Assemblages of Fishes and Their Associations with Environmental Variables, Lower San Joaquin River Drainage, California

BY LARRY R. BROWN

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FOREWORD

The mission of the U.S. Geological Survey (USGS) is to assess the quantity and quality of the earth resources of the Nation and to provide information that will assist resource managers and policymakers at Federal, State, and local levels in making sound decisions. Assessment of water-quality conditions and trends is an important part of this overall mission.

One of the greatest challenges faced by water-resources scientists is acquiring reliable information that will guide the use and protection of the Nation's water resources. That challenge is being addressed by Federal, State, interstate, and local water-resource agencies and by many academic institutions. These organizations are collecting water-quality data for a host of purposes that include: compliance with permits and water-supply standards; development of remediation plans for specific contamination problems; operational decisions on industrial, wastewater, or water-supply facilities; and research on factors that affect water quality. An additional need for water-quality information is to provide a basis on which regional- and national-level policy decisions can be based. Wise decisions must be based on sound information. As a society we need to know whether certain types of water-quality problems are isolated or ubiquitous, whether there are significant differences in conditions among regions, whether the conditions are changing over time, and why these conditions change from place to place and over time. The information can be used to help determine the efficacy of existing water-quality policies and to help analysts determine the need for and likely consequences of new policies.

To address these needs, the U.S. Congress appropriated funds in 1986 for the USGS to begin a pilot program in seven project areas to develop and refine the National Water-Quality Assessment (NAWQA) Program. In 1991, the USGS began full implementation of the program. The NAWQA Program builds upon an existing base of water-quality studies of the USGS, as well as those of other Federal, State, and local agencies. The objectives of the NAWQA Program are to:

- Describe current water-quality conditions for a large part of the Nation's freshwater streams, rivers, and aquifers.
- Describe how water quality is changing over time.
- Improve understanding of the primary natural and human factors that affect water-quality conditions.

This information will help support the development and evaluation of management, regulatory, and monitoring decisions by other Federal, State, and local agencies to protect, use, and enhance water resources.

The goals of the NAWQA Program are being achieved through ongoing and proposed investigations of 59 of the Nation's most important river basins and aquifer systems, which are referred to as study units. These study units are distributed throughout the Nation and cover a diversity of hydrogeologic settings. More than two-thirds of the Nation's freshwater use occurs within the 59 study units and more than two-thirds of the people served by public water-supply systems live within their boundaries.

National synthesis of data analysis, based on aggregation of comparable information obtained from the study units, is a major component of the program. This effort focuses on selected water-quality topics using nationally consistent information. Comparative studies will explain differences and similarities in observed water-quality conditions among study areas and will identify changes and trends and their causes. The first topics addressed by the national synthesis are pesticides, nutrients, volatile organic compounds, and aquatic biology. Discussions on these and other water-quality topics will be published in periodic summaries of the quality of the Nation's ground and surface water as the information becomes available.

This report is an element of the comprehensive body of information developed as part of the NAWQA Program. The program depends heavily on the advice, cooperation, and information from many Federal, State, interstate, Tribal, and local agencies and the public. The assistance and suggestions of all are greatly appreciated.

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Chief Hydrologist

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CONVERSION FACTORS

Multiply	By	To obtain
cubic meter per second (m^3/s)	35.31	cubic foot per second
kilometer (km)	0.6214	mile
meter (m)	3.281	foot
meter per second (m/s)	3.281	foot per second
millimeter (mm)	0.03937	inch
square kilometer (km^2)	0.3861	square mile

Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as follows:

$$°F=1.8\ °C+32.$$

VERTICAL DATUM

Sea level: In this report "sea level" refers to the National Geodetic Vertical Datum of 1929 (NGVD of 1929)--a geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called Sea Level Datum of 1929.

WATER-QUALITY UNITS

Specific conductance is given in microsiemens per centimeter at 25 degrees Celsius (µS/cm at 25 °C).

Concentrations of chemical constituents in water are given either in milligrams per liter (mg/L) or micrograms per liter (µg/L).

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Abstract

Twenty sites in the lower San Joaquin River drainage, California, were sampled from 1993 to 1995 to characterize fish assemblages and their associations with measures of water quality and habitat quality. In addition, four fish community metrics were assessed, including percentages of native fish, omnivorous fish, fish intolerant of environmental degradation, and fish with external anomalies. Of the 31 taxa of fish captured during the study, only 10 taxa were native to the drainage. Multivariate analyses of percentage data identified four site groups characterized by different groups of species. The distributions of fish species were related to specific conductance, gradient, and mean depth; however, specific conductance acted as a surrogate variable for a large group of correlated variables. Two of the fish community metrics—percentage of introduced fish and percentage of intolerant fish—appeared to be responsive to environmental quality but the responses of the other two metrics—percentage of omnivorous fish and percentage of fish with anomalies—were less direct. The conclusion of the study is that fish assemblages are responsive to environmental conditions, including conditions associated with human-caused disturbances, particularly agriculture and water development. The results suggest that changes in water management and water quality could result in changes in species distributions. Balancing the costs and benefits of such changes poses a considerable challenge to resource managers.

INTRODUCTION

Aquatic habitats around the world are rapidly being altered by human activities (Dudgeon, 1992; Moyle and Leidy, 1992; Allan and Flecker, 1993). These alterations in habitat are often accompanied by declines in the native species that are dependent on those habitats. Alterations to stream environments can take many forms, including changes in water quality, instream habitat, riparian habitat, and the introduction of new species. If native species and the communities they form are to be preserved, their responses to such human-induced changes must be understood. Only with such understanding can human activities be modified to reverse, or at least moderate, the detrimental effects on native biodiversity.

The lower San Joaquin River drainage of California exemplifies many of the problems that can occur as a result of human activities. The San Joaquin Valley, part of the San Joaquin Basin and the associated Tulare Basin (fig. 1), once had a wide variety of terrestrial and aquatic habitats, which provided rich resources for Native Americans and early settlers (San Joaquin Valley Drainage Program 1990; Brown,1997). However, as the San Joaquin Valley was converted to agricultural land use, native ecological communities declined. Intensive agricultural activity on the valley floor, accompanied by increasing urbanization, has resulted in changes in water quality and aquatic habitats through several mechanisms. Intensive use of pesticides and fertilizers, which enter surface waters in various ways, has altered water quality (Kuivila and Foe, 1995; Domagalski and others,1997; Kratzer and Shelton,1997; Brown and others, in press). Pesticide concentrations sometimes reach concentrations acutely toxic to sensitive invertebrates (Kuivila and Foe, 1995).

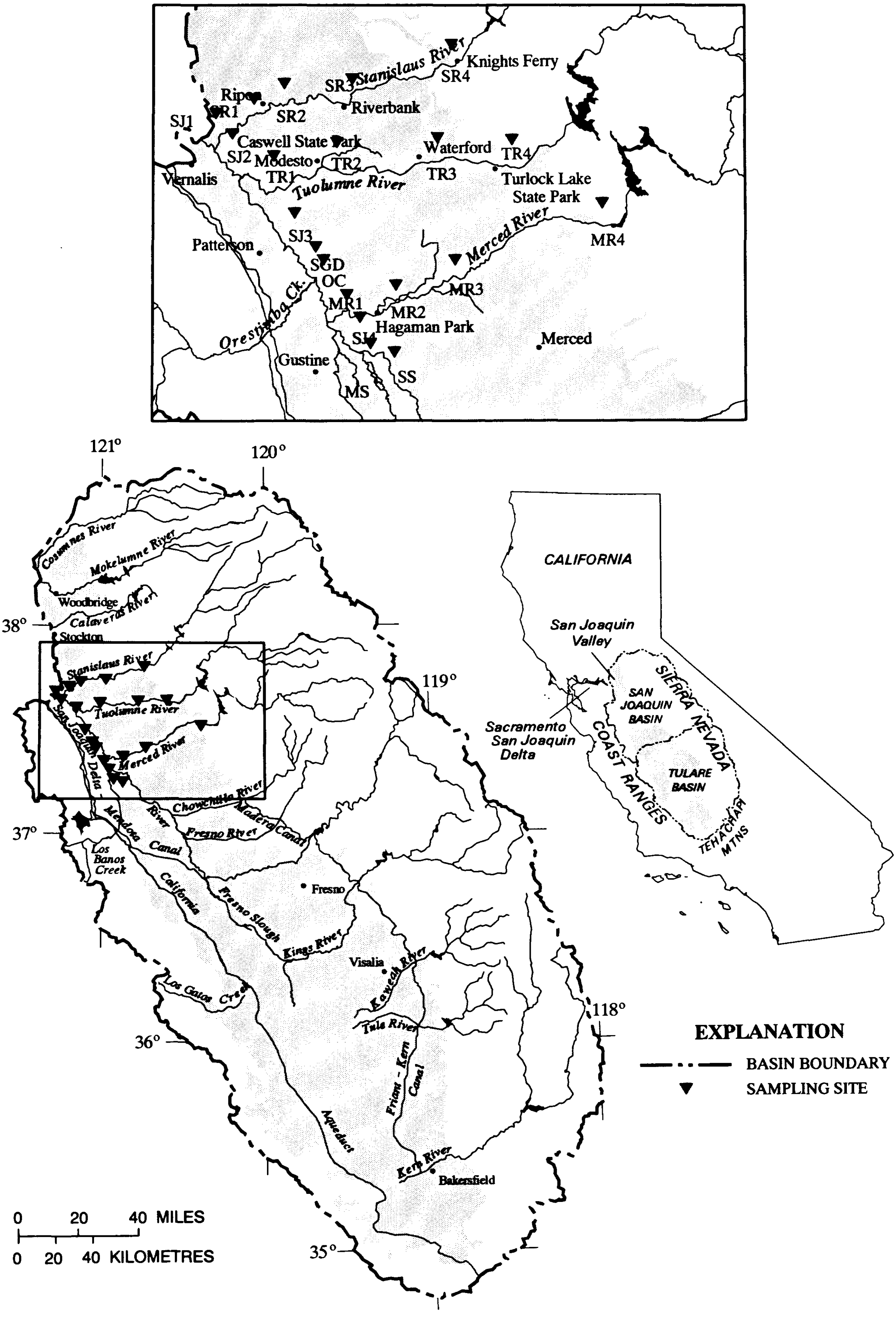

Figure 1. Locations of study sites in the lower San Joaquin River drainage, California. Refer to table 1 for full site names.

