Ecology of Some Native and Introduced Fishes of the Sierra Nevada Foothills in Central California

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Collections were made of fishes occurring in the streams of the Sierra Nevada foothills in Central California. Environmental factors associated with each collection were recorded. Correlation analyses indicated which environmental factors affected the distribution of 11 of the 21 species collected: ***Micropterus salmoides, Lepomis cyanellus, L. macrochirus, Gambusia affinis, Notemigonus crysoleucas, Lavinia exilicauda, Ptychocheilus grandis, Mylopharodon conocephalus, Hesperoleucus symmetricus, Catostomus occidentalis*** and ***Salmo gairdneri.*** The fishes were found to belong to four distinct fish associations, each found in a distinctive set of environmental conditions. The Rainbow Trout Association was found in the cold, clear permanent streams of the higher elevations. The California Roach Association was found in the small, warm intermittent tributaries to the larger streams. The Native Cyprinid–Catostomid Association was found in the larger low elevation streams. The Introduced Fishes Association was found in low elevation intermittent streams that had been highly modified by man's activities.

CALIFORNIA'S great Sacramento-San Joaquin River complex has long been isolated from other drainage systems. This isolation has produced a varied and interesting fish fauna that is over 75 percent endemic (Miller, 1958). Since the late nineteenth century, intensive agriculture, mining, industry and the development of large population centers in the Sacramento-San Joaquin Valley and contiguous areas has drastically changed the quality and distribution of the water, particularly on the Valley floor. These changes, combined with wide-spread introduction of fish of many species from the eastern United States, have had serious repercussions on the native fish fauna. At least one species, the thicktailed chub, *Gila crassicauda* (Baird and Girard), is now either extinct or extremely rare (Miller, 1963). Other species such as the tule perch, *Hysterocarpus traskii* Gibbons, the tidewater goby, *Eucyclogobius newberryi* (Girard), and the Sacramento perch, *Archoplites interruptus* (Girard), are becoming increasingly uncommon within their original range. A few species, such as the hitch, *Lavinia exilicauda* Baird and Girard, the Sacramento blackfish, *Orthodon microlepidotus* (Ayres), and the Sacramento sucker, *Catostomus occidentalis* Ayres, still maintain populations and occasionally even become "pest" fish in reservoirs, where large numbers may severely limit the abun[illegible] dance of game fish (Calhoun, 1966).

Whatever the status of the individual [illegible] tive species, the original associations of [illegible] tive fish species have been disrupted co[illegible] pletely on the Valley floor and to a le[illegible] extent at higher altitudes. Fortunately, [illegible] are still relatively undisturbed associa[illegible] of native fishes in many of the intermi[illegible] streams of the foothills of the Sierra Ne[illegible] mountains. Four such associations have [illegible] described by Murphy (1941) and Hop[illegible] (1967) for the Sacramento River system [illegible] named according to their most characte[illegible] native species: hitch, sucker, roach and [illegible] The future of the foothill fish associatio[illegible] precarious at best. Development of the [illegible] hills, including changes in land and [illegible] use, has been proceeding at an accele[illegible] pace in recent years. Dams are now pl[illegible] for most of the larger streams that d[illegible] already have them. The purpose of th[illegible] per, therefore, is to describe the foothil[illegible] associations as they are today in the [illegible] Joaquin River system and to analyze [illegible] cally the ecological factors that affect [illegible] distribution of the more abundant spe[illegible] well as the associations themselves.

THE STUDY AREA

The study was carried out on the [illegible] in the Sierra Nevada foothills betwe[illegible]

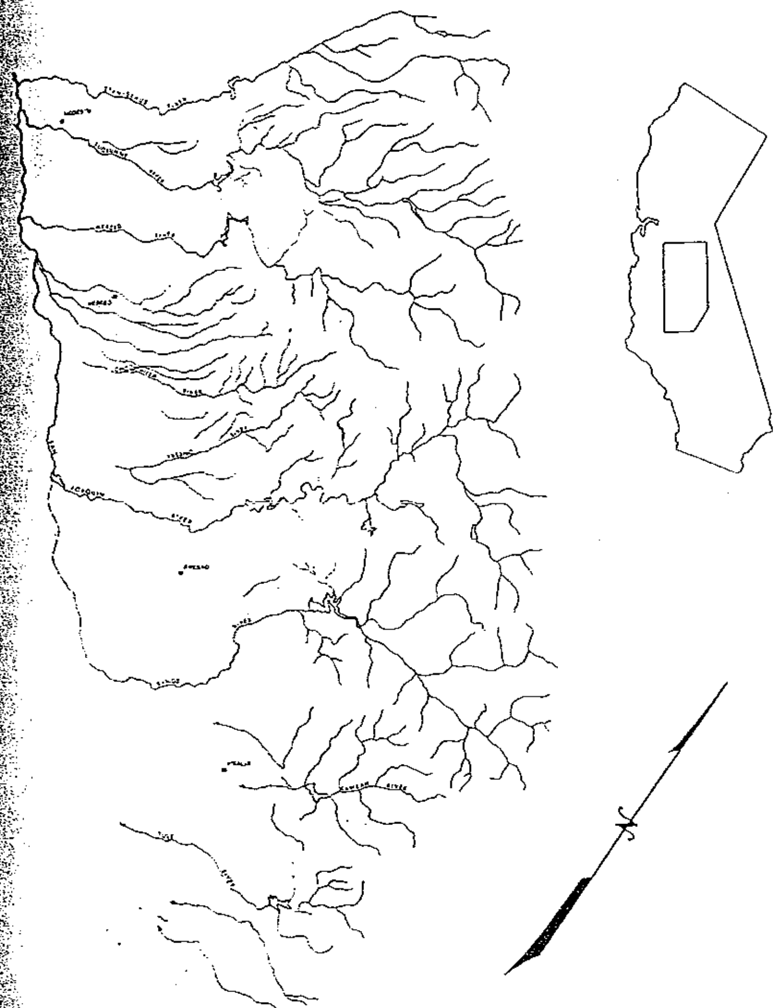

Fig. 1. Central California drainage systems sampled for foothill fishes, 27 July–4 September, 1970. The foothill region includes about the middle third of each of the main river systems.

