, as most of the fish taken near the ranch show characters that indicate hybridization and backcrossing between the rainbow and native cutthroat (observations in 1950 and 1959; material at Michigan). In 1910, Mr. Gardner said that he easily caught 100 native trout a day.

Depletion and extermination of the cutthroat trout fishery in Pyramid Lake, Nevada, have been described at length (Sumner, 1940; Trelease, 1949), and numerous other instances of the disappearance of native trouts could be cited (e.g., see Pratt, 1937).

The Colorado squawfish or "salmon," as it is locally known, is one of the world's largest minnows and was an important source of food for the aborigines that lived along the lower Colorado and Gila rivers (Miller, 1955). It probably approached a maximum length of 6 feet and a weight of nearly 100 pounds, although record weights over the past 35 years are not known to have exceeded 40–50 pounds. At one time this predatory, pikelike fish was common in the river channels throughout the Colorado River basin, wherever there was sufficient depth and current. Until about 1911, the species was so abundant in the lower Colorado that individuals got into the irrigation ditches and were pitchforked out onto the banks by the hundreds for use as fertilizer. Vast numbers of "salmon," bonytails, and humpback suckers perished in this fashion or died when they were unable to re-enter the river from the irrigated lands (testimony of Walter K. Bowker, Jr., Imperial Valley Irrigation District, March 23, 1950). In the early days the Indians used to tie 2 sticks together, with netting between, and dip "salmon" out of the river. From 1911 to 1920, "salmon" were numerous in the Gila River near Dome, according to R. C. Richardson, Bureau of Reclamation employee and long-time fisherman. Earlier, between about 1845 and 1885, the species occurred more widely in the Gila River basin in Arizona (Miller, 1955), and it may still persist in the deep canyons of Salt River where 2 young were caught by R. R. Miller and party on May 18, 1950 (at mouth of Cibecue Creek, Gila County; UMMZ 162779). A sharp decline in abundance was noticed in the lower Colorado in the 1930–35 period, during the construction and completion of Hoover Dam and the great 1934 drought, at the height of which the river was reduced to a shallow trickle at Yuma (Dill, 1944). Specimens of *Ptychocheilus* weighing 6 to 34 pounds (Wallis, 1951, p. 90) were caught along the lower Colorado in the 1930's and 1940's but records of the species after 1949 are scarce. In the Gila River basin the last adult was caught in 1937 (in Salt River, above Roosevelt Dam), according to T. T. Frazier, informed local resident, who reported that the species had been fairly common there in 1906.

Changing ecological conditions, competition, and direct predation have no doubt strongly influenced the depletion of the Colorado squawfish and bonytail, so that both species are now nearly extirpated from the lower river. The humpback sucker, however, appears to be holding its own in the man-made reservoirs. Extensive recent sampling in the lower Colorado by the California Department of Fish and Game, in connection with an evaluation of the introduced

threadfin shad (*Dorosoma petenense*), has failed to reveal native fishes other than *Xyrauchen texanus* (letter of January 6, 1958, from J. B. Kimsey to Carl L. Hubbs). Both *Ptychocheilus lucius* and *Gila robusta elegans* may still be caught in sections of the Colorado River above Grand Canyon, but the series of dams now under construction there may well mean extermination for these fishes in the not too distant future.

The Conchos pupfish, *Cyprinodon eximius* Girard, was described from Chihuahua City, Chihuahua, Mexico, in 1859. On May 29, 1903, S. E. Meek collected it in the independent drainage of the Río Sauz at Sauz, about 30 miles northward from Chihuahua City. Testimony obtained by Clark Hubbs during the summer of 1954 indicates that the Río Sauz went dry in 1947 and that "there is no living water anywhere in the valley" (letter of July 6, 1954, from Clark Hubbs to Carl L. Hubbs). Whatever local attributes this population may have developed during its isolation from the main range of the species will have to be determined solely from the preserved material.