Agricultural return flows also may contain high concentrations of dissolved solids (salinity) and trace elements (Saiki, 1984; Hill and Gilliom, 1993; Brown, 1997) that can degrade water quality. Clearing of land for agriculture and flood control activities have resulted in the loss of wetland and riparian habitat, leaving less than 10 percent of the historical area (San Joaquin Valley Drainage Program, 1990; Brown, 1997). Finally, the natural hydrologic regime and geomorphic processes of the rivers have been substantially changed due to dams and diversions that provide water supply and flood control for agricultural and municipal purposes (Kahrl and others, 1978; Mount, 1995).

The San Joaquin and Tulare basins also include forest lands in the Sierra Nevada foothills and mountains. Changes in water and habitat quality at elevations above the valley floor have been less dramatic with streams affected by logging, grazing, urbanization, and smaller-scale dams and diversions operated for municipal water supply and production of hydroelectricity.

These changes in water quality and habitat have been accompanied by changes in the fish fauna, including declines or extinctions of native species and the introduction of new species (Moyle and Nichols, 1974; Moyle, 1976, Jennings and Saiki, 1990; Brown and Moyle, 1993). Introduced species appear to be better adapted for the altered habitat conditions and may affect native species through both competition and predation.

Fish have been suggested as valuable indicators of environmental quality (Karr, 1991; Moyle, 1994). The purpose of this paper is to characterize the fish assemblages (fish species composition at a site) of the lower San Joaquin River drainage of California and to assess their associations with measures of water quality and habitat quality. In addition, four fish community metrics commonly included in metric-based approaches to the use of fish as indicators of environmental degradation (for example, Fausch and others, 1984; Hughes and Gammon, 1987), are calculated to assess the potential for developing such a system for the study area. The metrics calculated are percentages of native fish, omnivorous fish, fish intolerant of environmental degradation, and fish with external anomalies, including lesions, tumors, parasites, and infections.

METHODS

Study Design

Twenty sites were sampled at varying levels of intensity (table 1). In 1993, a total of nine sites were sampled. In 1994, 16 sites were sampled—11 sites sampled for the first time and 5 sites previously sampled in 1993. In 1995, three of the sites sampled in the previous two years were sampled for a third year; two additional stream reaches were also sampled at each of the three sites during the 1995 sampling. The multiple year sampling conducted from 1993 to 1995 was designed to indicate the annual variability of fish assemblages. The multiple reach sampling was designed to indicate the spatial variability in a particular year. The fishes were sampled in August or September of each year. Habitat data and nutrient samples were collected within a month of fish sampling (nutrient samples were not collected in 1995).

Data Collection

Water samples collected for field measurements of specific conductance, pH, alkalinity, and for nutrient analyses were grab samples, except for the 1993 nutrient samples, which were collected using width- and depth-integrated sampling. Field measurements of specific conductance, pH, water temperature, and dissolved oxygen were made with electronic meters. Alkalinity was determined by titration. Nutrient samples were analyzed using standard analytical methods (Fishman and Friedman, 1989). Water temperature and dissolved-oxygen measurements were taken directly in the river. Instantaneous discharge was determined at ungaged sites.

At each site, fish were sampled by an appropriate combination of electrofishing (boat or backpack), seining (3, 9 or 15 m length with 6-mm mesh), or snorkeling. Captured fish were identified and counted, and at least the first 30 individuals of each species were weighed, measured, and examined for external anomalies. Fish observed during snorkeling surveys were identified, counted, and had their lengths estimated.

Table 1. Site name, site code, type of site, and sampling period for all sites sampled during the study in the lower San Joaquin River drainage, California

[Site types: MR, sites where three reaches were sampled in one year; MY, sites sampled in more than one year; and SY, sites sampled in only one year]

Site name	Site code	Site type	Sampling period
Merced River at River Road	MR1	MR, MY	1993-95
Merced River at Hagamann County Park	MR2	SY	1994
Merced River at McConnell State Park	MR3	SY	1994
Merced River near Snelling Diversion Dam	MR4	SY	1994
Mud Slough near Gustine	MS	SY	1993
Orestimba Creek at River Road	OC	SY	1993
Salt Slough at Lander Avenue	SS	SY	1993
San Joaquin River near Vernalis	SJ1	MY	1993-94
San Joaquin River at Maze Road	SJ2	SY	1994
San Joaquin River near Patterson	SJ3	MY	1993-94
San Joaquin River at Fremont Ford	SJ4	SY	1994
Spanish Grant Drain	SGD	SY	1993
Stanislaus River at Caswell State Park	SR1	SY	1994
Stanislaus River near Ripon	SR2	MR, MY	1993-95
Stanislaus River near Riverbank	SR3	SY	1994
Stanislaus River near Knights Ferry	SR4	SY	1994
Tuolumne River at Shiloh Road	TR1	SY	1994
Tuolumne River at Modesto	TR2	MR, MY	1993-95
Tuolumne River near Waterford	TR3	SY	1994
Tuolumne River at Turlock State Recreation Area	TR4	SY	1994

Length of the sampling reach was determined in one of two ways. If there were repeating habitat units (pools, riffles, runs), then the reach was defined as the length of stream containing two repetitions of the habitat units present. When repeating habitat units were not present, reach length was defined as 20 times the channel width to an upper limit of about 1,000 m. Actual reach lengths ranged from 120 to 1,200 m.

Habitat variables were measured at each of six transects within each sampling reach. At sites with distinct habitat types (pool, riffle, run), transects were placed to reflect the availability of each habitat; otherwise, the transects were placed at equally spaced intervals. Stream width (wetted channel) was measured directly from the transect tape. Open canopy was measured from midstream with a clinometer as the number of degrees (of 180 degrees) of sky above the transect not obscured by objects. Instream cover for fish was visually estimated as the percentage of stream area with object cover within 2 m of both the upstream and downstream sides of the transect tape. Depth, velocity, and substrate were measured at three or four points at each transect, including points at about one-quarter, one-half, and three-quarters of the stream width. Additional measurements were made to account for morphological features, such as channel bars and islands. Depth was measured with a wading rod. Velocity was measured with an electronic meter (Marsh-McBirney). Substrate was estimated as the dominant substrate at each transect point, and was classified as (1) organic detritus, (2) silt, (3) mud, (4) sand (0.02-2 mm), (5) gravel (2-64 mm), (6) cobble (64-256 mm), (7) boulder (>256 mm), or (8) bedrock or hardpan (solid rock or clay forming a continuous surface). Stream gradient, stream sinuosity, and elevation were determined from U.S. Geological Survey 1:24,000 topographic maps. Stream sinuosity was measured as river distance divided by the straightline distance between the upstream and downstream ends of a segment of stream (minimum length of 2 km) containing the sample site. Basin areas and percentages of agricultural and urban land use within each basin area were determined using geographic information system databases.

Data Analysis

The data set used for TWINSPAN and canonical correspondence analysis consisted of one sample from each of the 20 sites. For the 16 sites sampled in more than one year, the 1994 samples were used to minimize the effect of any inter-year variability in fish assemblages, physical conditions, or sampling team experience. Data from four sites sampled only in 1993 also were included. The possible effects of inter-year variation are considered in a separate analysis described later in this section.

For data collected during fish and habitat/ nutrient sampling, maximum values of temperature, specific conductance, pH, and alkalinity were used, as were minimum values for discharge and dissolved oxygen. These values represent levels most stressful to fish and would most likely affect their survival and distribution. Habitat variables were analyzed as the mean of the 6 transect values or the mean of the 18 or more point values.

Water-quality variables with fewer than 50 percent detections were deleted from analyses. The remaining water-quality and habitat variables were examined for normality and $\log_{10}(x+1)$ transformed (when appropriate), standardized to a mean of 0 and standard deviation of 1, then analyzed with principal components analysis (PCA). Only principal components (PC) with eigenvalues greater than one were retained for interpretation. A reduced set of environmental variables was selected for association with fish assemblages by choosing one variable to represent groups of variables with high (>0.70) loadings on one of the PCs. This selection was somewhat arbitrary but emphasis was placed on variables that were accurately measured in the field or from maps. All variables that did not load highly (>0.70) on one of the retained PCs also were included.

For multivariate analysis, fish data were converted to percentage abundance of each species in a sample. Western mosquitofish (*Gambusia affinis*) and lampreys (*Lampetra* spp.) were not included in these analyses because they were not sampled in a consistent manner at all sites. To reduce the influence of rare species, only species found at three or more sites and making up at least 5 percent of the fish captured at one site were included. Calculation of metric values included all individuals captured. Native species were determined from Moyle (1976). Omnivory and intolerance to environmental degradation were derived from Moyle (1976), Hughes and Gammon (1987), Moyle and Nichols (1973), Brown and Moyle (1993), and P.B. Moyle (University of California, Davis, written commun,, 1996).

Two-way indicator species analysis (TWINSPAN) (Hill, 1979) was used to derive site groupings and species groupings (species assemblages). TWINSPAN is a divisive classification technique that produces an ordered data matrix of sites and species. The analysis was limited to three sequential divisions that could potentially produce eight groups. The four site groups defined by the second level of division were used for comparison of environmental variables and fish metrics using one-way analysis of variance (ANOVA). Site groups after three divisions were used for more fine-scaled interpretation of site and species groupings. Groups defined by the third level of division were not used for ANOVA analyses because some groups consisted of only one site.

Canonical correspondence analysis (CCA) (ter Braak 1986,1987; Jongman and others, 1995) was used to explore the associations of fish assemblages with the final set of environmental variables resulting from PCA. CCA was conducted in the forward selection mode with the significance of each variable tested with a Monte Carlo simulation algorithm before being added to the final model. All variables significant at $P<0.05$ were included in the final model.

Similarity among years and reaches at the multiple year and multiple reach sites were evaluated with correspondence analysis (CA). Data for all years and reaches were included. Only species present in four or more samples, and making up at least 5 percent of the fish captured at one sample, were included. Correspondence analysis is a multivariate technique derived from reciprocal averaging that maximizes the correlation between species scores and sample scores along an assumed gradient (Hill and Gauch, 1980). Thus, sample scores are constrained by species scores, and species scores are constrained by sample scores in an iterative process until a solution is reached.