elevations of 90 and 1100 m. Mean elevation of the collections was 401 m. At least one collection of fish was made from most of the streams accessible by road in Tulare, Fresno, Madera, Mariposa, and Tuolumne counties, California. A few collections were also made in Stanislaus County (Fig. 1). Most of the streams that were sampled are seasonally intermittent and flow over their entire course only when there is water from winter rains and runoff from the spring melt of snow in the mountains. During the study period (July 27–September 4, 1970), most streams sampled were not flowing, particularly at lower elevations, except where exposed bedrock brought the small underground flow to the surface. At this time, the fish were confined to and concentrated in isolated pools. The hillsides along the streams are rocky, heavily grazed, dry grasslands with a scattering of oaks (*Quercus* spp.) and, at the higher elevations, digger pine (*Pinus sabiniana*).

Methods

Three major considerations determined the methods used: (1) the study area was large and the streams few and far between; (2) to assure seasonal consistency, all sampling had to be done in as short a time as possible, during the period when stream flows were

TABLE 1. NATIVE (N) AND INTRODUCED (I) FISHES COLLECTED AT 130 SAMPLING SITES IN STREAMS OF THE SIERRA NEVADA FOOTHILLS, CALIFORNIA, JULY 27–SEPTEMBER 4, 1970.

Name	Origin	%*
Family Centrarchidae		
Largemouth bass, *Micropterus salmoides*	I	31
Smallmouth bass, *Micropterus dolomieui*	I	7
Green sunfish, *Lepomis cyanellus*	I	46
Bluegill, *Lepomis macrochirus*	I	23
Redear sunfish, *Lepomis microlophus*	I	1
Family Cottidae		
Prickly sculpin, *Cottus asper*	N	2
Riffle sculpin, *Cottus gulosus*	N	2
Family Gasterosteidae		
Threespine stickleback, *Gasterosteus aculeatus*	N	1
Family Poecilidae		
Mosquitofish, *Gambusia affinis*	I	26
Family Cyprinidae		
Carp, *Cyprinus carpio*	I	2
Goldfish, *Carassius auratus*	I	1
Golden shiner, *Notemigonus crysoleucas*	I	8
Hitch, *Lavinia exilicauda*	N	10
Sacramento squawfish, *Ptychocheilus grandis*	N	38
Hardhead, *Mylopharodon conocephalus*	N	9
California roach, *Hesperoleucus symmetricus*	N	32
Family Catostomidae		
Sacramento sucker, *Catostomus occidentalis*	N	42
Family Ictaluridae		
White catfish, *Ictalurus catus*	I	9
Brown bullhead, *Ictalurus nebulosus*	I	7
Family Salmonidae		
Rainbow trout, *Salmo gairdneri*	N	20
Brown trout, *Salmo trutta*	I	1

lowest; and (3) the available collecting and water sampling gear was limited. At each of the 130 sampling sites as many fish as possible were collected using minnow seines of several sizes. The number of fish of each species caught was then recorded and the fish returned to the water. Visual checks of the sample sites, by snorkeling when necessary, indicated that the seining provided a good estimate of the relative numbers of fish of each species present. Using the information from both seine hauls and visual checks each fish species was assigned an abundance rating, on a *0–5* scale. On this scale a rating of *0* meant that no fish of that species was present; *1* meant that only one or two individuals were observed; *2* that 3–10 individuals were observed; *3* that the species was common; *4* that the species was abund… and *5* meant that the area was swarm… with the fish, a large number being bro… up with every seine haul. A similar rat… was also made for abundance of all the… combined. Using the seining counts, … percentage of fish of each species in the … tire sample was calculated.

At each site data were gathered on … easily measured or estimated environme… variables that were judged likely to … the distribution of fishes. Those sele… are: 1) elevation, in meters; 2) air and … temperature. Since air temperatures … ated 11–17 C during the day and the … temperatures tended to fluctuate with … air temperatures, the data analysis was … on the difference between the air and … temperatures. The data differences … coded: *1*, a difference of 0–2.8 C; *2*, … C; *3*, 5.8–8.6 C; *4*, 8.7–11.5 C; *5*, 11.6–… 3) mean depth of water of the area … measured in meters; 4) maximum dep… meters; 5) width of water surface in … 6) water flow in liters per second as est… with a velocity head rod; 7) turbidity … on a *0–5* scale, where *0* is extremely clea… *5* is extremely turbid; 8) percentage … bottom covered with rooted aquatic … 9) percentage of the water surface … with floating mats of algae, water… (*Azolla* spp.) or duckweed (*Lemna* spp.… percentage of sampling area made … pools, which are defined as wide … water with little or no noticeable flo… the percentage of the sampling area … up of riffles where the water flow…

