Distribution and Abundance of Chinook Salmon and Resident Fishes of the Lower Tuolumne River, California

Tim Ford and Larry R. Brown

Abstract

The Tuolumne River chinook salmon (*Oncorhynchus tshawytscha*) population represents one of the southernmost populations of the species and is of considerable management interest. This paper compiles and analyzes data available through 1997 for chinook salmon and other fish species occurring in the lower Tuolumne River. Estimates of adult fall-run chinook salmon varied from about 100 to 130,000 from 1940 to 1997 (mean: 18,300; median: 7,100). Age composition varied widely from 1981 to 1997; however, three-year-old fish usually dominated the population. The percentage of females in the population varied from 25% to 67% during 1971–1997. The percentage of tagged adult salmon increased from less than 2% before 1987 to an average of 20% during 1992–1997. Density of juvenile chinook salmon generally declined each year after a winter peak in fry abundance. Average, minimum, and maximum fork length of juvenile chinook salmon typically increased after February; although, declines occurred in some years because of large captures of fry in late spring. Few juvenile chinook salmon resided in the river over the summer during 1988–1993. A total of 33 taxa of fish (12 native and 21 introduced), including chinook salmon, was captured during various sampling programs. Native species were most frequent in upstream areas above river kilometer (rkm) 80. Introduced species dominated areas downstream of rkm 50. The resident fish community appeared to vary in response to annual differences in flow conditions with native species becoming more abundant in the year following a high flow year. There was no discernible seasonal change in fish communities when early summer (early June) and late summer (mid September) samples from the same sites were compared. Monitoring of the Tuolumne River chinook salmon population has provided valuable data on both chinook salmon and populations of other fish species.

Introduction

The chinook salmon (*Oncorhynchus tshawytscha*) populations in the tributaries to the San Joaquin River, including the Tuolumne River, constitute the southernmost extant populations of the species (Moyle 1976). The San Joaquin River tributary populations of fall-run chinook salmon, along with other Central Valley fall-run populations are presently considered candidate species under the federal Endangered Species Act (NMFS 1999). Even before candidate status, San Joaquin fall-run chinook salmon were of great management concern and were managed as a distinct stock. Historic declines in San Joaquin fall-run chinook salmon numbers and current threats to their survival have been attributed to a number of factors including habitat loss, habitat suitability, survival of emigrants, harvest, genetic effects of hatcheries, and water quality (USFWS 1995).

The earliest estimates of fall-run chinook salmon spawning escapement in the Tuolumne River date from 1940, with more detailed information collected since 1981. Since 1973, several other types of studies have been conducted within the lower 84 km of the Tuolumne River (from La Grange Dam to the confluence with the San Joaquin River) available for salmon spawning. Most of these studies have focused on winter-spring sampling when juvenile fall-run chinook salmon are abundant; but biologists have also gathered considerable data on the distribution and abundance of other fish species. A few studies have focused primarily on the resident fishes. The purpose of this paper is to compile and analyze data available through 1997 for chinook salmon and other fish species occurring in the lower Tuolumne River. The salmon data are clearly important to the proper management of Tuolumne River fall-run chinook salmon. Data on the other species can be used to develop understanding of interactions between salmon and other species, environmental conditions when salmon are not present, and the biology of species that become of management concern, such as splittail (*Pogonichthys macrolepidotus*, federally listed as threatened) and hardhead (*Mylopharodon conocephalus*, a California species of special concern) (Moyle and others 1995).

Methods

Adult Fall-run Chinook Salmon

Chinook salmon spawning runs in the Tuolumne River have been monitored to some degree since 1940, with estimates of adult escapement available for all years since 1951. Counts of migrating adult salmon were made at a weir in Modesto at river kilometer (rkm) 25.9 by the California Department of Fish and Game (DFG) in 1940, 1941 (partial count), 1942, and 1944, and by the U.S. Fish and Wildlife Service (USFWS) in 1946 (Fry 1961). DFG conducted carcass surveys for estimating escapements after 1946 (Fry 1961; Fry and Petrovich 1970), except that no estimate was made in 1950 due to an early flood. The results of spawning surveys since 1971 are described in a series of reports submitted by Turlock and Modesto irrigation districts (TID and MID) as part of the Federal Energy Regulation Commission (FERC) license process (EA 1991, 1997; TID and MID 1998). Tagging of some carcasses to obtain information on carcass recovery rates began in 1967, and since 1979, the DFG estimates are based on variations of Peterson or Schaefer mark-recapture formulas.

Carcass surveys were generally conducted in the reach of the Tuolumne River from La Grange at rkm 81.6 downstream to rkm 54.6 (Reed Rock Plant or Nielsen Ranch) just upstream of Waterford (Figure 1). Within this reach, data were segregated into three smaller sections that have varied over time. Since 1981 these sections have been divided at Basso Bridge (rkm 76.4) and Turlock Lake State Recreation Area (rkm 67.4). In some years, additional reaches were surveyed, including an upstream reach from rkm 81.6 to rkm 83.1 near La Grange Powerhouse and/or a downstream reach from rkm 54.6 to rkm 42.0 near Geer Road. Since 1981, population estimates for river sections not included in weekly carcass surveys were usually estimated by counting the number of redds in the section and then multiplying by the number of salmon per redd observed in the surveyed sections.