RESULTS

A total of 31 taxa of fish were captured based on all samples collected, including one hybrid (bluegill-green sunfish). Ten taxa were native to California and 21 taxa were introduced (table 2). In the 20 samples used for the assemblage analyses, 29 taxa of fish were captured, including 9 native species (table 2). Tule perch was only abundant in the lower Stanislaus River (SR1-4) with a few individuals captured at a San Joaquin River mainstem site (SJ2). Sacramento splittail were only capture at two sites (MR1 and TR2) and only in 1995. The lamprey ammocoetes (larvae) captured in the lower drainage could not be identified to species because species identification is based on adult characters. The lampreys were most likely Pacific lamprey (*Lampetra tridentata*) but could also have been river lamprey (*Lampetra ayersi*).

TWINSPAN Site Groupings

The first TWINSPAN division separated the sites on the valley floor from sites in the upper reaches of the large eastern tributaries, except several lower sites on the Stanislaus River were included with the higher elevation group (fig. 2). The division was based on high percentages of a wide variety of introduced species at the valley floor sites and high percentages of native species and introduced smallmouth bass at the other sites.

The second TWINSPAN division of the valley floor sites separated a group of sites including the mainstem San Joaquin River sites and the small southern and western tributaries to the San Joaquin River (San Joaquin mainstem sites) and a group of sites including the lower elevation locations on the large east-side tributaries (lower large tributary sites). The first group was strongly associated with high percentages of fathead minnow, red shiner, threadfin shad and inland silverside. The lower tributary group was associated with high percentages of largemouth bass, smallmouth bass, bluegill, redear sunfish and white catfish.

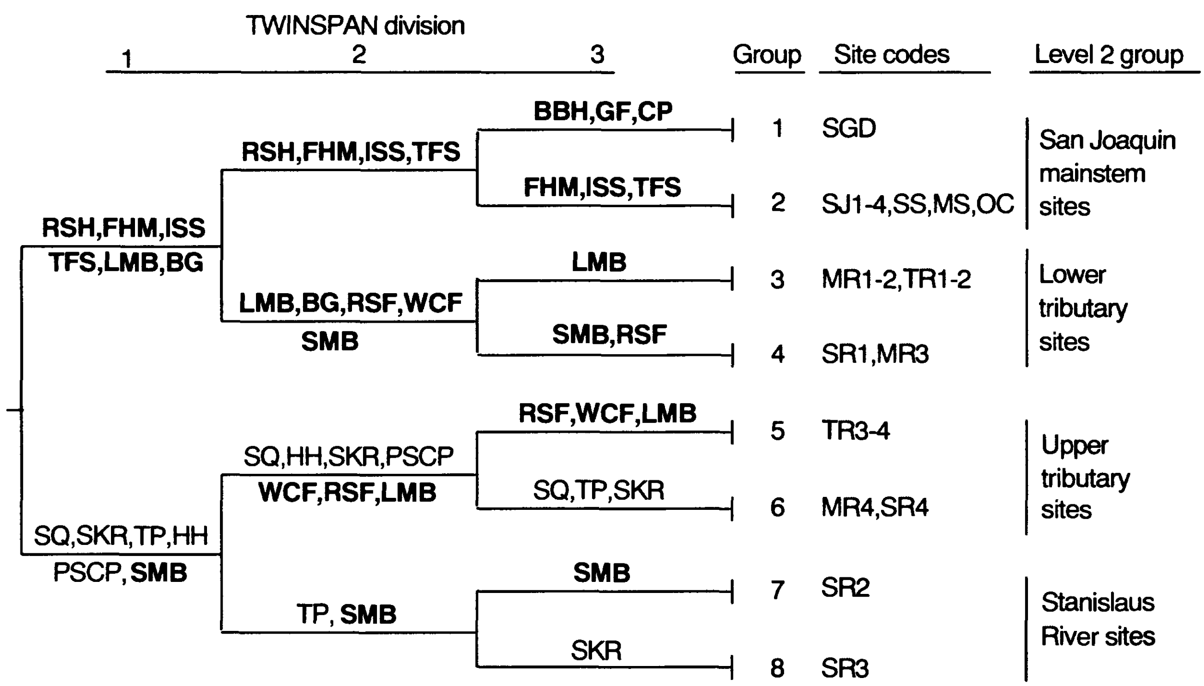

Figure 2. Site groups derived by TWINSPAN analysis and the species associated with each division for the lower San Joaquin River drainage, California. The indicated species are not equivalent to the TWINSPAN species groups identified in table 2. See table 1 for full sites names and table 2 for species names. Regular font indicates native species, and bold font indicates introduced species.

Table 2. Common and scientific names of species captured, origin, species codes, and frequency of occurrence in the 20 site data set and all samples collected from the lower San Joaquin River drainage, California

[**All samples:** 34 samples were collected. **Origin:** I, introduced to California; N, native to California. Trophic group, tolerance to environmental degradation, and TWINSPAN grouping after 2 and 3 divisions also are given. **Trophic groups:** Det, detritivore; Inv, invertivore; Inv/Pis, combination invertivore and piscivore; Omn, omnivore; Pis, piscivore; and Plank, planktivore. **Tolerances to environmental degradation:** I, intolerant, M, moderately tolerant, and T, tolerant]

Family name common name	Scientific name	Origin	Species code	Number of sites		Trophic group	Tolerance	TWIN-SPAN group
				Data set	All samples			
Petromyzontidae (lampreys)								
unknown lampreys	*Lampetra* spp.	N	([1])	1	2	Det	I	([1])
Clupeidae (shad and herring)								
Threadfin shad	*Dorosoma petenense*	I	TFS	6	8	Plank	M	1,1
Salmonidae (salmon and trout)								
Rainbow trout	*Oncorhynchus mykiss*	N	([1])	1	1	Invert	I	([1])
Cyprinidae (minnows)								
Common carp	*Cyprinus carpio*	I	CP	18	30	Omn	T	1,2
Fathead minnow	*Pimephales promelas*	I	FHM	8	10	Omn	T	1,1
Goldfish	*Carassius auratus*	I	GF	10	20	Omn	T	1,2
Hardhead	*Mylopharodon conocephalus*	N	HH	5	8	Omn	I	4,7
Hitch	*Lavinia exilicauda*	N	([1])	2	8	Plank	M	([1])
Red shiner	*Cyprinella lutrensis*	I	RSH	9	18	Omn	T	1,1
Sacramento blackfish	*Orthodon microlepidotus*	N	SBF	2	7	Plank	T	([1])
Sacramento splittail	*Pogonichthys macrolepidotus*	N	ST	0	5	Omn	M	([1])
Sacramento squawfish	*Ptychocheilus grandis*	N	SQ	5	10	Inv/Pis	M	4,7
Catostomidae (suckers)								
Sacramento sucker	*Catostomus occidentalis*	N	SKR	9	18	Omn	M	4,7
Ictaluridae (catfish)								
Black bullhead	*Ameiurus melas*	I	BLBH	8	10	Inv	T	1,2
Brown bullhead	*Ameiurus nebulosus*	I	([1])	3	3	Inv	T	([1])
Channel catfish	*Ictalurus punctatus*	I	CCF	11	18	Inv/Pis	M	1,2
White catfish	*Ameiurus catus*	I	WCF	14	22	Inv/Pis	T	2,3
Poeciliidae (livebearers)								
Western mosquitofish	*Gambusia affinis*	I	([1])	15	20	Inv	T	([1])
Atherinidae (silversides)								
Inland silverside	*Menidia beryllina*	I	ISS	6	15	Plank	M	1,1
Percichthyidae (temperate basses)								
Striped bass	*Morone saxatilis*	I	([1])	4	7	Pis	M	([1])
Centrarchidae (sunfish)[2]								
Black crappie	*Pomoxis nigromaculatis*	I	([1])	3	6	Inv/Pis	M	([1])
Bluegill	*Lepomis macrochirus*	I	BG	16	29	Inv	T	1,2
Green sunfish	*Lepomis cyanellus*	I	GSF	16	28	Inv	T	1,2
Largemouth bass	*Micropterus salmoides*	I	LMB	15	27	Pis	T	2,3
Redear sunfish	*Lepomis microlophus*	I	RSF	11	21	Inv	M	2,4
Smallmouth bass	*Micropterus dolomieu*	I	SMB	12	23	Pis	M	3,5
White crappie	*Pomoxis annularis*	I	([1])	2	3	Inv/Pis	T	([1])
Percidae (perch)								
Bigscale logperch	*Percina macrolepida*	I	([1])	1	7	Inv	T	([1])
Embiotocidae (surf perch)								
Tule perch	*Hysterocarpus traski*	N	TP	5	10	Inv	I	4,6
Cottidae (sculpin):								
Prickly sculpin	*Cottus asper*	N	PSCP	7	13	Inv	M	4,7

[1] Species not included in statistical analyses because of rarity or because of sampling method limitations.

[2] A single bluegill-green sunfish hybrid was collected but is not listed in the table. The hybrid was counted as a separate taxa for the total taxa count.

The second TWINSPAN division of the sites in the upper reaches of the large tributaries resulted in the sites in an upper large tributary group being separated from the middle two Stanislaus River sites. The upper large tributary sites were characterized by high percentages of hardhead, Sacramento squawfish, Sacramento sucker, prickly sculpin, largemouth bass, redear sunfish and white catfish. The Stanislaus River sites were characterized by large percentages of native tule perch and introduced smallmouth bass.

The third level of division separated sites on the basis of different percentages of characteristic species identified at the second level of division, with a couple of exceptions (fig. 2). Spanish Grant drain was separated from the other San Joaquin mainstem sites because of high percentages of black bullhead, goldfish, and carp. The two Stanislaus River sites were separated because of high percentages of smallmouth bass at one and Sacramento sucker at the other. Tule perch were common at both sites.

The four groups of sites defined at the second level of TWINSPAN division had distinctly different physical characteristics (table 3). Twelve of twenty-four comparisons among the site groups were statistically significant. The San Joaquin mainstem sites were most often distinct from the other site groups. The Stanislaus River sites appeared to be intermediate between the upper tributary site group and the other two site groups. These results also are consistent with the PCA analysis.