Arivaca Creek, a small spring-fed stream that rises just above Arivaca, southern Arizona (Fig. 1), was originally fishless, according to Fred C. Noon (contacted on April 15, 1950, at Oro Blanco Ranch). It was stocked by the Arizona State Health Department with *Gambusia* during a malaria outbreak about 1936. Thorough examination in 1950 of the main part of the creek (about 175 yards long), above and below the road crossing, revealed only the Gila topminnow (*Poeciliopsis occidentalis*), which may have been the fish introduced as "*Gambusia*" about 1936, reportedly from the vicinity of Tucson. It was stated that catfish and bass had been planted on the flat above Arivaca, but these species were unknown in the creek. The native topminnow was again found to be common there on April 12, 1957, when I secured a live stock for experimental work. On March 30, 1959, however, when the stream was revisited to replenish our live material, *Poeciliopsis* had been completely replaced by the exotic mosquitofish, *G. affinis affinis.* How and when the latter species gained entry to Arivaca Creek is not known, but *P. occidentalis* was replaced by the more competitive alien in a rather short time—apparently in less than 2 years. Charles H. Lowe, Jr., of the University of Arizona, visited the creek in June, 1959, expressly to check my finding and also was unable to locate a single specimen of *Poeciliopsis.* The introduction of *G. affinis* in other parts of the Southwest has led to the reduction or elimination of the less competitive native fishes (see p. 389), even including cyprinids (personal observations in California, and observations by Clark Hubbs in Texas—personal communication, 1959). *P. occidentalis* is now so scarce throughout Arizona that it is definitely threatened with extinction there.

Factors in Depletion and Extinction

In a very perceptive unpublished report[7] resulting from 2 months of field work in Arizona in the spring of 1904, the late F. M. Chamberlain (an assistant with the old U. S. Bureau of Fisheries) outlined the major causes of the depletion and extinction of fish life in Arizona. His material is incorporated into the following summary, which includes a consideration of additional factors that later became operative in further changing the native fauna of the Southwest. Many of the factors discussed below were effective at a much earlier time in producing faunal change in eastern North America (e.g., see Barnickol and Starrett, 1951, p. 323; Lachner, 1956; Trautman, 1957, pp. 13–24).

Destruction of vegetation.—Over much of the Southwest, large expanses were originally covered by a luxuriant growth of grasses and other succulent herbage which, during the rainy season, reached a height of 2 feet or more (Leopold, 1951). As the dry season advanced, the vegetation died down but formed a protective mulch, and its roots were remarkably effective in binding the soil. Such a cover acts like a sponge in retaining rainfall and hence is a potent defense against erosion. Not only were valley floors covered in part by dense sacatón grass but there were extensive ciénegas (wet meadows) near their centers, and elsewhere the water table was often within a few feet of the surface (Thornber, 1910, p. 334). Consequently, there were many more permanent streams than now, and large floods were rare (Antevs, 1952).

With the introduction and establishment of livestock, the vegetation was not only eaten progressively shorter but it was severely trampled to expose the soil over much of the area within a radius of daily movement from water (Gregory, 1950, pp. 44–45). Such denudation by herds became particularly noticeable after 1875 (Antevs, 1952) and led to increased floods and severe erosion. Unbelievably destructive floods may originate in a region of depleted soil and plant cover whereas adjacent, well-vegetated areas may at the same time receive no damaging runoff (Bailey, 1941, p. 245). The catastrophic nature of stream erosion after ecological disturbance by man has been dramatically described and illustrated for Kanab Creek, Arizona (Gregory, 1950, pp. 174–175, fig. 113). Bryan (1925, p. 342) stated that in only 10 years the channel of the San Pedro River of southern Arizona was incised from its mouth for 125 miles upstream.

[7] Deposited in the Division of Fishes, U. S. National Museum, Washington, D. C.

Destruction of the climax grassland by excessive grazing and trampling has, since about 1890, allowed the rapid spread of the aggressive mesquite tree beyond the bottom lands to which it was formerly confined. The serious effects of this invasion are recognized by those concerned with the use and conservation of vegetative cover, land, and water. The increase and spread of mesquite has been accompanied by a rise in the population of certain small rodents which further disseminate the mesquite; thus a vicious circle has set in. Rodent pressure alone may prevent the revegetation of deteriorated grasslands that are overburdened with mesquites (Glendening and Paulsen, 1955, pp. 45–47).

The conspicuous arroyos of our semiarid regions, so prominent in Arizona and New Mexico, were largely cut between about 1880 and 1910. Their streams are mostly ephemeral, their channels have flat bottoms and vertical walls, and they range in size to 100 feet deep, many hundreds of feet wide, and 140 miles long (Antevs, 1952). That these erosive gashes were brought on by excessive numbers of livestock has been fully demonstrated by Thornber (1910) and others (see Thornthwaite et al, 1942, pp. 120–122).