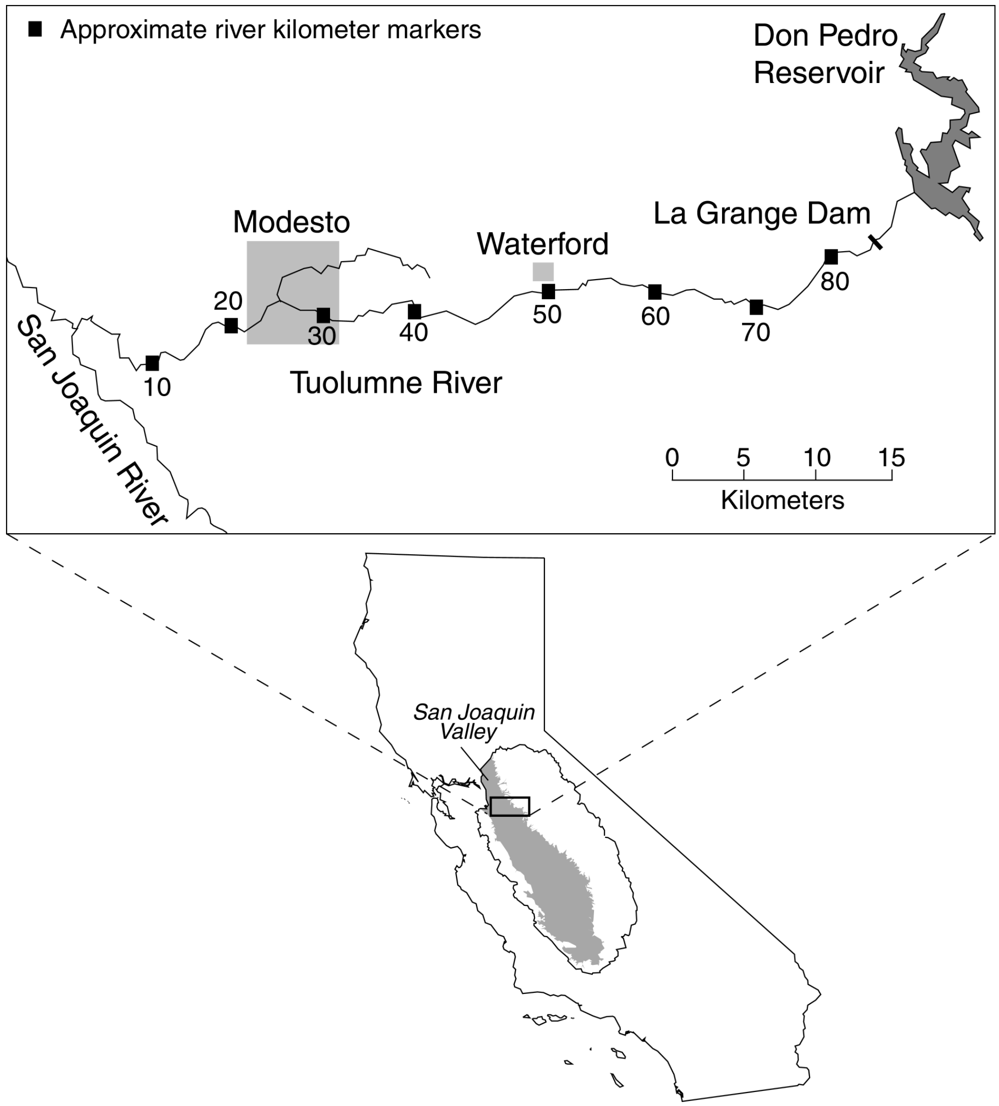


Figure 1 Location map for the lower Tuolumne River, California

DFG conducted weekly carcass surveys, generally by boat, using two- or three-person crews. Salmon carcasses were recovered by gaff for tagging and examination. Carcass mark-recapture sampling was conducted by attaching a marker to the upper jaw of some of the carcasses with a metal hog ring. Tagged carcasses were released in moving water for recovery during subsequent surveys. All other carcasses, including those marked with tags from earlier releases, were counted and chopped by machete to avoid double counts. Before 1988, only fresh carcasses were used for tagging and recovery. Beginning in 1988, both fresh (indicated by clear eyes) and non-fresh carcasses were tagged, with a distinction made between "adult salmon" and "grilse" (two-year olds). Carcasses under 60 cm fork length (FL) (considered grilse) were not tagged. From 1989 to 1991, fresh grilse carcasses were also tagged, but non-fresh grilse were not. Beginning in 1992, all carcasses were tagged. Fork length, sex, and condition (fresh or non-fresh) of measured carcasses were recorded. Snouts of carcasses possibly having coded-wire tags (CWT), externally indicated by a missing adipose fin, were saved for tag recovery. Redd counts for individual riffles and live salmon counts for the survey reach were also recorded. The annual survey periods are shown in Table 1.