Table 3. Mean and range for selected water-quality and habitat variables for site groups resulting from TWINSPAN analysis of fish species percentage abundances at sites in the lower San Joaquin River drainage, California

[TWINSPAN site groups: See figure 3 for sites in each group. Mean: Geometric mean for log-transformed variables. **Bold letters** indicate significant differences among site groups (one-way analysis of variance). Values with the same letters were not significantly different (Fischers LSD multiple comparison test). In a few cases, groups were omitted from an analysis because all sites in the group had identical measurements. mg/L, milligram per liter; μS/cm, microseimen per centimeter at 25 degrees Celsius; m, meter; km^2, square kilometer; m^3/s, cubic meter per second; °C, degree Celsius]

Variable	TWINSPAN site groups							
	San Joaquin mainstem		Lower large tributary		Upper large tributary		Stanislaus River	
	Mean	Range	Mean	Range	Mean	Range	Mean	Range
Water-quality variables								
pH[1]	8.1	7.7-8.6	8.0	7.6-8.6	7.7	7.3-8.1	7.9	7.8-7.9
Specific conductance (μS/cm)[1]	1,282 **A**	492-4,670	198 **B**	74-418	85 **B**	42-213	78 **B**	76-80
Oxygen, dissolved (mg/L)	8.1	5.8-9.7	7.7	6.9-9.3	8.8	7.6-9.3	8.3	8.1-8.5
Oxygen saturation (percent)	94	68-113	90	82-115	98	90-107	91	90-92
Alkalinity (mg/L as $CaCO_3$)	171 **A**	72-389	72 **B**	30-128	40 **B**	18-72	35 **B**	34-36
Ammonia (mg/L as N)[1]	0.05 **A**	0.02-0.18	0.02 **AB**	<0.01-0.03	0.01 **B**	<0.01-0.03	0.02 **AB**	0.01-0.03
Nitrite + nitrate (mg/L as N)[1]	1.39 **A**	<0.05-4.00	0.71 **A**	0.05-3.10	0.04 **B**	<0.05-0.12	0.13 **AB**	0.12-0.15
Phosphorus, total (mg/L as P)[1]	0.22 **A**	0.08-0.49	0.08 **B**	0.03-0.28	0.02 **C**	<0.01-0.05	0.02 **BC**	0.02-0.03
Phosphorus, dissolved (mg/L as P)[1]	0.12 **A**	0.05-0.30	0.08 **A**	0.04-0.37	0.03 **B**	0.02-0.05	0.02 **B**	0.02-0.03
Orthophosphate (mg/L as P)[1]	0.11 **A**	0.05-0.29	0.06 **A**	0.02-0.34	0.01 **B**	<0.01-0.04	0.02	0.02
Habitat variables								
Discharge (m^3/s)[1]	2.28	0.06-22.60	2.76	1.38-10.75	2.02	0.76-7.79	9.71	9.49-9.95
Temperature, water (°C)	24.1	21.0-27.0	23.8	21.5-27.5	21.7	18.5-25.5	20.7	19.5-22.0
Mean depth (m)[1]	0.74	0.52-0.95	0.57	0.37-1.17	0.76	0.61-1.69	1.21	0.97-1.51
Mean velocity (m/s)	0.33	0.08-0.55	0.28	0.19-0.39	0.22	0.13-0.41	0.36	0.30-0.42
Mean dominant substrate	3.6 **A**	3.0-4.0	4.0 **A**	3.9-4.3	6.3 **B**	5.9-6.8	4.1 **A**	4.0-4.2
Mean width (m)[1]	19.4	3.8-93.2	27.6	21.2-38.9	36.4	26.9-51.7	30.3	26.8-34.2
Open canopy (degrees)	131	51-166	131	116-146	125	114-137	105	95-114
Instream cover (percent)[1]	4 **A**	2-11	13 **B**	7-31	22 **B**	12-28	33 **B**	18-62
Stream gradient (percent)[1]	0.03	0.01-0.17	0.04	0.02-0.06	0.11	0.09-0.21	0.03	0.01-0.06
Stream sinuosity[1]	1.41	1.04-2.12	1.62	1.06-2.77	1.18	1.11-1.31	1.66	1.42-1.95
Elevation (m)[1]	12 **A**	4-21	14 **A**	8-27	41 **B**	22-88	17 **AB**	13-22
Agricultural land (percent)[1]	52.0 **A**	22.7-95.5	7.5 **B**	4.5-13.7	0.6 **C**	<0.1-2.2	5.5 **B**	5.4-9.4
Agricultural + urban land (percent)[1]	53.7 **A**	24.1-100.0	9.1 **B**	5.0-14.4	1.6 **C**	<0.1-2.2	7.2 **B**	5.4-9.4
Basin area (km^2)[1]	1,484	28-19,023	3,752	2,963-4,822	3,287	2,587-4,053	2,790	2,705-2,877

[1]Variable was log-transformed for analysis.

The fish community metrics also varied among groups (table 4). The percentage of fish with external anomalies was highest at the lower large tributary sites. The percentage was also high for the San Joaquin mainstem group but not statistically different from the other two site groups. Percent intolerant fish was lowest and percent introduced fish highest for the San Joaquin mainstem group and lower large tributary group. Percent omnivorous fish also varied significantly among groups. The highest percentages were found at the San Joaquin mainstem and upper large tributary sites. The Stanislaus River sites were intermediate and the lower large tributary sites had the lowest percentage of omnivorous fish.

TWINSPAN Species Groups

The first TWINSPAN division separated native from introduced species except smallmouth bass was included with the native species group (table 2). The second level of division resulted in four groups of species. A group of species characteristic of the San Joaquin mainstem sites included black bullhead, bluegill, carp, channel catfish, fathead minnow, goldfish, green sunfish, inland silverside, red shiner, and threadfin shad (San Joaquin mainstem species) (table 2). The third TWINSPAN division of this group divided fathead minnow, inland silverside, red shiner, and threadfin shad from the other species. The former species were found almost exclusively at the San Joaquin mainstem sites and all four species were found together at all the sites except Orestimba Creek and Spanish Grant Drain. The remaining species were more broadly distributed and were often found at the lower large tributary sites at low percentages.

The second division also identified a group of species associated with the lower large tributary sites (table 2). This group included largemouth bass, redear sunfish, and white catfish. These species were widely distributed but tended to have their highest percentage abundances in the lower reaches of the large east-side tributary streams. All these species were consistently found at the San Joaquin mainstem sites. The third division of this group separated redear sunfish from largemouth bass and white catfish.

The third species group identified after two TWINSPAN divisions consisted of smallmouth bass (table 2). This species was unique because of its broad distribution. Smallmouth bass was most abundant at Stanislaus River sites. Smallmouth bass occurred in the same geographic areas as native species; however, smallmouth bass also was widely distributed at sites dominated by introduced species.

The fourth level 2 group included the native species. The third division separated tule perch because it was found almost exclusively in the Stanislaus River.

Table 4. Mean and range for selected fish community metrics for site groups resulting from TWINSPAN analysis of fish species percentage abundances at sites in the lower San Joaquin River drainage, California

[TWINSPAN site groups: See figure 3 for sites in each group. Mean: Geometric mean for log-transformed variables. **Bold letters** indicate significant differences among site groups (one-way analysis of variance). Values with the same letters were not significantly different (Fischers LSD multiple comparison test)]

Variable (percent)	TWINSPAN site groups							
	San Joaquin mainstem		Lower large tributary		Upper large tributary		Stanislaus River	
	Mean	Range	Mean	Range	Mean	Range	Mean	Range
External anomalies	17.4**A,B**	10.3-26.6	21.7**A**	12.7-33.3	6.2**B**	1.3-16.1	3.0**B**	1.1-4.8
Omnivorous fish[1]	51.5**A**	17.8-87.1	6.4**B**	2.1-14.2	44.6**A**	27.6-72.6	16.0**A,B**	7.1-34.9
Intolerant fish[1]	<0.1**A**	0-0.4	0.2**A**	0-2.1	9.8**B**	1.4-21.0	32.8**B**	21.4-50.0
Introduced fish[1]	98.3**A**	89.0-100.0	99.1**A**	97.9-100.0	12.5**B**	0-53.2	29.0**A,B**	11.0-73.8

[1]Variable was log-transformed for analysis.

Environmental Variables

The sites varied widely in water-quality and habitat characteristics (table 3). Principal components analysis resulted in five PCs with eigenvalues greater than one, which explained 86 percent of the variance in the data (table 5). The first two PCs explained the majority of the variance (59 percent).

The first principal component described a gradient from sites at high elevations with coarse substrates, high gradients, low values for water quality variables, and low percentages of human landuse to sites at lower elevations with low gradients, fine substrates, high values for water-quality variables and higher percentages of human land use.

Mean width, discharge, sinuosity, and basin area had the highest loadings on PC2. This indicates that the narrowest streams were the straightest and also had the smallest discharges and drainage areas. There was little variability in PC2 scores for sites with high scores on PC1. Sites with low scores on PC1 had highly variable scores on PC2. Thus, sites at lower elevations with similar water quality, substrate and cover characteristics varied greatly in width, discharge, sinuosity, and basin area.