Cutting of timber in the forested headwater areas for use in mines, for fuel, for house construction, and in clearing land also promoted rapid runoff, and often a lowering of the water table, and resulted in damaging erosion from floods. Removal of protective vegetation led not only to depletion of perennial streams and lowering of the water table but also to the destruction of habitats for fish life in the surviving waters. The filling in of deep pools by sand and silt has eliminated species that habitually seek and require such places for survival, and the water has been rendered unfit for respiration when completely saturated with silt (Ellis, 1936; Wallen, 1951). Reduction or elimination of aquatic plants and increasing water temperatures have also profoundly affected the survival of aquatic organisms.

Irrigation and dams.—Consumption of water is the chief way in which irrigation operations affect fish life. Once diverted from the river it is expended on the land and lost by evaporation. Fishes may be carried out into the canals and ditches at the point of diversion and later perish when the water is cut off or as the habitat becomes unsuitable. Dams prevent upstream migration and in years of low water all fish below them may be killed as the stream bed becomes dry. The prevention of upstream movement may particularly affect large fishes, such as the Colorado squawfish, that develop in the lower courses of rivers but spawn in tributaries. The greatly altered habitat produced by impoundments may prove to be wholly unsuited to the native species—especially when, as so frequently happens, they are placed into competition with introduced species.

Mining operations.—The sediments from concentrating mills rapidly fill up river channels and destroy fish habitats in much the same way as do floods. Thus streams become barren for considerable distances below the point of entry of such wastes. Cyanide and other poisons resulting from ore processing also may denude a stream of all life if such chemicals are permitted free access to surface waters. Although chemical pollution is very destructive, its effects have generally been local in the Southwest and have not seriously threatened the native fish fauna. It has had more serious consequences outside of the area under discussion (Ellis, 1914, pp. 128–129; Sumner and Smith, 1940). Industrial pollution has risen in importance with increasing population trends. Familiarity with powder in mining operations has also led to the use of dynamite as a means of obtaining fish—a destructive practice since only a small proportion of the animals killed can usually be recovered. Such a fishing method, if widely used, may lead to streams nearly barren of fish life.

Depletion of ground water.—Pumping of water and the deep trenching of the valley floors has gradually lowered the water table in the Southwest. Springs and ciénegas went dry, streams ceased to flow or diminished in size, and wells had to be drilled to greater depths. Continuing demands for increased water supply following the population explosion since World War II have brought about an even more drastic lowering of the water table. For example, in 1950, one of the few remaining perennial flows of the Santa Cruz River went dry near San Xavier Mission for the first time in recorded history. Even when exceptionally heavy runoff occurs, the expected additional recharge of the water table by downward percolation now fails to be effective—probably because of shallow penetration and subsequent evaporation (Smith, 1940, p. 41).

Introduction of exotics.—With the establishment of the U. S. Fish Commission in 1872 the march of exotics began with the introduction of the carp. Today the number of native and introduced species inhabiting certain southwestern states shows that the indigenous fauna of any state does not outnumber the planted kinds by more than 3 to 1, generally only about 2 to 1; in Arizona, however, there are more exotics than there are natives. The following figures are derived from the references cited plus the author's manuscript checklists: Colorado, 54 native and 33 exotic species (Beckman, 1952); New Mexico, 61 native and 22 introduced kinds (Koster, 1957); Arizona, 28 native, 37 stocked fishes; Utah, 26 native, 24 planted species; Nevada, 41 native and 21 exotic kinds (La Rivers and Trelease, 1952); and California, 67 native fresh-water and anadromous species and 32 introduced species (Shapovalov, Dill, and Cordone, 1959).

The period of intensive introductions occurred chiefly between 1930 and 1950, along with the construction of major dams and diversions and the marked increase in human population. Most of these alien species—numbering approximately 36—came from eastern United States, in large part as intentional plants of game fishes. Only 8 exotic species are known to have become established in the West prior to 1930.

Many of the established aliens have affected the native species either directly—through predation, competition, and hybridization (Hubbs and Miller, 1953, and earlier references cited)—or indirectly, by altering the habitat (as carp have done). In the Mohave River of eastern California the one native fish has been almost wiped out through competition and hybridization with a better-adapted exotic species (Hubbs and Miller, 1943, 1948, and subsequent unpublished studies). The western mosquitofish, *Gambusia a. affinis*, has ousted native species and subspecies through competition and predation, so that some indigenous forms are now threatened with extermination. The complete replacement of *Poeciliopsis* by *Gambusia* at Arivaca Creek, Arizona, possibly in less than 2 years, has been described above. Ellis (1914, p. 129) attributed the scarcity of the yellowfin trout of Twin Lakes, Colorado, to the introduction of a deep-water competitor, the lake trout (*Salvelinus namaycush*)—a species that has raised havoc with native trouts in other lakes of the West.