Initial run timing was based on the first report, by TID and MID staff, of adult salmon near La Grange. Age composition of the run was estimated from visual examination of length frequency histograms for each sex. A spawning use index was calculated from redd counts in carcass survey sections using the following formula.

$$\text{Spawning use index} = \frac{\text{\% of total redds in a survey section}}{\text{\% of total stream length surveyed in that section}}$$

Juvenile Fall-run Chinook Salmon and Other Species

Winter-spring Seining Surveys

Winter-spring seining surveys for juvenile salmon were conducted annually by TID and MID in 1986–1997 (EA 1991, 1996; TID and MID 1998). The sampling interval and number of locations and sample periods varied depending on the year. These studies also documented the distribution and abundance of other fish species and represent the longest continuous juvenile salmon monitoring effort in the San Joaquin River system, upstream of the Sacramento-San Joaquin Delta.

The locations sampled each year are shown in Table 2. Seining was conducted with 1.2 to 1.8 m high, 3.2 mm mesh nylon seine nets in lengths of 6.1, 9.1, or 15.2 m. The same general areas were sampled during each visit during a given year to facilitate comparative analysis throughout the sampling period. Sample areas varied somewhat as a result of changes in flow. Seine hauls were generally made in the direction of the current and parallel to shore, although offshore-to-onshore hauls were sometimes used. In general, three hauls were made during each visit to a site. The three hauls sampled an area of approximately 140 to 186 m^2.

Table 1 Salmon survey periods, peak live counts, and arrival dates[a]

Year	Survey dates: Start	Survey dates: End	Peak live count: Date	Peak live count: No.	Population estimate (x 1,000)	Peak live percentage (%)	Date fish first observed at La Grange
1940	26 Sep	02 Dec	04 Nov	5,447	122.0	4.5	---
1941	21 Sep	18 Nov	13 Nov	2,807	27.0	10.4	---
1942	13 Sep	30 Nov	01 Nov	3,386	44.0	7.7	---
1944	30 Sep	30 Nov	06 Nov	10,039	130.0	7.7	---
1946	11 Oct	20 Nov	04 Nov	6,002	61.0	9.8	---
		--	**No data available from 1947 to 1956**			--	
1957	05 Nov	03 Jan	---	---	8.0	---	--
1958	06 Nov	09 Jan	---	---	32.0	---	---
1959	03 Nov	01 Jan	---	---	46.0	---	---
1960	12 Nov	13 Jan	---	---	45.0	---	---
1961	---	---	---	---	0.5	---	---
1962	08 Nov	04 Jan	---	---	0.2	---	---
1963	10 Feb	---	---	---	0.1	---	---
1964	04 Nov	18 Dec	---	---	2.1	---	---
1965	19 Nov	12 Jan	---	---	3.2	---	---
1966	08 Nov	18 Jan	09 Nov	271	5.1	5.3	---
1967	18 Oct	13 Jan	21 Nov	184	6.8	2.7	---
1968	11 Nov	15 Dec	22 Nov	1,490	8.6	17.3	---
1969	20 Nov	12 Jan	---	---	32.2	---	---
1970	19 Nov	20 Jan	20 Nov	1,517	18.4	8.2	---
1971	15 Nov	27 Dec	16 Nov		21.9	9.7	---
1972	13 Nov	23 Jan	27 Nov	349	5.1	6.8	---
1973	05 Nov	17 Jan	---	---	2.0	---	---
1974	---	---	---	---	1.2	---	---
1975	06 Nov	31 Dec	06 Nov	154	1.6	9.6	---

[a] Data for 1940–1946 are from Modesto; all later count data are from weekly carcass surveys in the spawning reach. Dashes (--) indicate no data. Population estimates are subject to revision.

Table 1 Salmon survey periods, peak live counts, and arrival dates[a] (Continued)

Year	Survey dates		Peak live count		Population estimate (x 1,000)	Peak live percentage (%)	Date fish first observed at La Grange
	Start	End	Date	No.			
1976	03 Nov	29 Dec	15 Nov	241	1.7	14.2	---
1977	29 Nov	20 Dec	---	---	0.5	---	---
1978	26 Oct	19 Dec	24 Nov	81	1.3	6.2	---
1979	05 Nov	17 Dec	02 Nov	153	1.2	12.8	---
1980	12 Nov	18 Dec	12 Nov	112	0.6	18.7	---
1981	04 Nov	16 Dec	---	---	14.3	---	14 Oct
1982	08 Nov	29 Nov	15 Nov	545	7.1	7.7	29 Sep
1983	07 Nov	01 Dec	15 Nov	263	14.8	1.8	13 Oct
1984	01 Nov	30 Nov	01 Nov	1,084	13.8	7.9	04 Oct
1985	29 Oct	20 Dec	12 Nov	2,986	40.3	7.4	24 Sep
1986	27 Oct	05 Dec	03 Nov	1,123	7.3	15.4	10 Sep
1987	28 Oct	16 Dec	17 Nov	2,155	14.8	14.6	06 Oct
1988	25 Oct	29 Dec	14 Nov	1,066	6.3	16.9	17 Oct
1989	24 Oct	29 Dec	09 Nov	291	1.3	22.8	15 Oct
1990	23 Oct	26 Dec	19 Nov	44	0.1	45.8	24 Oct
1991	22 Oct	02 Jan	25 Nov	24	0.1	45.3	06 Nov
1992	05 Nov	21 Dec	19 Nov	49	0.1	38.3	31 Oct
1993	14 Oct	18 Dec	06 Nov	94	0.4	24.2	26 Sep
1994	03 Nov	05 Jan	21 Nov	226	0.5	45.2	26 Oct
1995	27 Oct	30 Dec	03 Nov	270	1.0	27.0	05 Oct
1996	22 Oct	04 Dec	31 Oct	636	3.3	19.3	--
1997	14 Oct	23 Dec	12 Dec	1258	7.2	17.5	09 Oct
1971–1997 cumulative data							
First	14 Oct	29 Nov	31 Oct	---	---	---	10 Sep
Last	29 Nov	23 Jan	27 Nov	---	---	---	06 Nov
Median	02 Nov	20 Dec	11 Nov	---	---	---	11 Oct