and gravel and there were distinct the water surface; 12) percentage bottom composed of silt; 13) percentage of bottom composed of sand, defined particles less than 2 mm in diameter; percentage of the bottom composed of defined as pieces of rock, mostly 2–75 diameter; 15) percentage of bottom with cobbles, mostly 75–300 mm in diameter; 16) percentage of bottom covered bedrock or boulders larger than 300 diameter; 17) the quality and amount cover available to the fish, rated on a *0–5* where *0* indicated no cover and *5* that cover was plentiful and varied; 18) percentage of the water surface that was apparently shaded most of the day; 19) the extent which human activities had visibly altered stream channel and water quality as rated *0–5* scale, where *0* indicates no apparent alterations and *5* indicates that both the channel and water had been markedly altered; 20) stream type, which was rated as follows: *1*, small, with intermittent flow; *2*, medium sized, with intermittent flow; *3*, large with intermittent flow; *4*, small (1–15 cfs) with permanent flow; *5*, medium (15–30 cfs) permanent flow; and *6*, large (30+ cfs) with permanent flow. Each stream was classified by observing the flow at the time of sampling and by information from topological maps.

For each of the 130 collection localities, the following information was placed on punch cards: 1) the data from the foregoing environmental variables, 2) the abundance rating and the catch percentage for each of the eleven most abundant fish species, 3) the abundance rating and the catch percentage of all other species captured combined, 4) total number of species captured, and 5) percentage of fish captured that belonged to endemic species. All 130 cards were then run through a computer programmed to obtain a Pearson correlation matrix for the 46 variables, as well as the means and standard deviations of the variables. The 130 cards were then sorted eleven separate times, each time separating out all the cards for samples that contained one of the eleven most abundant fish species. The means and standard deviations for all the variables in these samples were then calculated. The means and standard deviations of the variables were also obtained for the four fish associations defined later in this paper. In the analysis of the abundance relationships between species, only the correlations between the abundance ratings are used in this paper since the abundance ratings and the sample percentages for each species were highly correlated.

Species Ecology

In all, twenty species of fish were collected from the foothill streams during the study. Only eleven of these species were collected in large enough numbers to warrant a detailed statistical analysis of their ecology (Table 1). Nine of the twenty species (45%) are native, the remaining eleven species are introduced.

In the following sections the ecological relationships of the eleven most abundant fish species are discussed. The means of the habitat variables, and their relationships to each other, are presented in Tables 2, 3, 4 and 5. Abbreviations for fish species in these tables are: LMB—largemouth bass; GSF—green sunfish; BG—bluegill; GAM—mosquitofish; GSH—golden shiner; HCH—hitch; SQ—Sacramento squawfish; HH—hardhead; RCH—California roach; SKR—Sacramento sucker; and RB—rainbow trout.

Largemouth bass.—This introduced predatory centrarchid occurred in 31% of the 130 collections and made up, on the average, only 8% of the fish in collections in which it occurred (Tables 1, 2). It was most abundant in warm turbid pools of intermittent streams at lower elevations (Table 3). These pools usually had sand or mud bottoms and were not well shaded. They often had extensive growths of rooted and floating aquatic vegetation (Table 3). Sites where largemouth bass were taken showed signs of heavy use by man, such as small dams, rip-rapping and cattle trampled banks. As might be expected of a largely piscivorous carnivore, at the top of the food chain, the largemouth bass was found where fish species diversity was high compared to that in other foothill areas. On the average four other species occurred with it. Those which were found most frequently are mosquitofish, green sunfish and bluegill (Tables 2, 4). Hitch and golden shiner were also often found where bass were most abundant, as were the less common introduced species, especially redear sunfish, white catfish, brown bullhead and carp (Tables 2, 4).

TABLE 2. PATTERNS OF FISH SPECIES CO-OCCURRENCE IN THE SIERRA NEVADA FOOTHILLS, CALIFOR SHOWN BY MEANS OF ABUNDANCE RATINGS (*0–5* SCALE) AND MEANS OF THE PERCENTAGES OF FISH CURRING IN SAMPLES CONTAINING AT LEAST ONE MEMBER OF A SPECIES SELECTED FROM THE E MOST ABUNDANT FOOTHILL FISH SPECIES. Species abbreviations are listed in the text.

	Species Selected									
	LMB	GSF	BG	GAM	GSH	HCH	SQ	HH	RCH	SKR
N	40	60	30	34	11	13	49	12	42	54
LMB	1.9	0.9	1.4	1.3	1.4	1.6	0.6	0.6	0.2	0.5
%	8	3	7	4	7	5	2	2	1	2
GSF	1.5	2.1	1.2	1.5	1.5	1.9	0.7	1.1	0.6	0.6
%	14	25	10	10	9	12	5	3	4	2
BG	1.1	0.5	1.9	0.8	0.8	0.3	0.5	0.5	0.2	0.4
%	8	4	17	6	6	4	4	1	1	3
GAM	1.5	1.0	0.9	2.4	1.8	1.5	0.4	0.4	0.2	0.6
%	25	16	16	44	27	27	8	3	1	7
GSH	0.4	0.3	0.3	0.4	2.0	0.2	0.1	0.2	0.0	0.1
%	2	2	2	2	11	< 1	< 1	< 1	0	< 1
HCH	0.7	0.5	0.1	0.5	0.5	2.5	0.3	0.3	0.1	0.3
%	5	4	< 1	2	< 1	2	2	3	< 1	2
SQ	0.9	0.7	1.0	0.7	0.9	1.1	2.4	2.6	0.9	1.6
%	10	8	16	7	8	13	32	32	9	23
HH	0.2	0.3	0.4	0.3	0.3	0.2	0.7	2.8	0.1	0.4
%	3	6	5	5	5	1	9	40	< 1	5
RCH	0.3	0.6	0.5	0.4	0.0	0.3	0.9	0.3	2.7	1.0
%	6	15	8	9	0	6	14	3	65	18
SKR	0.7	0.7	0.9	0.8	1.1	0.9	1.5	1.4	1.0	2.2
%	6	8	11	9	9	4	16	11	13	27
RB	0.0	0.1	0.0	0.0	0.0	0.0	0.2	0.3	0.4	0.4
%	0	< 1	0	0	0	0	1	< 1	4	3
Other Spp.	1.0	0.8	0.9	0.7	1.2	0.7	0.5	0.3	0.2	0.4
%	15	9	10	3	18	7	7	2	2	8