Chemical treatment.—The use of toxic chemicals, such as rotenone and toxaphene, for the control or eradication of fish populations may have serious consequences for the native species. Such a management tool is being employed more and more widely in the control of "rough fish"; without prior determination of its harmful effects, this practice may needlessly exterminate localized species or relict populations (see above and Koster, 1957: 106). Its relatively indiscriminate use in streams has already reduced certain native fishes to dangerously low levels or has seemingly brought about local extinction (Clark Hubbs, *in litt.*, 1960). Conservationists should make a determined effort to prevent the decimation of aquatic biota in this way, if necessary through the enactment of protective legislation.

Changing climate.—This factor has been cited by some as the initial cause of the recent excessive erosion in the arid Southwest (see on the contrary, Bailey, 1935, and Antevs, 1952). Tree-ring and other records clearly indicate that periods of arid and of wet conditions are recurrent and are a basic character of climate (Sears, 1957). However, the severe erosion of the past century is invariably associated with man's direct or indirect disturbance of the environment. Had the native vegetation been left alone the arroyo cutting that commenced in the 1880's would probably not have materialized.

Summary

During the past 100 years, the aquatic habitats and the fish faunas of the American Southwest have undergone marked changes. Six or 7 species have become extinct and at least 13 others have been either locally exterminated or are so endangered that they too may soon vanish. These 19 or 20 species constitute almost 20 per cent of the known aboriginal fishes of Western North America (north of Mexico).

Reduced flow of surface waters has shrunk the ranges of many species and the distribution of others has been curtailed by the construction of barrier dams. Drastic reduction in ground-water levels has also eliminated or restricted the habitats of aquatic organisms. The establishment of some 36 species of exotic fishes has brought about replacement as well as reduction of the native forms through competition, predation, and hybridization. Because of the depauperate nature of the fauna and the circumstance that the distribution of many of the endemic species has been restricted (some are recent, others old, relicts), they probably lack the defense mechanisms that characterize species of more saturated faunas; thus they are rather easy prey for the typically more aggressive introduced fishes.

There is little evidence that the aborigines had much effect on the original fauna. The changes began soon after colonization by the white man, around the middle of the nineteenth century. During the period from 1880 to 1915, when most of the deep trenching (arroyo cutting) of the valley floors took place in the arid Southwest, once permanent streams withered through erosion from accelerated runoff, drainage of ciénegas, and lowering of the water table. The major modifications that have taken place over much of the region are illustrated by the changes that certain rivers and valleys have undergone. The deterioration of the fish faunas is indicated by repeated collections, some of which span a century, at several stations in Arizona. Testimony of old-timers indicates the general trend toward depletion of native stocks.

Interference by man with delicate and complex ecological balances has had dire consequences in many parts of the world. Perhaps nowhere else in North America has the upset of natural conditions been more strikingly reflected by biotic change than in the arid Southwest, particularly in southern Arizona. Overwhelming evidence indicates that modern man, rather than climatic change, has been the chief agent in producing the observed changes. Removal of vegetation by overgrazing and forest cutting has been the most important single cause of erosion. The deterioration of the native fish faunas can also be plausibly attributed to construction of dams, water diversions, pollution, mining operations, use of toxic chemicals, depletion of ground water, and the introduction of alien species.

LITERATURE CITED

Antevs, Ernst. 1952. Arroyo-Cutting and Filling. Jour. Geol., 60(4): 375–385.

Antisell, Thomas. 1857. Geological Report. *In*: Pacific Railroad Expl. and Surv., 7(2): 1–204, pls. 1–14, 2 maps.

Bailey, Reed W. 1935. Epicycles of Erosion in the Valleys of the Colorado Plateau Province. Jour. Geol., 43(4): 337–355, figs. 1–11.

—— 1941. Land Erosion—Normal and Accelerated—in the Semiarid West. Trans. Am. Geophys. Union, pt. 2: 240–250.

Barnickol, Paul G., and William C. Starrett. 1951. Commercial and Sport Fishes of the Mississippi River between Caruthersville, Missouri, and Dubuque, Iowa. Bull. Ill. Nat. Hist. Surv., 25(5): 267–350, figs. 1–15, col. frontis.

Beckman, William C. 1952. Guide to the Fishes of Colorado. Univ. Colo. Mus., Leaflet 11: 1–110, figs. 1–13, illus.