[a] Data for 1940–1946 are from Modesto; all later count data are from weekly carcass surveys in the spawning reach. Dashes (--) indicate no data. Population estimates are subject to revision.

Table 2 Primary winter-spring seining locations for each year of sampling[a]

Location	*River kilometer*	*86*	*87*	*88*	*89*	*90*	*91*	*92*	*93*	*94*	*95*	*96*	*97*
Old La Grange Bridge	81.3	X	X	X	X	X	X	X	X	--	--	X	X
Riffle 4B	77.9	X	X	X	X	X	X	--	--	--	X	X	X
Riffle 5	77.1	--	X	X	X	X	X	X	X	X	--	--	--
Tuolumne River Resort	68.2	--	--	X	X	X	X	X	X	X	X	X	X
Turlock Lake State Rec. Area	67.6	X	X	--	--	--	--	--	--	--	--	--	--
Reed Gravel	54.7	X	X	X	X	X	X	--	--	--	--	--	--
Hickman Bridge	50.8	X	X	X	X	X	X	X	X	X	X	X	X
Charles Road	40.1	--	X	X	X	X	X	X	X	--	--	--	X
Legion Park	27.7	X	X	X	X	X	X	X	X	X	X	X	X
Riverdale Park	19.8	--	X	X	X	X	X	--	--	--	--	--	--
McCleskey Ranch	9.7	X	X	X	X	X	X	X	X	X	--	--	--
Shiloh Bridge	5.8	X	X	X	X	X	X	--	X	--	X	X	X
Total locations		8	11	11	11	11	11	7	8	5	5	6	7
Mean interval (days)		9	7	10	11	10	21	28	18	19	19	21	15
Number of sample periods		18	21	14	13	14	8	5	7	7	8	8	10

[a] Mean interval is the mean number of days between samples. Dashes (--) indicate location not sampled.

Captured salmon were anesthetized, measured (FL in mm), and then revived before being released. If more than 100 salmon were caught, a random subsample of approximately 100 salmon was measured and the remaining salmon were counted and released. The number of fish caught, and fork lengths were recorded. Other fish species were counted and recorded separately.

Minimum, maximum, and average fork length of juvenile chinook salmon were plotted for each year and sample period. Density was calculated as the number of salmon captured per square meter of area seined. Seining data were stratified by river section and summed for the entire river. Three river sections were used for comparison: upper section (La Grange Powerhouse, rkm 83.7 to rkm 59.5), middle section, and lower section (Dry Creek, rkm 26.4 to mouth, rkm 0).

All fish species other than chinook salmon were included in the analyses of resident fish species. Total catch was summarized as species percentage abundance for all fish captured in all samples. Seining data were used for three types of analyses: frequency of occurrence of species at specific sites along the river, number of species captured per sampling effort, and resident fish assemblage structure.

Frequency of occurrence was determined on the basis of the number of samples collected at a site, from 1986 to 1997. Frequency of occurrence was the percentage of the total number of samples that included a particular species. The total number of samples at a site varied from 33 to 129. For each sample at each site, the number of species captured other than chinook salmon was determined. A mean value and standard deviation was then calculated for each site based on all samples from all years of sampling.

Assemblage structure of the resident fishes was described using detrended correspondence analysis (DCA). DCA is a multivariate ordination technique based on reciprocal averaging that results in an ordination of species based on occurrence at sites and an ordination of sites based on the species assemblage at each site. DCA was conducted with species percentage data. Only sites sampled consistently through the study were included. Review of the data resulted in selection of eight sites for analysis. These sites were sampled consistently from 1987 to 1993 and then more sporadically through 1997. Because of the low number of species captured per sample, all fish captured at a site each year were combined into a single sample and then the percentage of each species in the combined sample calculated. Years when a site was sampled fewer than four times were excluded from analysis. Species were only included in the analysis if they were present in at least 10% of the samples and comprised at least 5% of the fish captured in at least one sample. One-way analysis of variance (ANOVA) was used to test for annual differences in mean site scores on DCA axes 1 and 2.

Fyke Netting

Winter-spring fyke netting for juvenile salmon was conducted by the USFWS in 1973, 1974, 1977, and 1980. DFG performed the sampling in 1981, 1982, 1983, and 1986 (EA 1991). The locations and sampling periods are in Table 3. The fyke nets used were 7.6 m long with a 0.9 x 1.5 m opening and 12.2 m long with a 1.5 x 2.7 m opening. The variable mesh netting tapered to 0.3 x 0.3 m at the cod end into an attached aluminum holding box. Nets were usually deployed for two to four nights per week and checked once every 24 hours. The number and size of captured juvenile salmon were recorded as was the number of individuals of other fish species. Resident fish captured during fyke netting were summarized as percentage abundance of each species captured at each site for each year of sampling.