Table 5. Principal component loadings for habitat and water-quality variables from principal components analysis of physical data from sites in the lower San Joaquin River drainage, California

[Principal component: **Bolded values** were considered high (greater than 0.70). mg/L, milligram per liter; µS/cm, microseimen per centimeter at 25 degrees Celsius; m, meter, km^2, square kilometer; m^3/s, cubic meter per second; °C, degree Celsius]

Variable	Principal component				
	1	2	3	4	5
Phosphorus, total (mg/L as P)[1]	**-0.91**	([2])	([2])	([2])	([2])
Specific conductance (µS/cm)[1 3]	**-0.90**	([2])	([2])	([2])	([2])
Orthophosphate (mg/L)[1]	**-0.87**	([2])	([2])	0.32	([2])
Agricultural + urban land (percent)[1]	**-0.84**	0.41	([2])	([2])	([2])
Agricultural land (percent)[1]	**-0.83**	0.39	([2])	-0.30	([2])
Phosphorus, dissolved (mg/L as P)[1]	**-0.81**	([2])	([2])	0.32	([2])
Nitrate + Nitrite (mg/L as N)[1]	**-0.76**	([2])	-0.39	([2])	([2])
Ammonia (mg/L as N)[1]	**-0.75**	0.31	([2])	([2])	([2])
Alkalinity (mg/L as $CaCO_3$)	**-0.70**	([2])	0.50	-0.35	([2])
Elevation (m)[1]	0.73	0.41	([2])	([2])	([2])
Instream cover (percentage of area)[1]	0.76	([2])	([2])	0.40	([2])
Mean dominant substrate	0.83	([2])	([2])	([2])	([2])
Mean width (m)[1 3]	0.29	**-0.94**	([2])	([2])	([2])
Basin area (km^2)[1]	([2])	**-0.92**	([2])	([2])	([2])
Discharge (m^3/s)[1]	([2])	**-0.82**	-0.50	([2])	([2])
Sinuosity[1]	-0.26	**-0.71**	-0.34	([2])	([2])
Gradient (percent)[1 3]	0.65	0.55	([2])	([2])	([2])
Mean depth (m)[1 3]	([2])	([2])	-0.52	-0.63	([2])
Mean velocity (m/s)[1]	([2])	([2])	-0.69	([2])	0.43
Open sky (percent)[1]	([2])	-0.65	0.49	([2])	-0.46
Oxygen, dissolved (mg/L)[1]	([2])	([2])	0.56	-0.46	0.60
Oxygen saturation (percent)[1]	([2])	([2])	0.62	-0.30	0.69
pH[1 3]	-0.68	-0.36	([2])	0.37	([2])
Temperature, water (°C)[1]	-0.56	([2])	0.30	0.45	([2])
Percentage of variance explained	40	19	12	8	7

[1]Variable was log-transformed for analysis.

[2]Loadings of less than 0.30.

[3]Variables included in the canonical correspondence analysis.

Canonical Correspondence Analysis

The forward selection procedure resulted in the retention of three variables in the model (table 6). Specific conductance was an important variable for both CCA axes 1 and 2, though it was most important only for CCA axis 1 (table 6). Gradient was an important variable on all three CCA axes and was most important on axis 3. Mean depth was the most important variable on CCA axis 2.

Separation among the TWINSPAN site groups was most pronounced for the San Joaquin mainstem sites (fig. 3*A*). The species plot (fig. 3*B*) indicates that the percentages of fathead minnow, inland silverside,

Table 6. Results of canonical correspondence analysis relating fish assemblages to environmental variables for sites in the lower San Joaquin River drainage, California

Environmental variable	Eigenvalue	Canonical coefficent		
		Axis 1	Axis 2	Axis 3
Specific conductance	0.72	[1]1.14	[1].51	0.46
Mean depth	.36	.05	[1]1.02	-.27
Gradient	.30	[1].23	[1].55	[1]1.13
Percentage of species variance explained		21.1	10.9	7.6
Percentage of species-environment relation explained		53.2	27.7	19.1

[1]T-value for the canonical coefficient was greater than 2.1 indicating that the variable made an important contribution to a canonical axis (ter Braak, 1987).

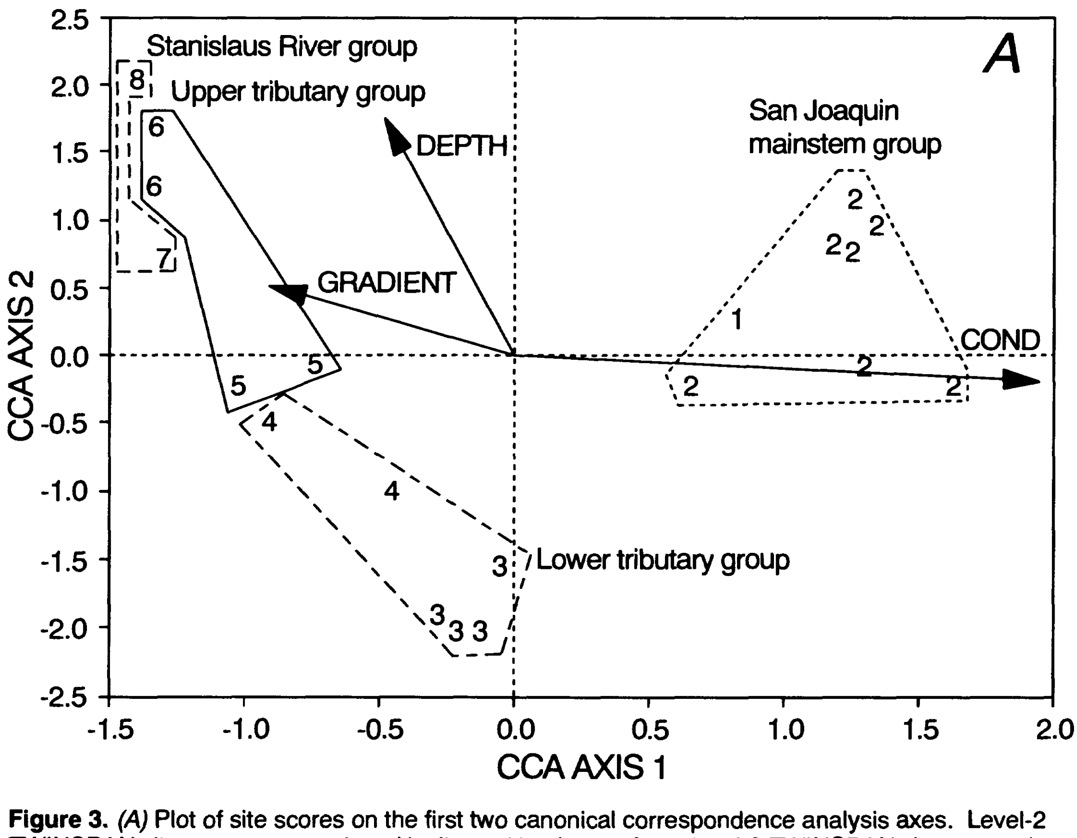

Figure 3. *(A)* Plot of site scores on the first two canonical correspondence analysis axes. Level-2 TWINSPAN site groups are enclosed by lines. Numbers refer to level-3 TWINSPAN site groups (see fig. 2 for sites included in each group), *(B)* Plot of species scores on first two canonical correspondence analyses axes. Level-2 TWINSPAN groups are enclosed by lines. See table 2 for species names. For both plots, the arrows represent the correlation of physical variables with the axes (COND=specific conductance). Arrows parallel to an axis indicate a high correlation and perpendicular to an axis indicate a low correlation.

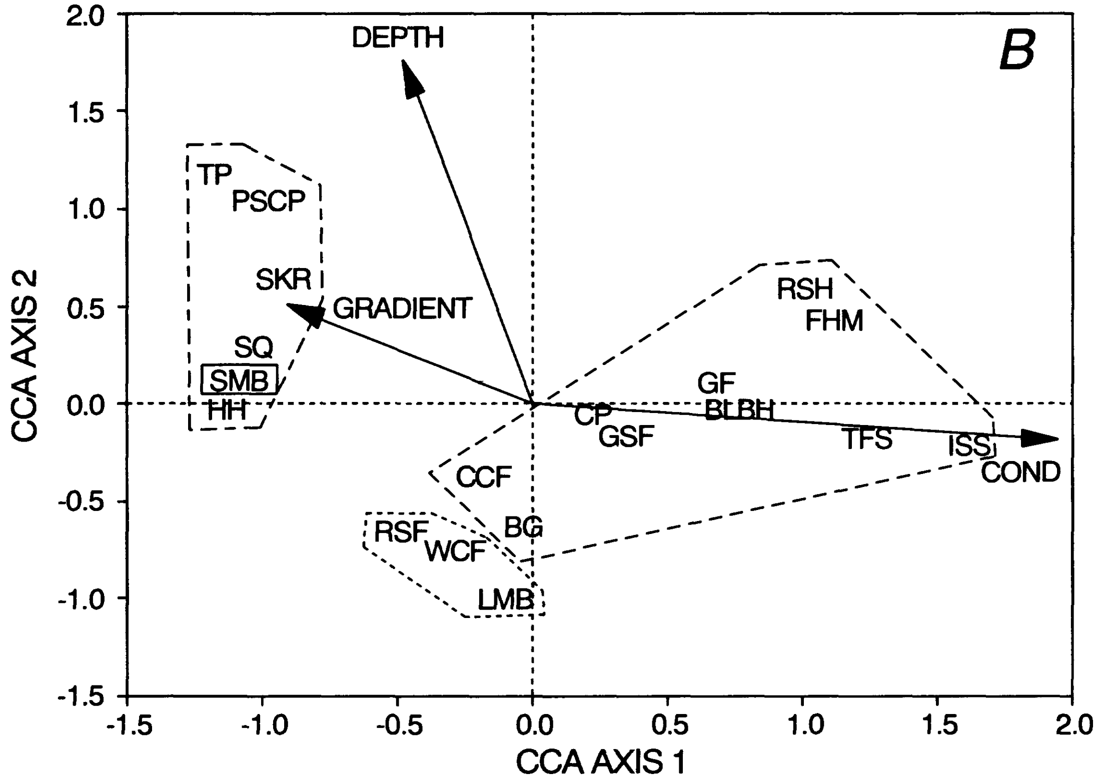

Figure 3.—*Continued.*

red shiner, and threadfin shad were most important in separating the San Joaquin mainstem group from the others. The lower large tributary site group was also well separated from other groups except for SR1 (the 4 in the upper left of the group) which appeared more closely related to the upper large tributary sites. The Stanislaus River group does not appear distinctive in the ordination and is closely associated with the upper tributary sites. TWINSPAN is a divisive technique and divides groups on the basis of differences. The presence of tule perch and high percentages of smallmouth bass were sufficient for TWINSPAN to separate the groups. However, in the ordination, the species common among the two site groups (hardhead, Sacramento squawfish, Sacramento sucker, and prickly sculpin) were responsible for the sites grouping together (fig. 3*B*).

Annual and Spatial Variability

The first four CA axes explained 57.1 percent of the variance in the species data. The first two axes explained 19.2 and 14.8 percent of the variance, respectively. Visual inspection of plots of reach scores on the first two CA axes indicated that the differences among reaches at a site were generally smaller than differences between sites (fig. 4*A*). Except for reach B at MR1, reaches are similarly clustered and the choice of any reach would not substantially change interpretation of the associations among sites. Reach B differed primarily because of a higher percentage of common carp and lower percentage of inland silverside.