Beland, Richard D. 1953a. The Effect of Channelization on the Fishery of the Lower Colorado River. Calif. Fish and Game, 39(1): 137–139, fig. 1.

—— 1953b. The Occurrence of Two Additional Centrarchids in the Lower Colorado River, California. *Ibid.*, 39(1): 149–151.

Bryan, Kirk. 1925. Date of Channel Trenching (Arroyo Cutting) in the Arid Southwest. Science, 62: 338–344.

Colton, Harold S. 1937. Some Notes on the Original Condition of the Little Colorado River: A Side Light on the Problems of Erosion. Mus. Notes, Mus. N. Ariz., 10(6): 17–20, figs. 1–3.

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.

Culver, George B., and Carl L. Hubbs. 1917. The Fishes of the Santa Ana System of Streams in Southern California. Lorquinia, 1(11): 82–83.

Dill, William A. 1944. The Fishery of the Lower Colorado River. Calif. Fish and Game, 30(3): 109–211, figs. 45–82.

Dipeso, Charles C. 1951. The Babocomari Village Site on the Babocomari River, Southeastern Arizona. Amerind Foundation, No. 5: i–xii, 1–248, figs. 1–49, pls. 1–76.

Ellis, Max M. 1914. Fishes of Colorado. Univ. Colo. Stud., 11(1): 1–136, 1 fig., 3 maps, pls. 1–12.

—— 1936. Erosion Silt as a Factor in Aquatic Environments. Ecol., 17(1): 29–42, fig. 1.

Emory, W. H. 1848. Notes of a Military Reconnoissance, from Fort Leavenworth, in Missouri, to San Diego, in California, Including Parts of the Arkansas, Del Norte, and Gila Rivers. 30th Cong., 1st Sess., Senate Exec. No. 7: 1–126, illus.

Fenneman, Nevin M. 1931. Physiography of Western United States. McGraw-Hill Book Co., i–xiii, 1–534, figs. 1–173, pl. 1.

Gehlbach, Frederick E., and Robert Rush Miller. 1961. Fishes from Archeological Sites in Northern New Mexico. Southwestern Nat.

Gilbert, Charles H., and Norman B. Scofield. 1898. Notes on a Collection of Fishes from the Colorado Basin in Arizona. Proc. U. S. Nat. Mus., 20: 487–499, pls. 36–39.

Glendening, George E., and Harold A. Paulsen, Jr. 1955. Reproduction and Establishment of Velvet Mesquite as Related to Invasion of Semidesert Grasslands. U. S. Dept. Agr. Tech. Bull. 1127: 1–50, figs. 1–24.

Glidden, E. H. 1941. Occurrence of *Elops affinis* in the Colorado River. Calif. Fish and Game, 27(4): 272–273.

Gregory, Herbert E. 1950. Geology and Geography of the Zion Park Region, Utah and Arizona. U. S. Geol. Surv., Prof. Pap. 220: i–vi, 1–200, figs. 1–133, pls. 1–5.

Harris, Benjamin Butler. 1960. The Gila Trail/The Texas Argonauts and the California Gold Rush. Univ. Oklahoma Press, i–xv, 1–175, illus.

Hemphill, Jack E. 1954. Toxaphene as a Fish Toxin. Prog. Fish-Cult., 16(1): 41–42.

Henderson, Junius, and Wilfred William Robbins. 1913. Climate and Evidence of Climatic Changes. *In:* The Physiography of the Rio Grande Valley, New Mexico, in Relation to Pueblo Culture. Smith. Inst. Bur. Am. Ethnol., Bull. 54: 41–70, figs. 1–2.

Hubbs, Carl L. 1953. *Eleotris picta* Added to the Fish Fauna of California. Calif. Fish and Game, 39(1): 69–76, figs. 1–2.

—— 1954. Establishment of a Forage Fish, the Red Shiner (*Notropis lutrensis*), in the Lower Colorado River System. *Ibid.*, 40(3): 287–294, figs. 1–3.

—— and Robert R. Miller. 1943. Mass Hybridization between Two Genera of Cyprinid Fishes in the Mohave Desert, California. PMASAL,[8] 28 (1942): 343–378, figs. 1–2, pls. 1–4.

—— and ——. 1948. Correlation between Fish Distribution and Hydrographic History in the Desert Basins of Western United States. *In*: The Great Basin, with Emphasis on Glacial and Postglacial Times. Bull. Univ. Utah, 38(20): 17–166, figs. 10–29, 1 map.