Green sunfish.—The green sunfish was the most widely distributed introduced fish in the study area, ranging from the valley floor to an elevation of 690 m. It occurred in 46% of the samples. This is not too surprising because it is small, very aggressive and is native to warm intermittent and sluggish streams of the Midwest (Cross, 1967; Hubbs and Lagler, 1958). Green sunfish were abundant in small intermittent streams at lower elevations, especially in warm, turbid, muddy-bottomed pools that had large amounts of aquatic vegetation and where there were sizable populations of largemouth bass and mosquitofish (Tables 2, 3, 4). Although the abundance of green sunfish was negatively correlated with the abundance of most of the native fishes, it frequently was found streams with them, but in low numbe bles 2, 4). It was not unusual to find sunfish the sole or numerically do species in smaller streams at low ele especially in those streams that had considerably modified by human (Table 3).

Bluegill.—Bluegill were present in the samples but seldom in large They were most abundant at low in the deeper, more heavily vegetated where fish diversity was relatively hig ble 3). Largemouth bass and mosq were usually present here also. Many fish in these pools may have gotte

…3. MEANS OF ENVIRONMENTAL VARIABLES ASSOCIATED WITH FIVE INTRODUCED SPECIES OF FISHES …s OF THE SIERRA NEVADA FOOTHILLS, CALIFORNIA. Explanations of species abbreviations and …ables are given in the text.

…able	Species				
	LMB	GSF	BG	GAM	GSH
…r samples	40	60	30	34	11
… (1–5)	2.8*	2.7*	2.9	2.8*	3.2
… (m)	254 *	331 *	288 *	245 *	277
… (m)	0.5	0.5	0.5	0.4	0.5
…Depth (m)	1.5	1.4	1.7**	1.3	1.1
… (m)	5.0	4.0	5.6	4.8	4.5
… (l/sec)	8.9	4.6*	11.2	7.6	4.1
…ity (1–5)	2.4**	2.4**	2.1	2.5**	1.8
…d veg. (%)	35 **	36 **	31 **	39 **	35
…ng veg. (%)	23 **	26 **	20	27 **	35 **
… (%)	67 **	73 **	65 **	56	57
… (%)	19 **	17 **	24 *	24 *	25
… types (%):					
…	14	15 **	14	19 **	8
…nd	36	40	39	37	44
…ravel	12	9	6	15	14
…obbles	23	18	18	19	21
…ulders	16	18 *	22	11 *	12
… (1–5)	2.6	2.7	2.8	2.7	2.1*
…	25 *	36	26 *	27 *	11 *
… mod. (1–5)	2.9**	3.0**	2.7	2.8	3.2**
… type (1–6)	2.7	2.0*	2.9	2.7*	2.5
… fish abund. (1–5)	2.9	3.0**	2.7	2.9**	3.3**
…ber species	4.9**	3.9**	4.5**	4.5**	4.9**
… fish (%)	31 *	40	40 *	32 *	22 *

* Significant positive correlation ($P < .05$) between the variable and the fish species abundance ratings, in …matrix for all localities (N–130).
** Significant negative correlation, as above.

…4. CORRELATIONS BETWEEN ABUNDANCE RATINGS OF THE ELEVEN MOST ABUNDANT FISHES IN …SAMPLES OF FISHES FROM STREAMS OF THE SIERRA NEVADA FOOTHILLS, CALIFORNIA. Boldface co…cients are significant ($P < .05$).

	LMB	GSF	BG	GAM	GSH	HCH	SQ	HH	SKR	RCH	RB
	1.00										
	.29	1.00									
	.60	.10	1.00								
	.48	.40	.19	1.00							
	.23	.20	.23	.30	1.00						
	.37	.29	–.09	.17	–.01	1.00					
	–.01	–.16	.02	–.12	–.03	.01	1.00				
	–.01	.05	.03	–.05	.01	–.00	.44	1.00			
	–.10	–.30	–.06	–.07	–.00	.01	.43	.14	1.00		
	–.29	–.22	–.18	–.23	–.18	–.12	–.07	–.15	.07	1.00	
	–.30	–.39	–.25	–.27	–.13	–.15	–.18	–.07	–.07	–.02	1.00

from farm ponds which occasionally overflow in the spring. Bluegill and largemouth bass are commonly stocked in such ponds.

Mosquitofish.—Schools of this small (10–40 mm TL) introduced larvivorous species were taken most frequently from warm turbid pools of intermittent streams at low elevations (Table 3). In such pools it was usually found in aquatic vegetation or in shallow water along the edges of pools where water temperatures approached daytime air temperatures (33–38 C). Centrarchids were usually abundant in the deeper waters of these pools but native cyprinids, except the hitch, were uncommon (Tables 2, 4). Streams with mosquitofish usually showed signs of having been extensively changed by human activity, particularly cattle raising (Table 3).

Golden shiner.—The golden shiner, although widely used as a bait fish in California, occurred in only 8% of the samples, and then usually in low numbers. It was found most often in the large warm pools or slow moving stretches of low-altitude streams where other introduced fishes were abundant (Tables 2, 3, 4).