In contrast, differences among years were more substantial. The 1995 results were different from the other two years. The major differences in 1995 were the presence of native species, including Sacramento blackfish, Sacramento squawfish, Sacramento sucker, and splittail, at the Merced and Tuolumne River sites and the presence of large percentages of young-of-year goldfish and carp at the Stanislaus River sites (fig. 4*B*). The 1993 and 1994 results were most different for SJ1 and MR1. A boat electroshocker was not available in 1993 and the combination of backpack shocking and seining utilized in 1993 was only partially effective at these sites. This was one of the reasons that the 1994 data was emphasized in the previous analyses.

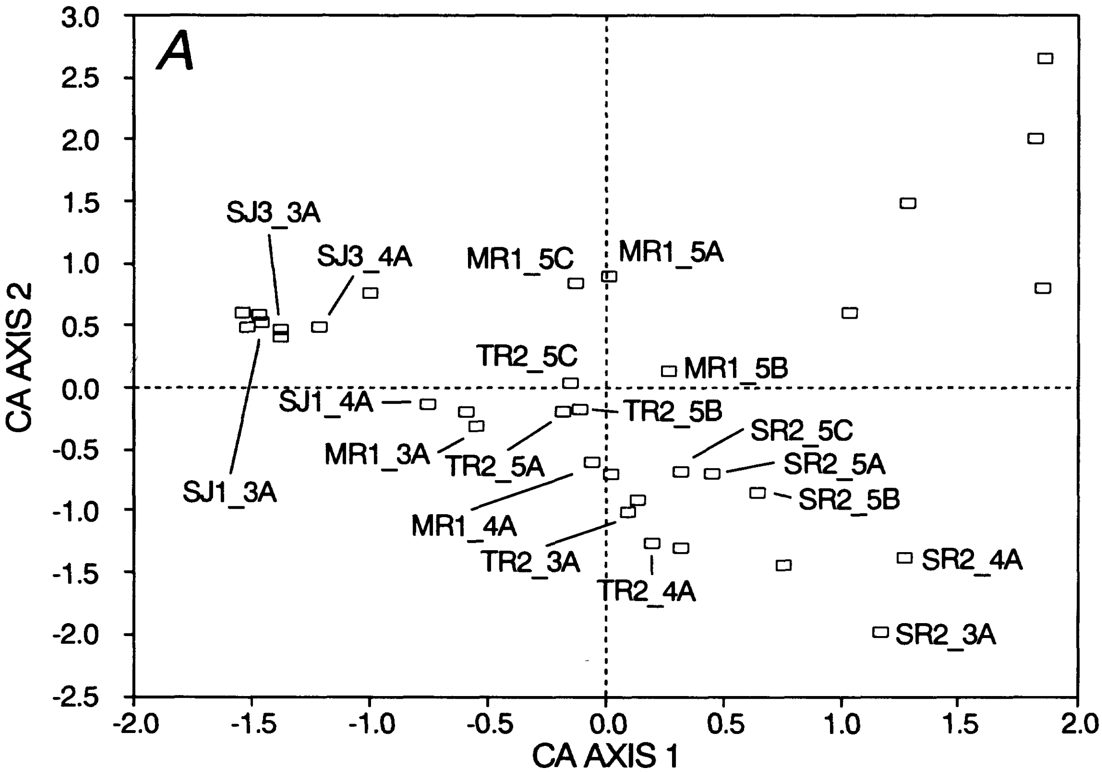

Figure 4. Plots of site (*A*) and species (*B*) on the first two correspondence analysis axes derived from the multiple-year, multiple-reach data set for sites in the lower San Joaquin River drainage, California. See table 1 for full site names. The number and letter associated with a site indicates year (3=1993, 4=1994, and 5=1995) and reach (A, B, or C in 1995 only) sampled. Only reach A was sampled in 1993 and 1994. See table 2 for species names.

Differences in stream discharge among years is the most likely reason that species assemblages in 1995 were so different from those in the other years. Stream discharge in the lower San Joaquin drainage was much higher in water year 1995 (October 1 of previous year to September 30) compared to 1993 and 1994 (Mullen and others, 1993; Anderson and others, 1994; and Hayes and others, 1995). Annual mean daily stream discharges (m^3/s) in water years 1993 to 1995 were 66.6, 47.7, and 246.5 at the San Joaquin River near Vernalis (SJ1), 14.2, 8.4, and 42.6 at the Merced River at River Road (MR1), and 13.9, 10.4, and 93.5 at the Tuolumne River in Modesto (TR2). The exception was the Stanislaus River near Ripon (SR2) where stream discharge was relatively unchanged with values of 13.2, 12.7, and 16.5 m^3/s in 1993, 1994, and 1995, respectively. Stream discharge at the time of sampling followed the same pattern.

DISCUSSION

The overall conclusion of this study is that fish assemblage structure in the lower San Joaquin River drainage is responsive to environmental conditions, including conditions associated with human-caused disturbances, particularly those associated with agriculture and water development. The results are also consistent with the hypothesis that the introduced species compete with or prey upon the native species; however, the evidence is circumstantial and experimental work is necessary before the hypothesis can be accepted or rejected.

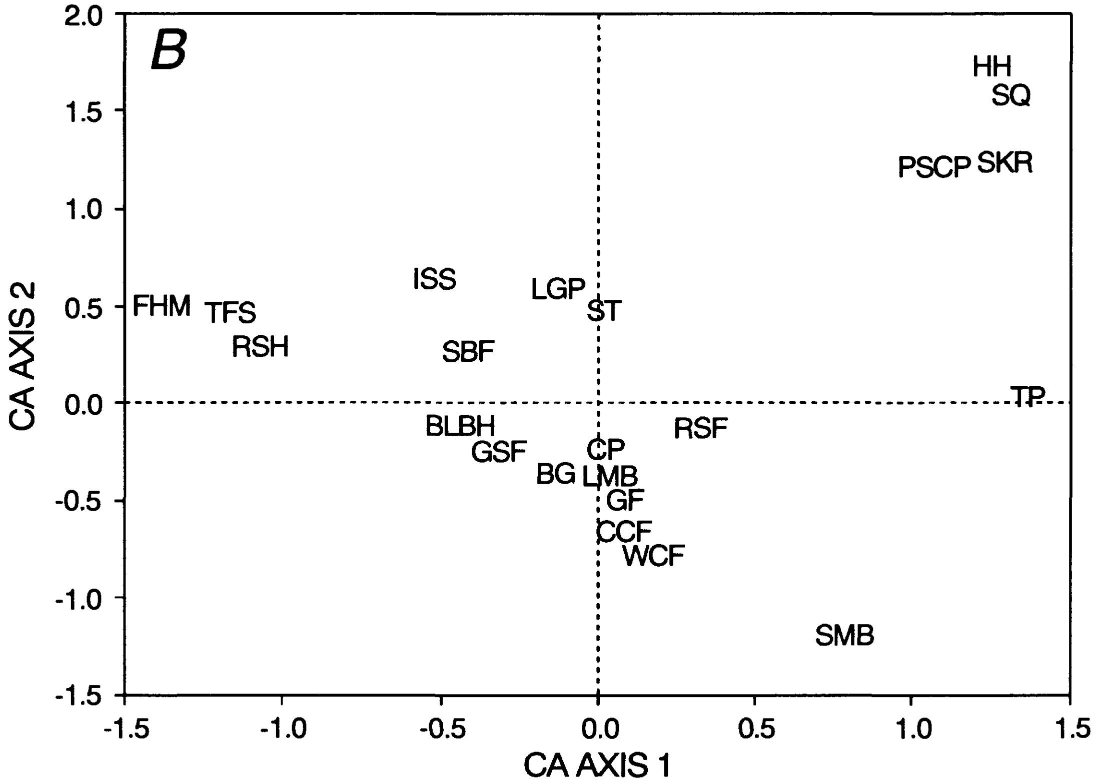

Figure 4.—*Continued.*

Fish Species Distributions

In general, the species distributions observed in this study are in agreement with previous studies of the streams of the Sierra Nevada foothills (Moyle and Nichols, 1973, 1974; Brown and Moyle, 1993) and the valley floor (Saiki, 1984; Jennings and Saiki, 1990) in the San Joaquin-Tulare basins area; however, there also were several exceptions.

The red shiner was in the process of invading the lower San Joaquin River in 1986 (Jennings and Saiki, 1990). The present study indicates that the invasion of the San Joaquin River is now complete with red shiner largely restricted to the San Joaquin mainstem sites. The presence of red shiner throughout the mainstem indicates that it has had the opportunity to move upstream into the large east-side tributaries. Furthermore, Jennings and Saiki (1990) suggested that invasion of the large east-side tributary streams was likely; however, the species does not appear to have established large permanent populations in these streams.

The high abundance of tule perch in the Stanislaus River was unexpected. Tule perch have been reported in the lower San Joaquin River system in the recent past (Saiki 1984) but did not appear to be common. However, Saiki (1984) did not sample the Stanislaus River.

Fish Assemblages

The upper large tributary sites were characterized by native fish species as expected based on descriptions of the squawfish-sucker-hardhead zone of previous studies (Moyle and Nichols, 1973;Moyle, 1976; Brown and Moyle, 1993). The characteristic species—hardhead, Sacramento squawfish, and Sacramento sucker—were present, as were the associated species of prickly sculpin and rainbow trout

(trout at MR4 only). Another associated species, California roach (*Hesperoleucas symmetricus*), was not observed. The native fishes characteristic of these sites have persisted in the human-modified stream reaches below the major foothill dams, but their downstream range appears to be limited, particularly in the Merced and Tuolumne Rivers. Also, though the native species are still present, they are not necessarily dominant at these sites. The limitation of native species to the upper tributary areas may be related to habitat and water quality conditions. For example, hardhead, Sacramento squawfish, and Sacramento sucker all spawn in riffles, and the upper tributary sites were the only sites with suitable spawning habitat. However, all these species were present in the valley floor fauna before human modification of the system (Schultz and Simons, 1973), and all can be found in the lower Sacramento River. One possible explanation for this is that under present environmental conditions the introduced species of the lower large tributary site group and the San Joaquin mainstem group compete with, and prey upon, any downstream migrant native fishes,.