—— and Robert Rush Miller. 1953. Hybridization in Nature between the Fish Genera *Catostomus* and *Xyrauchen*. PMASAL, 38(1952): 207–233, figs. 1–3, pls. 1–4.

—— and C. L. Turner. 1939. Studies of the Fishes of the Order Cyprinodontes. XVI. A Revision of the Goodeidae. Misc. Publ. Mus. Zool. Univ. Mich., 42: 1–80, pls. 1–4.

Hubbs, Clark. 1947. Mixture of Marine and Fresh-Water Fishes in the Lower Salinas River, California. Copeia, 1947(2): 147–149.

—— 1957. Distributional Patterns of Texas Fresh-Water Fishes. Southwestern Nat., 2(2–3): 89–104, figs. 1–2.

—— and Victor G. Springer. 1957. A Revision of the *Gambusia nobilis* Species Group, with Descriptions of Three New Species, and Notes on Their Variation, Ecology, and Evolution. Texas Jour. Sci., 9(3): 279–327, figs. 1–15.

Jordan, David Starr, and Barton Warren Evermann. 1896. The Fishes of North and Middle America. Part I. Bull. U. S. Nat. Mus., 47: i–lx, 1–1240.

Jordan, David S., and Charles H. Gilbert. 1894. List of the Fishes Inhabiting Clear Lake, California. Bull. U. S. Fish. Comm., 14 (1895): 139–140.

Kimsey, J. B., Robert H. Hagy, and George W. McCammon. 1957. Progress Report on the Mississippi Threadfin Shad, *Dorosoma petenensis atchafalayae*, in the Colorado River for 1956. Calif. Dept. Fish and Game,

[8] PMASAL = Papers Mich. Acad. Sci., Arts, and Letters.

Inland Fish. Branch, Admin. Rept. No. 57-23: 1–48 (mimeo.). [cited from Shapovalov et al., 1959]
KOSTER, WILLIAM J. 1957. Guide to the Fishes of New Mexico. Univ. New Mexico Press, i–vii, 1–116, illus.
LACHNER, ERNEST A. 1956. The Changing Fish Fauna of the Upper Ohio Basin. *In*: Man and the Waters of the Upper Ohio Basin. Pymatuning Lab. Field Biol., Spec. Publ. No. 1: 64–78.
LA RIVERS, IRA, AND T. J. TRELEASE. 1952. An Annotated Check List of the Fishes of Nevada. Calif. Fish and Game, 38(1): 113–123.
LEE, WILLIS T. 1907. Water Resources of the Rio Grande Valley in New Mexico. U. S. Geol. Surv. Water-Supply and Irrigation Pap. 188: 1–59, pls. 1–10.
LEOPOLD, LUNA B. 1951. Vegetation of Southwestern Watersheds in the Nineteenth Century. Geog. Rev., 41: 295–316, figs. 1–4.
MATTHIESSEN, PETER. 1959. Wildlife in America. The Viking Press, N. Y., 304 pp., illus.
MCGLASHAN, H. D. 1930. Surface Water Supply of Pacific Slope Basins in Southern California, 1894–1927. U. S. Geol. Surv. Water-Supply Pap. 636E: i–vi, 169–219.
MEINZER, OSCAR E. 1927. Large Springs in the United States. U. S. Geol. Surv. Water-Supply Pap. 557: i–vii, 1–94, figs. 1–23, pls. 1–17.
MENDENHALL, WALTER C. 1908. Ground Waters and Irrigation Enterprises in the Foothill Belt, Southern California. U. S. Geol. Surv. Water-Supply Pap. 219: 1–180, figs. 1–16, pls. 1–9.
MILLER, ROBERT RUSH. 1948. The Cyprinodont Fishes of the Death Valley System of Eastern California and Southwestern Nevada. Misc. Publ. Mus. Zool. Univ. Mich., 68: 1–155, figs. 1–5, maps 1–3, pls. 1–15.
—— 1950. Notes on the Cutthroat and Rainbow Trouts with the Description of a New Species from the Gila River, New Mexico. Occ. Pap. Mus. Zool. Univ. Mich., 529: 1–42, map 1, pl. 1.
—— 1952. Bait Fishes of the Lower Colorado River from Lake Mead, Nevada, to Yuma, Arizona, with a Key for Their Identification. Calif. Fish and Game, 38(1): 7–42, figs. 1–32.
—— 1954. A Drainage Map of Arizona. Syst. Zool., 3(2): 80–81.
—— 1955. Fish Remains from Archaeological Sites in the Lower Colorado River Basin, Arizona. PMASAL, 40(1954): 125–136, fig. 1, pls. 1–5.
—— 1959. Origin and Affinities of the Freshwater Fish Fauna of Western North America. *In*: Zoogeography. Amer. Assoc. Adv. Sci., Publ. 51 (1958): 187–222, figs. 1–19.
—— 1961. The Type Locality of *Gasterosteus aculeatus williamsoni* and Its Significance in the Taxonomy of Californian Sticklebacks. Copeia, 1960 (4).
—— In press. Speciation Rates in Some Freshwater Fishes of Western North America. *In*: Vertebrate Speciation. Univ. Texas Press.
—— AND CARL L. HUBBS. 1960. The Spiny-Rayed Cyprinid Fishes (Plagopterini) of the Colorado River System. Misc. Publ. Mus. Zool. Univ. Mich., 115: 1–39, figs. 1–2, pls. 1–3.