Table 3 Fyke net locations and sampling periods for each year sampled[a]

Location	*Rkm*	*1973*	*1974*	*1977*	*1980*	*1981*	*1982*	*1983*	*1986*
Turlock Lake SRA	68.2	2/15–6/8	2/13–6/7	2/14–5/18	1/28–6/13	2/17–5/14	1/19–4/30	1/26–6/1	2/05–3/28
Hickman Spill	52.3	--	--	--	3/27–6/13	--	1/19–4/30	--	--
Putnam Gravel	49.2	2/14–6/8	2/13–6/7	2/14–5/18	--	--	--	--	--
Charles Road	40.2	--	--	--	1/28 3/26	--	--	--	--
McCleskey Ranch	9.7	2/27–6/8	2/13–6/7	2/14–5/18	1/28–6/13	--	2/1–4/30	--	--

[a] Dashes (--) indicate location not sampled.

Rotary Screw Traps

Springtime juvenile salmon sampling was conducted with two 2.44-meter diameter rotary screw traps (RST) in 1995 (26 April to 1 June) by TID and MID and in 1996 (18 April to 29 May) by DFG at rkm 5.8 (Shiloh Road) (EA 1997). Only one trap was fished after 19 May in 1995 and after 17 May in 1996. The traps were located out of the main current in 1995 due to high flows and floating debris. The 1996 deployment was in the main current.

The two traps were fished side-by-side and were usually checked in the morning and evening, except when more frequent checks were required to remove debris. All fish and debris were removed from the RSTs each time they were checked. The fish were separated by species and counted. All of the juvenile salmon, or a subsample, were measured. Lengths of other fish species were estimated or occasionally measured.

Salmon data were summarized as daily catch per trap, because one or two traps were fished at a time. Resident fish captured during rotary screw trapping were summarized as percentage abundance of each species captured each year.

Summer Surveys

Summer surveys of resident fishes were conducted, generally during May to September, from 1988 to 1994. Unlike other sampling efforts, which focused on chinook salmon, these surveys were designed to document the distribution of all fish species throughout the river (Table 4). Two other sampling methods, electrofishing and snorkeling, in addition to seining, provided a greater likelihood of capturing other fish species. Seining was only conducted in the first year, 1988, because few species were captured. Snorkeling was sometimes limited due to water clarity and generally was not effective downstream of rkm 40. Only snorkeling was conducted in 1994. All years included both "early summer" and "late summer" sampling periods (Table 5) when intensive sampling was conducted to detect the presence of juvenile chinook salmon.

Table 4 Summer survey locations for each year sampled[a]

Location	*Rkm*	*1988*	*1989*	*1990*	*1991*	*1992*	*1993*	*1994*
Riffle A3	83.0	X	X	X	X	X	X	X
Riffle A7	81.6	X	X	X	--	--	--	--
Riffle 2	80.3	X	X	X	X	X	X	X
Riffle 5	78.7	X	X	X	X	X	--	X
Riffle 9	74.7	X	X	X	X	X	X	X
Riffle 23BC	68.1	X	X	X	X	X	--	--
Riffle 33	62.3	X	X	X	--	--	--	--
Riffle 39/40	57.8	X	X	X	X	X	X	X
Riffle 53	51.5	X	--	--	--	--	--	--
Riffle 58	50.7	--	X	X	X	X	X	X
Charles Road	40.1	X	X	X	X	X	X	X
Legion Park	29.3	X	X	X	--	--	--	--
Riverdale Park	19.8	X	X	X	X	X	--	--
McCleskey Ranch	9.7	X	X	X	--	--	--	--
Shiloh Bridge	5.8	X	X	X	X	X	X	--
Total number of locations sampled		14	14	14	10	10	7	7

[a] Dashes (--) indicate not sampled.

Table 5 Primary summer survey sampling periods

Year	*Early summer*	*Late summer*
1988	05 May – 02 Jun	20 – 22 Sep
1989	23 May – 02 Jun	05 – 15 Sep
1990	28 May – 06 Jun	18 – 28 Sep
1991	10 – 14 Jun	06 – 13 Sep
1992	01 – 10 Jun	21 – 29 Sep
1993	07 – 10 Jun	25 – 27 Oct
1994	13 – 14 Jul	03 – 04 Oct

Snorkeling was conducted by one or more persons. Observers would proceed through a specified area and record on dive slates the species, numbers, and sizes of all fish observed. In 1988, electrofishing was conducted with a Smith-Root Model 12 backpack electroshocker. In all other years, a gas-powered DC generator mounted on a tow barge with three hand-held anodes was used. Block nets were sometimes used to isolate sample areas. Stream reaches snorkeled and electrofished ranged from 50 to 150 m in length.

Salmon catch data from the primary sampling periods were summarized by sampling method, date, and location. For the other species, total catch for each sampling method was summarized as percentage abundance of species using data from all samples. Snorkeling and electrofishing data were used in additional resident fish analyses.

Frequency of occurrence was calculated as described for the winter-spring seining data. Only sites sampled at least five times were included in frequency of occurrence analyses. Analysis of the number of species captured per sampling effort was also calculated as described for the seining data.