Unlike the upper elevation sites, there are limited data describing the fish assemblages of the valley floor area. Moyle (1976) placed the valley floor areas in a deep-bodied fishes zone. This zone is now dominated by introduced species, but some of the native species hypothesized to be characteristic of this zone include hitch, Sacramento blackfish, Sacramento perch (*Archoplites interruptus*), Sacramento splittail, Sacramento sucker, tule perch, and the now extinct thicktail chub (*Gila crassicauda*) (Schulz and Simons, 1973; Moyle, 1976). Other native species associated with the area include hardhead, Sacramento squawfish, and prickly sculpin. Using Jaccard's index, Saiki (1984) noted high assemblage similarity in two lower tributary sites and in five San Joaquin River mainstem sites but low assemblage similarity between the two groups. Saiki (1984) also recognized differences in species distribution and abundance that closely correspond to the first TWINSPAN division of species and indicated that species distributions appeared to be associated with water quality parameters. However, Saiki (1984) did not recognize finer scale site and species groupings, perhaps because of the relatively small number of large east-side tributary sites or the methods of analysis used. The present study demonstrates clear groupings of sites in the valley floor on the basis of the presence of characteristic species.

The San Joaquin mainstem site group was characterized by a group of introduced species that are fairly recent invaders of the San Joaquin River. All were introduced to California after 1950 (Moyle, 1976) with red shiner being the most recent invader (1980s) (Jennings and Saiki,1990). These species share a number of life history characteristics that may explain their great abundance in the lower San Joaquin River system. All are short-lived, but fecund for their size, and have long reproductive seasons; thus, it is unlikely that any short-term environmental disturbances would severely affect reproductive success of the species. Such disturbances can include fluctuations in discharge, fluctuations in general water quality, and short-term, high concentrations of dissolved pesticides (Brown and others, in press). Species with more restricted spawning seasons would seem more vulnerable to these disturbances because a single event could result in the loss of the majority of a species' annual reproductive effort.

The similarity of fish assemblages in the small western and southern tributaries to the mainstem San Joaquin River was somewhat unexpected because of the relatively harsh conditions in these tributaries. Of the four such streams included in the study, all but Salt Slough are intermittent during part of the year because discharge is dependent on water releases or irrigation return flows. In particular, Orestimba Creek and Spanish Grant Drain are often reduced to isolated pools during certain periods of the year, primarily autumn and winter, when irrigation return flows are not occurring. Under these circumstances, the high percentage abundances of red shiner and fathead minnow also were expected because these species are native to physically harsh, disturbed streams (Moyle, 1976). Moreover, the absence of threadfin shad and inland silverside from the two sites was not surprising because those species, though tolerant of harsh environmental conditions, are native to larger, more permanent bodies of water. It is possible that small species like fathead minnow, green sunfish, and red shiner can maintain resident populations in these streams as long as they do not dry completely, but the presence of other fishes suggests that invasions from permanent waters also may be important. In particular, the presence at Spanish Grant Drain of several young-of-year striped bass, a large adult channel catfish, adult white catfish, and abundant large goldfish and carp suggests that immigration from the mainstem San Joaquin River or from upstream water supply canals may play an important role in maintaining fish populations in these systems.

The major difference between the San Joaquin mainstem sites and the lower tributary sites was the absence of fathead minnow, inland silverside, red shiner, and threadfin shad at the lower large tributary sites. The remaining San Joaquin mainstem species and all the species considered characteristic of the lower tributary sites were present in both groups, but at different percentages. It is unlikely that differences in water quality are important because the four species are found in the most extreme environment. It is possible that the four species are more vulnerable to predation in the smaller, clearer tributary streams. Inland silverside and threadfin shad are planktivores and also may be limited by food availability if the relatively swift tributaries produce few zooplankton.

One of the most interesting contrasts to emerge from the analysis is the separation of the two middle Stanislaus River sites from both the upper tributary and lower tributary site groups. These sites were distinctive because of large percentages of introduced smallmouth bass and native tule perch. The Stanislaus River sites did not appear physically distinct, but were similar to, or intermediate between, the upper and lower tributary site groups (table 3); however, the values reported for physical variables are based on instantaneous measurements. Continuous records of discharge, specific conductance and temperature from June through August 1993 and 1994 indicate that the Stanislaus River (SR2) had greater daily discharge, lower maximum daily specific conductance, and lower maximum daily temperature than the other two rivers (Mullen and others, 1993; Anderson and others, 1994; U.S. Bureau of Reclamation, 1996). The higher summer base flow and lower temperatures are likely important variables in explaining the differences in fish assemblages. Smallmouth bass are more stream-oriented and prefer cooler water than the other introduced species present in the system. Tule perch, a live bearer, is also a stream-oriented fish, but requires abundant cover for the near-term females and newborn young to escape predators. The Stanislaus River near Riverbank (SR3), where tule perch were the most abundant, was characterized by large areas of submerged aquatic vegetation. Though submerged aquatic vegetation was present in the other rivers, the vegetated areas tended to be small and patchy, probably because summertime water-level fluctuations and generally low discharge restricted submerged plants to deeper areas.

Canonical Correspondence Analysis

Changes in fish assemblages were related to physical characteristics of the environment (table 3, fig. 3). The CCA analysis stressed the importance of specific conductance, but, as the PC analysis demonstrated, this variable was largely acting as a surrogate for a number of correlated variables. Depending on the choice of surrogate variables or order of entry of variables to the model, if all variables had been used, a variety of plausible CCA models were possible. Specific conductance was chosen because it is measured easily and accurately with commonly available equipment. Also, past studies and the PCA analysis indicated that this variable is a good indicator of agricultural land use.

The fish assemblages probably were not responding to a specific aspect of a site, such as a single water quality or habitat quality variable, but to the general environmental quality of the aquatic ecosystem. This attribute of fish assemblages has been exploited by many researchers in the development of various refinements of the Index of Biotic Integrity (IBI) (Karr, 1981). Once scoring systems and standards for such an index can be established for a particular geographic region, sampling of fish assemblages can be a fast and inexpensive indicator of environmentally impaired locations. When such sites are identified, detailed studies of water chemistry and physical conditions then can be initiated to identify the specific problem.

Spatial and Annual Variability

Differences between reaches sampled at sites MR1, TR2, and SR2 were relatively small compared with differences in the same sites between years, primarily because of the large differences between 1995 and the prior sampling years. The results suggest that sampling of a single representative reach of a stream provides an adequate representation of a larger segment as long as appropriate sampling techniques are used. As already noted, stream discharges were high in 1995 and can account for differences in the fish assemblages through several mechanisms. The presence of native species, including hardhead, Sacramento squawfish, and Sacramento sucker, can be attributed largely to downstream transport or active migration from upper large tributary sites. The presence of young-of-year splittail suggests that upstream migration of species from the Sacramento-San Joaquin Delta was occurring because the species was not collected in 1993 or 1994. Other studies indicate only sporadic presence of splittail in the lower San Joaquin River system in previous years (Saiki, 1984; T. Ford, Turlock Irrigation District, written commun., 1995), but 1995 was an exceptional year with a large spawn of splittail in the San Joaquin River system (Sommer and others, 1997). Discharges were not as high, and high discharges did not extend through the summer in the Stanislaus River, but the large numbers of carp and goldfish, primarily young-of-year fish, indicate greater reproductive success of residents or perhaps upstream movement of spawning adults from the San Joaquin River. The mechanism for the apparent increase in reproductive success was presumably increased flooding of streamside vegetation which would supply the needed spawning substrate for these species.

Fish Community Metrics

Differences among site groups for the fish community metrics tested (table 4) suggest that an IBI could be developed for the streams of the San Joaquin Valley. Percentage of introduced fish and percentage of intolerant fish clearly differentiated the upper large tributary site group from the other groups. However, all intolerant species also are native species (table 2), making the two metrics redundant. An earlier IBI applied to San Joaquin Valley foothill streams (Brown and Moyle, 1992) relied heavily on native species with the percentages of native fish and native species constituting two of the four metrics applied to streams without salmonids. The earlier IBI was not particularly sensitive to moderate environmental degradation, probably because the native species can tolerate relatively degraded environmental conditions in the absence of introduced species (Brown and Moyle, 1993).

The results for the other two metrics were not as clear. The percentage of fish with external anomalies was highest at the lower large tributary sites; however, water quality and habitat quality were most extreme at the San Joaquin mainstem sites. Most of the sites sampled exceeded the 1-2 percent category of fish with anomalies considered indicative of degraded conditions in most IBIs (Karr, 1981; Fausch and others, 1984; Leonard and Orth, 1986; Hughes and Gammon, 1987; Bramblett and Fausch, 1991). Several of the low values for the upper tributary sites are not reliable because many of the fish at those sites were observed while snorkeling and could not be examined for anomalies.

The percentage of omnivorous fish was highest at the San Joaquin mainstem and the upper large tributary sites, the groups with the greatest differences in environmental conditions. This occurred because the native Sacramento sucker, an omnivore, tends to be the most numerous species at sites dominated by native species. Values for percentage of omnivorous fish greater than 20-35 percent have been considered indicative of degraded conditions in other IBIs (Karr, 1981; Fausch and others, 1984; Hughes and Gammon, 1987; Bramblett and Fausch, 1991). By this criterion, most of the upper large tributary sites would be considered degraded, and the lower large tributary sites would not. This reversal in expectation would be difficult to correct by simply rescaling the scoring criteria because the percentage also was high at the San Joaquin mainstem sites.

A more fundamental problem in developing a San Joaquin Valley IBI is the absence of reference conditions for the valley floor sites. Though this study shows clear differences among site groups, some level of difference would be expected between the upper large tributary and the San Joaquin mainstem sites on the basis of natural gradients in fish communities (Moyle, 1976). The native valley floor fish community has been almost completely replaced by introduced species. Should the reference condition for the IBI be based on a hypothetical reconstruction of a historic fish community that is not an attainable goal under existing land-use and water-use conditions or should the reference condition be based on an attainable condition determined by sampling additional sites over a range of water year (discharge) conditions? The latter implies an acceptance of introduced species as a permanent feature of the fish assemblages.

Conservation Implications

The results have interesting implications for fisheries management in the region. The enhancement of chinook salmon runs in the Merced, Tuolumne, and Stanislaus Rivers has always been the primary management effort in the area. Enhancement efforts have included supplementation with hatchery fish, flow manipulations to aid migration of both juveniles and adults, spawning gravel enhancement, and studies of factors affecting mortality of juveniles migrating out to sea. Efforts to enhance this economically and ecologically important native species should certainly be continued, but the results of this study suggest that enhancement of resident native species populations also is possible.