—— AND TERUYA UYENO. MS. Classification of the Cyprinid Fishes of the Genus *Gila* in Southwestern United States and Mexico.
MULCH, ERNEST E., AND WILLIAM C. GAMBLE. 1954. Game Fishes of Arizona. Ariz. Game and Fish Dept., 1954: 1–19, 5 figs., 8 col. pls., col. frontis.
MURPHY, GARTH I. 1948. A Contribution to the Life History of the Sacramento Perch (*Archoplites interruptus*) in Clear Lake, Lake County, California. Calif. Fish and Game, 34(3): 93–100, figs. 26–29.
—— 1951. The Fishery of Clear Lake, Lake County, California. *Ibid.*, 37(4): 439–484, figs. 175–179.
OLMSTEAD, FRANK H. 1919. A Report on Flood Control of the Gila River in Graham County, Arizona. 65th Cong., 3d Sess., Senate Doc. No. 436: 1–94, many maps and figs., pls. 1–32.
PARKE, JOHN G. 1857. General Report. *In*: Pacific Railroad Expl. and Surv., 7(1): 1–42, pls. 1–8.
PRATT, HAROLD. 1937. Population Studies of the Trout of the Gunnison River. Univ. Colo. Stud., 24(2): 107–116, figs. 1–2.
ROSS, CLYDE P. 1923. The Lower Gila Region, Arizona. U. S. Geol. Surv., Water-Supply Pap. 498: i–xiv, 1–237, figs. 1–16, pls. 1–23.
RUTTER, CLOUDSLEY. 1908. The Fishes of the Sacramento-San Joaquin Basin, with a Study of Their Distribution and Variation. Bull. U. S. Bur. Fish., 27(1907): 103–152, figs. 1–4, pl. 6.
SCHWALEN, HAROLD C. 1942. Rainfall and Runoff in the Upper Santa Cruz River Drainage Basin. Univ. Ariz. Agr. Expt. Sta., Tech. Bull. 95: 421–472, figs. 1–10, pls. 1–7, frontis.
SEARS, PAUL B. 1957. The Ecology of Man. Condon Lectures, Oregon State Sys. Higher Ed., Eugene, Ore., 1957: 1–61, figs. 1–15.
SHAPOVALOV, LEO, WILLIAM A. DILL, AND ALMO J. CORDONE. 1959. A Revised Check List of the Freshwater and Anadromous Fishes of California. Calif. Fish and Game, 45(3): 159–180.
SITGREAVES, L. 1853. Report of an Expedition down the Zuni and Colorado Rivers. 32d Cong., 2d Sess., Sen. Ex. Doc. 59: 1–29, 1 map, illus.
SMITH, G. E. P. 1940. The Groundwater Supply of the Eloy District in Pinal County, Arizona. Univ. Ariz. Agr. Expt. Sta., Tech. Bull. 87: 1–42, figs. 1–7, pls. 1–3.
SNYDER, JOHN OTTERBEIN. 1915. Notes on a Collection of Fishes Made by Dr. Edgar A. Mearns from Rivers Tributary to the Gulf of California. Proc. U. S. Nat. Mus., 49: 573–586, 1 fig., pls. 76–77.
—— 1917. The Fishes of the Lahontan System of Nevada and Northeastern California. Bull. U. S. Bur. Fish., 35(1915–16): 33–86, figs. 1–9, pls. 3–5.
ST. AMANT, J. A. 1959. Striped Bass Introduced into the Colorado River. Calif. Fish and Game, 45(4): 353.
SUMNER, FRANCIS H. 1940. The Decline of the Pyramid Lake Fishery. Trans. Am. Fish. Soc., 69(1939): 216–224, figs. 1–2.
—— AND OSGOOD, R. SMITH. 1940. Hydraulic Mining and Debris Dams in Relation to Fish Life in the American and Yuba Rivers of California. Calif. Fish and Game, 26(1): 2–22, figs. 1–10.