Hitch.—This native cyprinid is more characteristic of the sloughs and large sluggish rivers of the Valley floor than of the intermittent foothill streams (Calhoun, 1966; Murphy, 1948). Nevertheless, it occurred in 10% of the collections. Hitch dominated numerically in four of the samples. It was most abundant in warm, sandy-bottomed streams with large pools where other introduced species, usually green sunfish, largemouth bass and mosquitofish were common (Tables 4, 5). Most of the hitch taken were less than 150 mm long, although in large bodies of water they frequently exceed 300 mm (Calhoun, 1966).

Sacramento squawfish.—The squawfish, a large predaceous minnow, is widely distributed in foothill streams and reservoirs. It occurred in 38% of the samples and was most abundant in the larger intermittent and permanent streams at about the 300 m elevation level (Table 5). These streams contained deep sandy- or rock-bottomed pools that are fairly well shaded and show few signs of modification by man (Table 5). Squawfish were seldom abundant where introduced centrarchids were common. However, they tended to predomin[illegible] size and numbers, where other [illegible] nids and the Sacramento sucker [illegible] mon (Tables 2, 4). Although squ[illegible] often found with rainbow trout [illegible] fornia roach, they were seldom [illegible] where either was common.

Hardhead.—This large omnivoro[illegible] cyprinid was represented in only [illegible] samples but where it occurred it [illegible] dant (Table 2). It was found pr[illegible] clear, deep, sand- and rock-bottom[illegible] of the larger streams at elevation[illegible] 270 and 420 m (Table 5). The[illegible] showed little evidence of man-caus[illegible] and, on the average, only 10% of [illegible] taken with the hardhead were in[illegible] species. The hardhead was alwa[illegible] with the Sacramento squawfish and [illegible] with the Sacramento sucker (Table[illegible]

California roach.—The California [illegible] small (usually less than 100 mm TL) [illegible] minnow that was most abundant [illegible] shaded, clear and rock-bottomed po[illegible] small intermittent tributaries to [illegible] streams (Table 5). It was widely dis[illegible] in the foothills at moderate elevation[illegible] age, 458 m). Where it was taken it [illegible] to be numerically dominant, averagin[illegible] of the fish in 42 collections containing [illegible] 38% of these collections 90% or more [illegible] fish were roach. Fishes that were co[illegible] most commonly with the roach were [illegible] mento sucker, Sacramento squawfish [illegible] green sunfish (Tables 2, 4). For the [illegible] part, the roach was most abundant [illegible] introduced species were rare or absent [illegible] fact that roach were found most [illegible] crowded in large numbers in warm (30–[illegible] isolated pools indicates that it is able to [illegible] vive for extended periods in the summe[illegible] low dissolved oxygen levels. Low oxy[illegible] levels presumably keep other native [illegible] species from permanently occupying [illegible] roach's habitat. However, during the [illegible] dead and dying roach were observed in [illegible] eral of the shallower and more expo[illegible] pools.

Sacramento sucker.—This bottom feeder [illegible] the most widely distributed fish encounte[illegible] It occurred in 42% of the samples and [illegible] taken at elevations ranging from the Valley floor to 880 m. Although it was found [illegible]

...3. MEANS OF ENVIRONMENTAL VARIABLES ASSOCIATED WITH SIX SPECIES OF FISHES ENDEMIC TO ...EAMS OF THE SIERRA NEVADA FOOTHILLS, CALIFORNIA. Explanations of the species abbreviations ...variables are given in the text.

...riable	Species					
	HCH	SQ	HH	RCH	SKR	RB
...r samples	13	49	12	42	54	26
...ature (1–5)	2.5*	3.0	3.5	3.3	3.2	4.7**
...on (m)	276	312 *	294	458	371	748 **
... (m)	0.4	0.5	0.5	0.4	0.4	0.4
...Depth (m)	1.4	1.7**	1.8*	1.3	1.4	1.6
... (m)	3.7	5.8	4.6	3.3	6.2**	4.3
...l/sec)	7.4	10.2	5.1	6.1	10.2	11.7
...ity (1–5)	2.1	1.8	1.8	1.7*	1.7*	1.2*
... veg. (%)	31	20	28	24	22	6 *
...g veg. (%)	25	15	19	17	16	2 *
... (%)	69	53	53	55	47	34 *
... (%)	13 *	38	34	37	39 **	57 **
...m types (%)						
...	5	4 *	3	6	6 **	9
...nd	50	36	47	27 *	39	31
...ravel	15	9	6	10	10	4
...bbles	24	26	14	26	20	15
...ulders	6 *	26	28	30	25	40 **
... (1–5)	2.5	2.8	3.0	3.1**	2.7	3
... (%)	30	29 *	33	53 **	33	61 **
...mod. (1–5)	3.1	2.3*	1.7*	2.5	2.6	1.9*
...m type (1–5)	2.5	3.2	2.7	2.6	3.4**	4.1**
...l fish abund. (1–5)	2.9	2.8**	3.2**	2.8**	2.9**	2.1*
...ber species	5.2**	4.1	4.6**	3.0*	4.1**	2.0*
...e fish (%)	45	75 **	90 **	91 **	79 **	96 **

...gnificant positive correlation ($P < .05$) between the variable and the fish species abundance ratings in ...atrix for all localities.
...gnificant negative correlation, as above.