Assemblage structure of the resident fishes was described using detrended correspondence analysis (DCA) of the electrofishing data, as described for the seining data. A total of 10 sites was sampled consistently and included in the analysis. To determine if there were any seasonal changes in fish assemblage structure, analyses were conducted using two samples per year. An early summer sample was defined as the sample collected closest to 1 June of each year. A late summer sample was defined as the sample collected closest to mid-September of each year. Two-way ANOVA was used to test for annual and seasonal (that is, early versus late summer) differences in site scores on DCA axes 1 and 2.

Results

Adult Fall-run Chinook Salmon

Since 1940, the salmon runs varied from about 100 to 130,000 with an average estimate of 18,300 and a median estimate of 7,100 (Figure 2, Table 6). The date of the first observation of adult salmon at La Grange ranged from 10 September to 6 November with a median of 11 October for the period 1981–1997 (Table 1). The peak weekly count of live salmon during 1971–1997 ranged from 31 October to 27 November with a median date of 11 November.

Age composition of the 1981–1997 runs varied widely (Figure 3). Occasionally a strong year class would dominate consecutive years (arriving as two-year olds the first year and three-year olds the second) such as occurred in 1981–1982, 1987–1988, and 1996–1997. From 1981–1997 there were six years when two-year olds were most abundant and 11 years when three-year olds were most abundant. Four-year olds were always less than one-third of the 1981–1997 runs and five-year olds were always less than 5%.

The percentage of females varied from 25% to 67% during the period 1971-1997 (Figure 4). Sex composition varied with the age composition. Years with a high percentage of two-year olds tended to have a lower percentage of females (Figure 5). The percentage of adult salmon with coded-wire tags increased from less than 2% before 1987 up to an average of 20% during 1992–1997 (Figure 6). Redd counts during 1981–1997 varied from 51 to 3,034 (Table 7). Spawning use indices varied from 2.85 to 0.27, declining in a downstream direction (Table 7).

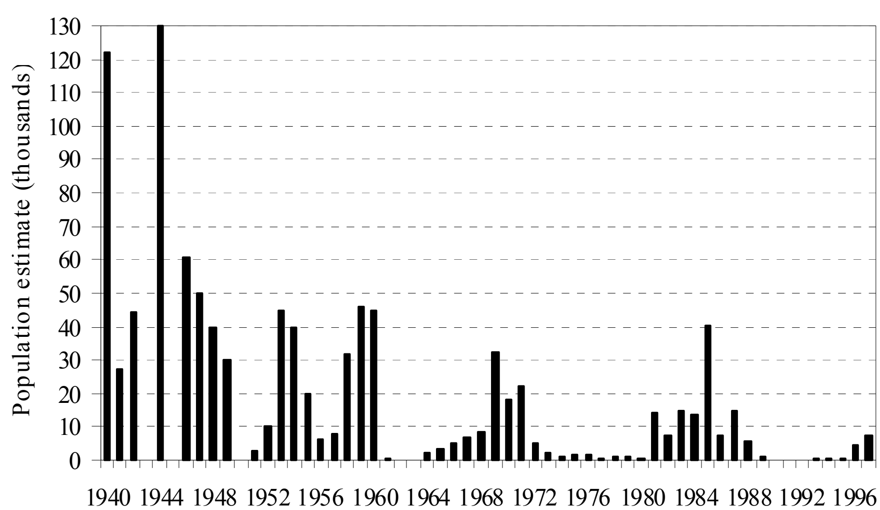
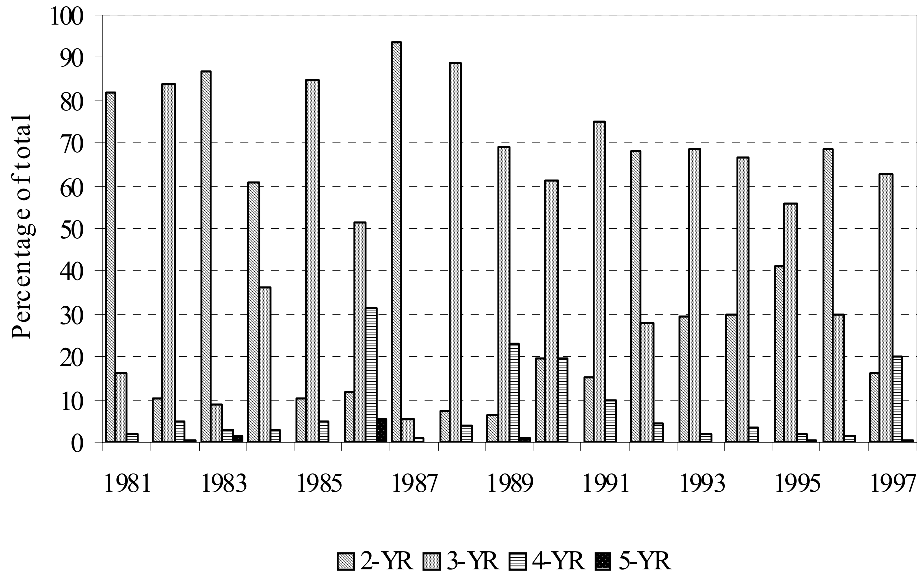


Figure 2 Estimates of adult fall-run chinook salmon in the Tuolumne River. There was only a partial count in 1941 and no counts in 1943, 1945, and 1950.