TANNER, VASCO M. 1936. A Study of the Fishes of Utah. Utah Acad. Sci., Arts and Letters, 13: 155–184, pls. 1–3.

THORNBER, J. J. 1910. The Grazing Ranges of Arizona. Ariz. Agr. Expt. Sta., Bull. 65: 335–338.

THORNTHWAITE, C. W., C. F. S. SHARPE, AND EARL F. DOSCH. 1942. Climate and Accelerated Erosion in the Arid and Semi-Arid Southwest with Special Reference to the Polacca Wash Drainage Basin, Arizona. U. S. Dept. Agr., Tech. Bull. 808: 1–134, figs. 1–57.

TRAUTMAN, MILTON B. 1957. The Fishes of Ohio. Ohio State Univ. Press, Columbus, xvii + 683 pp., 172 maps, 11 col. pls., 172 figs.

TRELEASE, THOMAS J. 1949. What Lies Ahead for Pyramid Lake. Nev. Hunting and Fishing, 1(2): 8–10, 23, 29–32, illus.

WALLEN, I. EUGENE. 1951. The Direct Effect of Turbidity on Fishes. Bull. Okla. Agr. and Mech. Coll., Biol. Ser. 2, 48(2): 1–27, figs. 1–5.

WALLIS, ORTHELLO L. 1951. The Status of the Fish Fauna of the Lake Mead National Recreational Area, Arizona-Nevada. Trans. Am. Fish. Soc., 80(1950): 84–92, fig. 1.

WHIPPLE, A. W. 1856. Report on the Topographical Features and Character of the Country. *In*: Pacific Railroad Expl. and Surv., 3(2): 1–77, illus.

PAPERS OF THE MICHIGAN ACADEMY OF SCIENCE, ARTS, AND LETTERS
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THE NORTH AMERICAN SCIOMYZIDAE RELATED TO *PHERBELLIA FUSCIPES* (MACQUART) (DIPTERA ACALYPTRATAE)

GEORGE C. STEYSKAL

Grosse Ile, Michigan

THE genera of the subfamily Sciomyzinae found in North America may be separated as follows:

1 (2). Fore tibiae with 2 preapical bristles.
2 (3). Arista with long black rays; face not tuberculate.... SCIOMYZA Fallén
3 (2). Arista densely short white plumose; face tuberculate above
OIDEMATOPS Cresson

4 (1). Fore tibiae with 1 preapical bristle.
5 (6). Anal vein not attaining wing margin; basal cells small; fore coxae with 3–5 bristles.................................... COLOBAEA Zetterstedt
6 (5). Anal vein attaining wing margin; basal cells large; fore coxae rarely with as many as 3 bristles.
7 (8). Propleural bristles fine and thin; center of propleura, nearly entire mesopleura and sternopleura, and center of pteropleura with fine longish hairs; fore coxae without bristles..... ATRICHOMELINA Cresson
8 (7). Propleural bristle strong; 1 or more of the above pleural regions without fine hairs; fore coxae with at least 1 bristle.
9 (10). Predominantly shining black species; cheeks linear; frons wholly shining.. PTEROMICRA Lioy
10 (9). Species of yellow, brown, or gray color, never shining black; cheeks at least moderately wide; frons partly or wholly opaque.
PHERBELLIA Robineau-Desvoidy

Pherbellia is likely a composite group. About a decade of genera have been proposed for various segregates, but the characters upon which they are based seem trivial and in some cases intergrading. Until an exhaustive study of the male postabdomen can be completed, it seems best to recognize but a single genus.

A key to one group of *Pherbellia*, those in which the shining interfrontal stripe extends two-thirds or more of the distance from the anterior ocellus to the frontal margin, including the generitype *P. schoenherri* (Fallén), has been presented.[1] The remainder of the genus at

[1] Steyskal, G. C., 1949. New Diptera from Michigan (Stratiomyidae, Sarcophagidae, Sciomyzidae) PMASAL, 33: 173–180.

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