...types of streams, it was most abundant in ...arger, clear, permanent streams at inter...iate elevations (Table 3). Its most usual ...associates were native minnows, espe...y squawfish and roach (Tables 2, 4). ...re the sucker was abundant, other fish ...tended to be abundant, both in species ...in numbers (Table 2). Most of the ...rs taken were shorter than 75 mm total ...h, and were presumably young of the ... Larger specimens were observed only ...sionally and these in larger pools and ...ing streams. This is not surprising since ...ally the adults live in the large rivers, ... and reservoirs, and make extensive ...ations up tributaries to spawn in spring ...oun, 1966).

...bow *trout.*—Although the rainbow trout ...een widely planted for sport fishing in streams throughout California, it is probably native to most of the streams where it was taken in this study (Calhoun, 1966). However, trout populations in some of these streams may now be artificially maintained by stocking. As is indicated in the extensive literature on rainbow trout in California (which is summarized in Calhoun, 1966), rainbows frequent the cool, clear, fast-flowing permanent streams at the higher elevations. In the foothill region these are streams that have been comparatively little modified by man (Table 5). Overall abundance of fishes and species diversity in such streams was found to be low, probably in part because of low natural productivity and in part because of the occasional use of piscicides by the California Department of Fish and Game to eliminate possible trout competitors, especially Sacramento squawfish

TABLE 6. AVERAGE ABUNDANCE RATINGS (AR) AND AVERAGE PERCENTAGES (%) IN SAMPLES OF F[illegible] IN THE FOUR FOOTHILL FISH ASSOCIATIONS.

	Associations							
N	Introduced Fish 41		Native Cyprinid-Catostomid 24		California Roach 24		Rainbow Trout 13	
Species	AR	%	AR	%	AR	%	AR	%
LMB	1.2	6	0.3	< 1	0.1	1	0.0	[illegible]
GSF	1.9	31	0.5	2	0.6	2	0.0	[illegible]
BG	0.8	9	0.4	1	0.1	1	0.0	[illegible]
GAM	1.4	32	0.2	< 1	0.2	1	0.0	[illegible]
GSH	0.4	3	0.1	< 1	0.0	0	0.0	[illegible]
HCH	0.3	1	0.1	< 1	0.1	1	0.0	[illegible]
SQ	0.4	2	2.6	49	0.3	1	0.0	[illegible]
HH	0.0	0	1.2	18	0.0	0	0.0	[illegible]
RCH	0.1	1	0.5	5	3.1	90	0.0	[illegible]
SKR	0.4	1	1.9	24	0.7	3	0.0	[illegible]
RB	0.0	0	0.2	< 1	0.3	1	0.2	[illegible]
Other Spp.	1.2	14	0.3	< 1	0.0	0	1.9	[illegible]
Native fish	—	4	—	96	—	97	—	[illegible]

and Sacramento sucker. The last two, along with California roach, were the only species ever collected in any numbers with the trout. It is likely, however, that sculpins may have been missed in the sampling of many of the trout streams.

FISH ASSOCIATIONS

When the correlation matrix for the entire set of data was examined, it became evident that there were four distinct associations of fish species. Abundance ratings of fishes in these associations were positively corr[illegible] with each other and showed negativ[illegible] relations or no correlations with spec[illegible] other associations (Table 4). The as[illegible] tions thus indicated are: 1) the Intro[illegible] Fishes Association, consisting of larg[illegible] bass, bluegill, green sunfish and mo[illegible] fish, along with other less-common [illegible] duced species and the native hitch; [illegible] Native Cyprinid-Catostomid Associatio[illegible] dominately Sacramento squawfish, S[illegible] mento sucker and/or hardhead, along [illegible]

TABLE 7. PERCENTAGES OF SAMPLES ASSIGNED TO EACH OF THE FOUR FISH ASSOCIATIONS TH[illegible] FOUND IN THE SIX TYPES OF STREAMS OF THE SIERRA NEVADA FOOTHILLS, CALIFORNIA[illegible]

	Fish Associations			
Stream Type	Introduced Fish	Native Cyprinid-Catostomid	California Roach	Rainbow Trout
1	73	29	67	0
2	3	12	0	0
3	0	4	0	0
4	7	25	29	0
5	3	21	4	78
6	14	8	0	22
Intermittent (1–3)	76	45	67	0
Permanent (4–6)	24	55	33	100
N	41	24	24	13

...numbers of California roach in some ...; 3) the California Roach Association, made-up almost completely of roach; 4) the Rainbow Trout Association, ...up mostly of rainbow trout.

...obtain means and standard deviations ...ach of the 46 variables for each association so that the environment where each ...ation was found could be characterized exactly, each sample was assigned to ...d the four associations if 70% or more ... fish in that sample belonged to the ...ant species of the association. The ...level was chosen because when the ...h cards were sorted for rainbow trout ...for California roach, both of which be... to associations dominated by single ...es, it was found that in most of the sam... containing these species, they either ...-up more than 70% or less than 30% of ...catch. On this basis, 78% of the samples ...d be assigned to one or another of the ... associations (Table 6). Twenty-two of ...28 remaining samples could be described ...epresenting transition populations since ... contained about an equal mixture of ... from two different associations. Eleven ...these 22 were transition collections be...en the Native Cyprinid-Catostomid Association and the Introduced Fishes Association. Of the remaining six collections, four ... samples from small streams dominated ...hitch, one was from a site dominated by ...spine stickleback and riffle sculpin, and ... was from a site containing a mixture of ...ies from all four associations. In all, ...y 57% of the collections contained 70% ... more of native fishes.