Table 6 Tuolumne River adult fall-run chinook salmon population estimates[a]

Year	*Population estimate (x 1,000)*	*Year*	*Population estimate (x 1,000)*	*Year*	*Population estimate (x 1,000)*
1940	122.0	1960	45.0	1980	0.6
1941	27.0	1961	0.5	1981	14.3
1942	44.0	1962	0.2	1982	7.1
1943	--	1963	0.1	1983	14.8
1944	130.0	1964	2.1	1984	13.8
1945	--	1965	3.2	1985	40.3
1946	61.0	1966	5.1	1986	7.3
1947	50.0	1967	6.8	1987	14.8
1948	40.0	1968	8.6	1988	6.3
1949	30.0	1969	32.2	1989	1.3
1950	--	1970	18.4	1990	0.1
1951	3.0	1971	21.9	1991	0.1
1952	10.0	1972	5.1	1992	0.1
1953	45.0	1973	2.0	1993	0.5
1954	40.0	1974	1.2	1994	0.5
1955	20.0	1975	1.6	1995	0.7
1956	6.0	1976	1.7	1996	4.6
1957	8.0	1977	0.5	1997	7.1
1958	32.0	1978	1.3		
1959	46.0	1979	1.2		

[a] There was only a partial count done in 1941 and no counts done in 1943, 1945, and 1950.



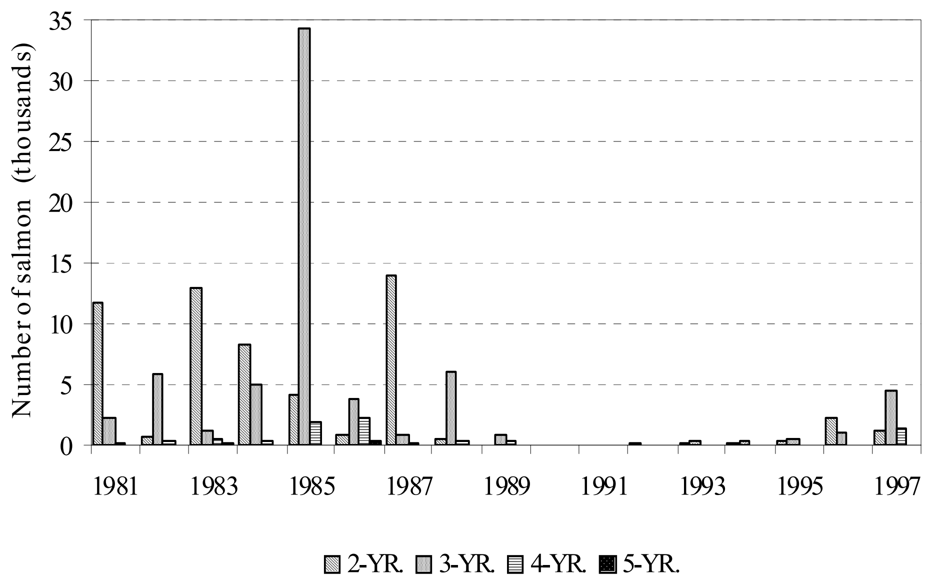


Figure 3 Estimated percentage and number of age classes in salmon runs based on fork length frequencies