Recent ideas for conservation of California native fish assemblages have appropriately concentrated on identifying watersheds where the assemblages are relatively intact rather than on areas with only remnant populations (Moyle and Yoshiyama, 1993). However, the results of this study indicate that manipulations of flow, water quality, and stream habitat have the potential to increase the range of native stream fish assemblages in the major tributaries and perhaps increase use of the system by migratory species. Recent work has indicated that a natural flow regime is one of the most important factors in maintaining native California stream fish assemblages (Baltz and Moyle, 1993; Brown and Moyle, 1997). Changes in the water management of large east-side tributaries, in combination with improvements in water quality of smaller tributaries, could result in a downstream extension of native species and shift the mainstem San Joaquin fish assemblage away from red shiner, fathead minnow, threadfin shad, and inland silverside to the assemblage, including many game species, that presently dominates at the lower large tributary sites. The value of such species shifts would have to be balanced against the possibility of increasing predation on migrating juvenile salmon in the spring. Balancing such conflicting costs and benefits poses a considerable challenge to resource managers, particularly in areas, such as the San Joaquin-Tulare basins, where long-established human land uses have had greater or equal importance to the enhancement of natural resources.

SUMMARY

A total of 31 taxa of fish were captured during sampling of 20 sites from 1993 to 1995 in the lower San Joaquin River drainage, California. Of these species, only 10 were native to the drainage. Multivariate analysis of percentage abundance data identified four groups of sites characterized by different fish assemblages. Fish assemblage structure was responsive to specific conductance, gradient, and mean depth. Two of four fish metrics tested—percentage of introduced fish and percentage of intolerant fish—appeared responsive to environmental quality. The responses of the other two metrics—percentage of omnivorous fish and percentage of fish with anomalies—were less clear. The results indicate that fish assemblage structure and the distributions of individual species are responsive to environmental conditions. Changes in water management that alter present environmental conditions may result in changes in fish assemblage structure or changes in species distributions.

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REFERENCES CITED

Allan, J.D., and Flecker, A.S., 1993, Biodiversity conservation in running waters: identifying the major factors that affect destruction of riverine species and ecosystems. Bioscience v. 43, p. 32-43.

Anderson, S.W., Hayes, P.D., and Rockwell, G.L., 1994, Water resources data, California, water year 1994, volume 3, southern central valley basins and the Great Basin from Walker River to Truckee River:U.S. Geological Survey Water-Data Report CA-93-3.

Baltz, D.M., and Moyle, P.B., 1993, Invasion resistance to introduced fishes by a native assemblage of California stream fishes: Ecological Applications, v. 3, p. 246-255.

Bramblett, R.G., and Fausch, K.D., 1991, Variable fish communities and the index of biotic integrity in a western Great Plains River: Transactions of the American Fisheries Society, v. 120, p. 752-769.

Brown, L.R., 1997, Aquatic biology of the San Joaquin-Tulare basins: analysis of available data through 1992: U.S. Geological Survey Water-Supply Paper 2471.

Brown, L.R., and Moyle, P.B., 1992, Native fishes of the San Joaquin drainage: status of a remnant fauna and its habitats, p. 89-98. *In:* D.F. Williams, S. Byrne and T.A. Rado (eds.) Endangered and sensitive species of the San Joaquin Valley, California: their biology, management, and Conservation. The California Energy Commission, Sacramento, California.

———1993, Distribution, ecology, and status of the fishes of the San Joaquin River drainage, California: California Fish and Game 79, p. 96-114.

———1997, Invading species in the Eel River, California: successes, failures, and relationships with resident species: Environmental Biology of Fishes, v. 49, p. 271-291.

Brown, L.R., Kratzer, C.R., and Dubrovsky, N.M., In press. Integrating chemical, water quality, habitat, and fish assemblage data from the San Joaquin River drainage, California. *In:* C. Smith and K. Scow (eds.) Integrated Assessment of Ecosystem Health: Chelsea, Michigan, Ann Arbor Press.

Domagalski, J.L., Dubrovsky, N.M., and Kratzer, C.R., 1997, Pesticides in the San Joaquin River, California: inputs from dormant sprayed orchards: Journal of Environmental Quality, v. 26, p. 454-465.

Dudgeon, D., 1992, Endangered ecosystems: a review of the conservation status of tropical Asian rivers: Hydrobiologia, v. 248, p. 167-191.

Fausch, K.D., Karr, J.R., and Yant, P.R., 1984, Regional application of an index of biotic integrity based on stream fish communities: Transactions of the American Fisheries Society, v. 113, p. 39-55.

Fishman, M.J., and Friedman, L.C., 1989, Methods for the determination of inorganic substances in water and fluvial sediments: U.S. Geological Survey Techniques of Water-Resources Investigations, Book 5, p. 546.

Hayes, P.D., Rockwell, G.L., and Anderson, S.W., 1995, Water resources data, California, water year 1995, volume 3, southern central valley basins and the Great Basin from Walker River to Truckee River: U.S. Geological Survey Water-Data Report CA-93-3.

Hill, B.R., and Gilliom, R.J., 1993, Streamflow, dissolved solids, suspended sediment, and trace elements, San Joaquin River, California, June 1985-September 1988: U.S. Geological Survey Water-Resources Investigations Report 93-4085, p. 21.

Hill, M.O., 1979, TWINSPAN— a FORTRAN program for arranging multivariate data in an ordered two-way table by classification of the individuals and attributes: Ithaca, New York, Ecology and Systematics, Cornell University, p. 90.

Hill, M.O., and Gauch, H.G., 1980, Detrended correspondence analysis, an improved ordination technique: Vegetatio, v. 42, p. 47-58.

Hughes, R.M., and Gammon, J.R., 1987, Longitudinal changes in fish assemblages and water quality in the Willamette River, Oregon: Transactions of the American Fisheries Society, v. 116, p. 196-209.

Jennings, M.R., and Saiki, M.K., 1990, Establishment of red shiner, *Notropis lutrensis*, in the San Joaquin Valley, California: California Fish and Game 76, p. 46-57.

Jongman, R.H.G., ter Braak, C.J.F., and Tongeren, O.F.R., 1995, Data analysis in community and landscape ecology: Cambridge University Press, Cambridge, U.K. p. 299.

Kahrl, W.L., W.A. Bowen, Brand, S., Shelton, M.L., Fuller, D.L., and Ryan, D.A., 1978, The California Water Atlas: The Governor's Office of Planning and Research, Sacramento, California.

Karr, J.R, 1981, Assessment of biotic integrity using fish communities: Fisheries, v. 6, p. 21-27.

———1991, Biological integrity: a long-neglected aspect of water resource management: Ecological Applications, v. 1, p. 66-84.

Kratzer, C.R., and Shelton, J.L., In press, Water-quality assessment of the San Joaquin-Tulare Basins, California: analysis of available data on nutrients and suspended sediment in surface water, 1972-1990: U.S. Geological Survey Professional Paper 1587.

Kuivila, K.M., and Foe, C.G., 1995, Concentrations, transport and biological effects of dormant spray pesticides in the San Francisco estuary, California: Environmental Toxicology and Chemistry, v. 14, p. 1141-1150.

Leonard, P.M., and Orth, D.J., 1986, Application and testing of an index of biotic integrity in small coolwater streams: Transactions of the American Fisheries Society, v. 115, p. 401-414.

Mount, J.F., 1995, California rivers and streams: the conflict between fluvial process and land use: Berkeley, California, University of California Press, p. 359.

Moyle, P.B., 1976, Inland fishes of California: Berkeley, California, University of California Press, 405 p.

———1994, Biodiversity, biomonitoring, and the structure of stream fish communities: p. 171-186. *In:* S.L. Loeb and A. Spacie (eds.) Biological Monitoring of Aquatic Systems: Boca Raton, Florida, Lewis Publishers.

Moyle, P.B., and Leidy, R.A., 1992, Loss of biodiversity in aquatic systems: evidence from fish faunas: *In:* P.L. Feidler and S. Jain (eds.), Conservation Biology: The Theory and Practice of Nature Conservation, Preservation, and Management, New York, Chapman and Hill, p. 127-169.

Moyle, P.B., and Nichols, R.D., 1973, Ecology of some native and introduced fishes of the Sierra Nevada foothills in Central California: Copeia, v. 1973, p. 978-990.

———1974, Decline of the native fish fauna of the Sierra Nevada foothills, central California: American Midland Naturalist, v. 92, p. 72-83.

Moyle, P.B., and Yoshiyama, R.M., 1993, Protection of aquatic biodiversity in California: a five-tired approach: Fisheries, v. 19, p. 6-18.

Mullen, J.R., Anderson, S.W., and Hayes, P.D., 1993, Water resources data, California, water year 1993, volume 3, southern central valley basins and the Great Basin from Walker River to Truckee River: U.S. Geological Survey Water-Data Report CA-93-3.

Saiki, M.K., 1984, Environmental conditions and fish saunas in low elevation rivers on the irrigated San Joaquin Valley floor, California: California Fish and Game 70, p. 145-157.

San Joaquin Valley Drainage Program, 1990, Fish and wildlife resources and agricultural drainage in the San Joaquin Valley, Final Report of the San Joaquin Valley Drainage Program: U.S. Department of the Interior and California Resources Agency, Sacramento, California, p. 440.

Schulz, P.D., and Simons, D.D., 1973, Fish species diversity in a prehistoric central California indian midden: California Fish and Game 59, p. 107-113.

Sommer, T., Baxter, R., and Herbold, B., 1997, Resilience of splittail in the Sacramento-San Joaquin estuary: Transactions of the American Fisheries Society, v. 126, p. 961-976.

ter Braak, C.J.F, 1986, Canonical correspondence analysis: a new eigenvector method for multivariate direct gradient analysis: Ecology, v. 67, p. 1167-1179.

———1987, CANOCO: a FORTRAN program for canonical community ordination by (partial) (detrended) (canonical) correspondence analysis, principal component analysis and redundancy analysis: Wageningen, The Netherlands, TNO Institute of Applied Computer Science.

U.S. Bureau of Reclamation, 1996, Water temperature data from the Stanislaus River near Ripon: Unpublished computer files, U.S. Bureau of Reclamation, Mid-Pacific Regional Office, Sacramento, California.