...oduced Fishes Association.—This was the ... common association encountered (32% ... the samples) and, because it occurred at ... lowest elevations in the foothills, it con...ed the greatest variety of fishes. In addi... to the four dominant introduced species, ... were frequently a few native fishes in ...ples from sites containing this associa.... These fish were usually large and had ...ently come from higher elevations dur... the high-water flows of winter. Fre...ntly present also in the samples were a ... representatives of the other introduced ...cies. These fish had presumably moved ...tream to the foothill pools during high ...er, from the large rivers and reservoirs where they are more abundant. This association is similar to the hitch association of Murphy (1948) and Hopkirk (1967).

The Introduced Fishes Association was most often found in the warm turbid pools of the smaller intermittent streams (Tables 7, 8). Such pools lacked shade, had large amounts of aquatic vegetation and had muddy-sandy bottoms (Table 8). The streams and the areas around them were usually extensively modified by human activities.

Native Cyprinid-Catostomid Association.—The Sacramento squawfish is usually the numerically dominant fish of this association, although sometimes the Sacramento sucker or the hardhead play this role (Table 6). This association occurred in several types of streams (Table 7) at intermediate elevations and often included some fish from other associations, most commonly green sunfish and California roach (Table 6). Although the Native Cyprinid-Catostomid Association occurred in all of the six stream types, the habitats in which the association was found had much in common. They tended to be clear and warm, bottoms were of sand or bedrock, and the stream stretches usually had pools (Table 8). Even the intermittent streams were usually flowing, if only a trickle, in the sections where this association was found. These stream stretches were largely unshaded, contained little aquatic vegetation, and showed few signs of having been altered by man.

California Roach Association.—Since California roach made up 90% of the fish of this association, the characteristics of the small, clear, mostly intermittent, streams where it was found are much like those already described for the roach as a species (Tables 6, 7, 8). However, the streams where the roach made up 70% or more of the fish population were even smaller than those associated with the overall range of the fish and contained a greater percentage of pools (Table 8).

Rainbow Trout Association.—This association is also dominated by a single species of fish, the rainbow trout, and is found in the cool permanent streams at higher elevations in the foothills (Tables 6, 7, 8).

These associations of the San Joaquin River system are approximately equivalent to the four associations of the Sacramento

TABLE 8. MEANS OF ENVIRONMENTAL VARIABLES ASSOCIATED WITH THE FOUR FISH ASSOCIATIONS [illegible] STREAMS OF THE SIERRA NEVADA FOOTHILLS, CALIFORNIA.

	Fish Associations			
	Introduced Fish	Native Cyprinid-Catostomid	California Roach	Rainbow Trout
Temperature (1–5)	2.6[c]	33.0[c]	3.6[c]	4.5
Elevation (m)	286 [c]	334 [c]	446 [b]	846
Depth (m)	0.5	0.4	0.4	0.5
Max. Depth (m)	1.3	1.8	1.0[c]	1.4
Width (m)	4.5	5.7	1.6[c]	2.1
Flow (l/sec)	7.1	11.7	2.5	11.9
Turbidity (1–5)	2.8[a]	1.6[c]	1.6[c]	1.[illegible]
Rooted veg. (%)	36 [c]	16	24	7
Floating veg. (%)	25	11	17	4
Pools (%)	68 [c]	41 [c]	60	33
Riffles (%)	20 [b]	47 [c]	31 [b]	58
Bottom types (%):				
Silt	21	1 [a]	9	15
Sand	33	43	26	31
Gravel	11	6	15	4
Cobbles	24	22	24	15
Boulders	11 [c]	29	27	36
Cover (1–5)	2.7	2	3	3.[illegible]
Shade (%)	32	30 [b]	61 [b]	68
Man mod. (1–5)	3.2[c]	1.7[b]	3.0[b]	1.[illegible]
Stream type (1–6)	2.3[c]	3.6	2.0[b]	4.[illegible]
Total fish abund. (1–5)	2.7[c]	2.9[c]	3.0[c]	1.9
Number species	3.7[c]	3.8[b]	2.3[c]	1.1
N	41	24	24	13

[a] Mean ± one standard deviation does not overlap the mean of any other association.
[b] Mean ± one standard deviation overlaps the mean of one other association.
[c] Mean ± one standard deviation overlaps the mean of two other associations. Means not footnoted [illegible] standard deviation overlap all other three means.

River system of Murphy (1948) and Hopkirk (1967). However, they seem to have less species diversity, presumably because the foothill streams of the San Joaquin River system are generally smaller and less permanent than those of the Sacramento River system.

DISCUSSION

As is shown in the tables, especially Tables 6, 7 and 8, there is considerable overlap in the characteristics of the four fish associations, both in environmental characteristics and in fish species present. The overlap of environmental characteristics is especially apparent when means and standard deviations are examined (Table 8). For most of the variables considered, the mean, plus or minus one standard deviation, for one association overlaps the mean of the same [illegible] for two or three other associations. The [illegible] bow Trout Association has the least [illegible] of overlap of variables, followed by [illegible] California Roach Association. How[illegible] each association, at least those of the [illegible] fishes, has its own set of means and [illegible] around those means for the environ[illegible] variables and these can be consider[illegible] intersect to form a hypervolume, [illegible] Hutchinson (1965) described for the [illegible] of individual species.

The Introduced Fishes Association [illegible] ever, does not fit this conceptual [illegible] very well, because it is recent in orig[illegible] less consistent in its species comp[illegible] Presumably, it has not had time to [illegible] and become established *in situ*. The [illegible] ties of its associated environmental [illegible]

TABLE 9. CORRELATIONS BETWEEN SELECTED ENVIRONMENTAL VARIABLES RECORDED AT THE 30 FISH STATIONS IN THE STREAMS OF THE SIERRA NEVADA FOOTHILLS, CALIFORNIA. Boldface coefficients are significant (P > .05).

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Temp. (1–5)	1.00														
Elev. (m)	.37	1.00													
Max. depth (m)	.14	.03	1.00												
Flow (l/sec)	.20	.01	–.45	1.00											
Turbidity (1–5)	–.39	–.40	–.11	–.26	1.00										
Rooted veg. (%)	–.27	–.33	–.17	–.31	.29	1.00									
Floating veg. (%)	–.27	–.31	–.21	–.38	.25	.86	1.00								
Pools (%)	–.30	–.19	.06	–.48	.45	.21	.25	1.00							
Riffles (%)	.26	.34	.06	.40	–.51	–.20	–.24	–.74	1.00						
Mud (%)	–.19	–.05	–.11	–.21	.27	.26	.27	.12	–.21	1.00					
Sand (%)	.05	.06	.08	–.20	.03	–.17	–.09	.11	–.20	–.34	1.00				
Boulder (%)	.28	.35	.27	.15	–.36	–.12	–.15	–.15	.42	–.25	–.19	1.00			
Shade (%)	.30	.45	–.20	–.26	–.13	–.24	–.20	.06	–.06	.12	–.07	.09	1.00		
Man mod. (%)	–.30	–.25	–.22	–.21	.20	.25	.23	.24	–.37	.31	–.06	–.45	–.05	1.00	
Stream type	.40	.13	.26	.76	–.35	–.30	–.36	–.69	.55	–.22	–.10	.18	–.09	–.33	1.00

...ics to those of the Native Cyprinid-Catostomid Association indicates that it may be still expanding its dominance into waters now occupied by the native fishes or will do so as the waters become more altered by human activities (Table 8). In the study area the introduced fishes were most often found where there were: 1) impoundments that decreased stream flow and increased the pool-type habitat; 2) organic pollution from livestock, and, to a lesser extent, from sewage that promoted algal growths and increased turbidity and 3) siltation, mostly from roadways and construction, that increased turbidity and made the pools shallower by deposition of mud and silt.

It should be emphasized that the individual environmental factors considered are not necessarily independent variables (Table 9). For example, two factors strongly associated with fish distribution, elevation and water temperature, were highly correlated with each other. As the elevation increased there was a greater divergence between water temperatures and air temperatures. Most of the other variables that seemed to be important in determining the distribution of the foothill fishes were either positively or negatively correlated with elevation and temperature (Table 9).

Not surprisingly, the variables which have positive or negative correlation with these two variables also had a similar correlation with rainbow trout abundance and, to a lesser extent, with the California roach abundance and with their respective associations. Conversely, correlations of these variables with member species of the Introduced Fishes Association, and also of the Native Cyprinid-Catostomid Association, tended to have the opposite sign.

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Olfactory Orientation in Breeding Mexican Toads, *Bufo valliceps*

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Breeding male toads, *Bufo valliceps*, were collected from or en route to breeding sites and tested in an olfactometer for the ability to discriminate and respond to the odor of water from their home breeding habitats. Six of seven populations tested demonstrated a preference for this odor. Alternatives discriminated against included slightly humidified air and the odors of distant and adjacent bodies of water, either temporary or permanent, all of which were used for breeding by conspecifics. The response diminished through time but could be revived by injection of gonadotropins. Toads in breeding condition which had not been exposed to their breeding habitat for at least one month responded positively to its odor. Tests for celestial orientation yielded no evidence of either a nocturnal or diurnal celestial-compass mechanism.

HOMING by anurans to breeding sites is well documented (Heusser, 1969; Jameson, 1957; Oldham, 1966, 1967; Tracy and Dole, 1969b). Several types of orientation mechanisms may function during these breeding movements. Individuals are sometimes attracted to conspecific mating calls (Bogert, 1947, 1960). However, breeding choruses do not seem to be of primary importance since animals returning to their home ponds after displacement often ignore choruses in foreign ponds and recorded choruses (Jameson, 1957; Oldham, 1966, 1967). Field studies involving sensory ablation have implicated both visual and olfactory mechanisms (Oldham, 1966, 1967). Several species respond positively to the odors of their breeding habitats in the laboratory (Grubb, in press; Jungfer, 1943; Martof, 1962). Celestial cues can guide some species along a particular compass course (Y-axis) relative to the shoreline of a breeding pond (Ferguson, 1967; Gorman and Ferguson, 1970; Tracy and Dole, 1969a). Other mechanisms, such as reference to local land[marks] and kinesthesia, are possible but ha[ve not] been satisfactorily investigated in an[urans]. A species may use more than one orient[ation] mechanism. Both *Bufo woodhousei* [...] and *Pseudacris triseriata* respond to [...] calls, celestial cues and pond odors (G[rubb], in press; Ferguson and Landreth, [...] Landreth and Ferguson, 1966; Martof, [...]

Some of the same mechanisms pr[obably] function in nonbreeding homing move[ments] in anurans although these have be[en] extensively studied. Y-axis orientat[ion is] used by some species (Ferguson, La[ndreth] and Turnipseed, 1965; Ferguson et al., [...] Taylor and Ferguson, 1970). Local [...] and olfactory cues have also been imp[licated] by sensory ablation studies (Dole, 1968; [...] Grubb, 1970).

In central Texas, the Mexican to[ad, *Bufo*] *valliceps*, breeds from March throu[gh Sep]tember, usually after rains (Blair, 19[...]. In]dividuals show fidelity to particular b[reeding] sites (Blair, 1960) and may move up[...]