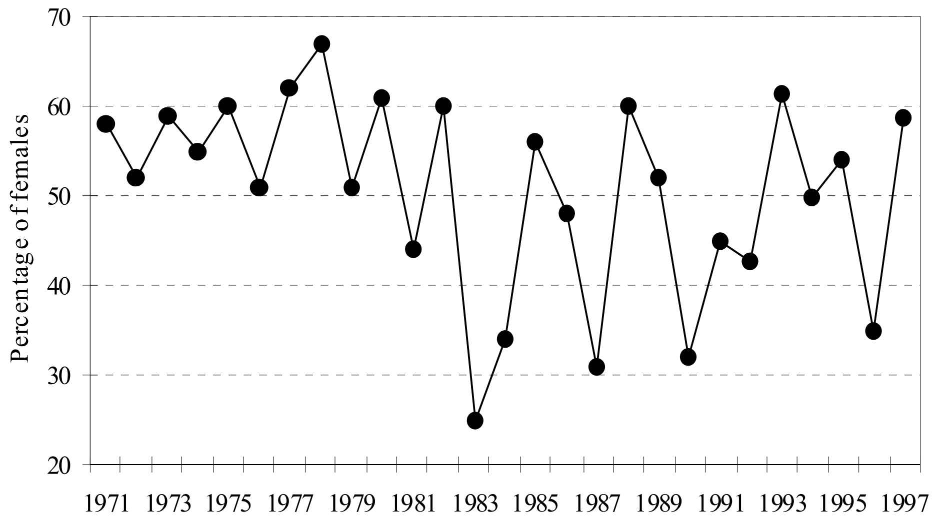


Figure 4 Percentage of females in Tuolumne River salmon runs

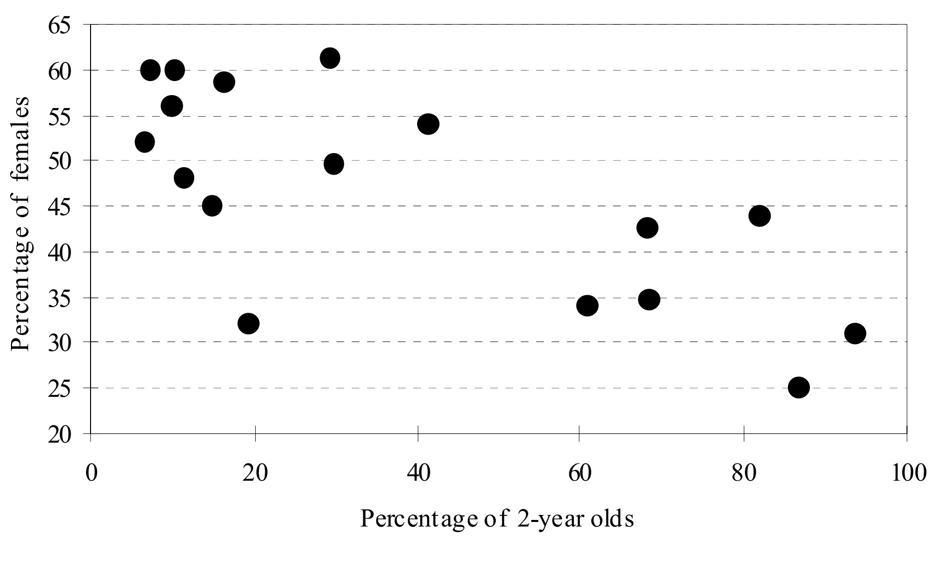


Figure 5 Percentage of females plotted against estimated percentage of two-year olds for 1981–1997 salmon runs

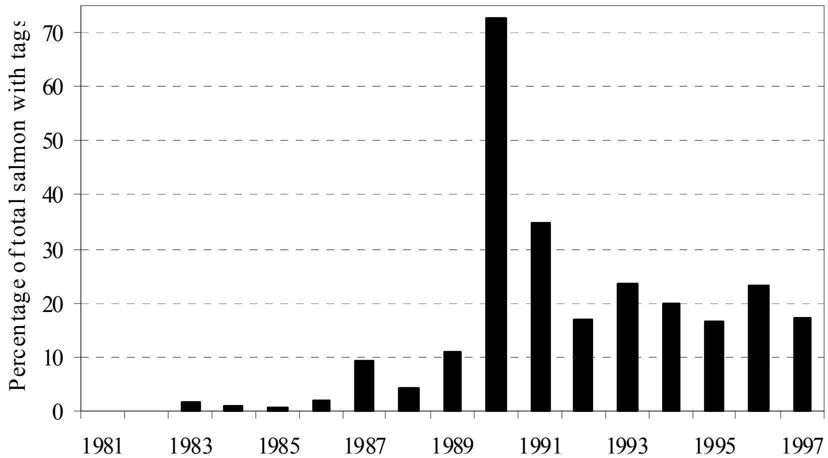


Figure 6 Estimated percentage of adult salmon with coded-wire tags in 1981–1997 salmon runs

Table 7 Total redd counts for each survey reach and the entire spawning reach[a]

Year	Survey reach (rkm to rkm) 42.0 – 54.6	54.6 – 67.4	67.4 – 76.4	76.4 – 81.6	81.6 – 83.1	No. of redds counted	Estimated no. of females	Females per redd
1981	137	440	461	510	128	1,676	6,292	3.8
1982	--	218	308	467	106	1,099	4,200	3.8
1983	18	155	180	110	2	465	3,700	8.0
1984	37	265	428	358	55	1,143	4,658	4.1
1985	140	605	874	1,230	185	3,034	22,568	7.4
1986	68	365	271	428	116	1,248	3,792	3.0
1987	77	209	216	246	102	850	4,619	5.4
1988	376	431	402	552	141	1,902	4,080	2.1
1989	76	149	130	181	48	584	676	1.2
1990	6	21	21	10	0	58	28	0.5
1991	7	13	9	16	6	51	27	0.5
1992	10	7	7	17	12	53	55	1.0
1993	17	49	61	78	45	250	238	1.0
1994	21	82	95	79	45	322	249	0.8
1995	25	56	61	48	39	229	522	2.3
1996	19	58	84	125	57	343	1,139	3.3
1997	26	171	272	404	108	981	4,224	4.3
Mean percentage of redds in survey reach								
	8.4%	23.7%	26.5%	31.0%	10.4%			
Spawning use index for survey reach								
	0.27	0.76	1.21	2.45	2.85			

[a] The ratio of female salmon to the number of redds is given for the entire spawning reach. The use index (% redds / % length) was calculated using data summed over all years.

Juvenile Fall-run Chinook Salmon

Density of juvenile salmon, as determined from winter-spring seining, declined each year after a winter peak in fry abundance (Figure 7). Juvenile salmon were abundant in the lower river section below Dry Creek (rkm 26.4) only in the high flow years of 1986, 1995, and 1997 (Figures 8 and 9). All measures of juvenile salmon size typically increased after February (Figures 10, 11, and 12), although in some years average size declined from April to May (Figure 10), because large numbers of smaller fry were captured.

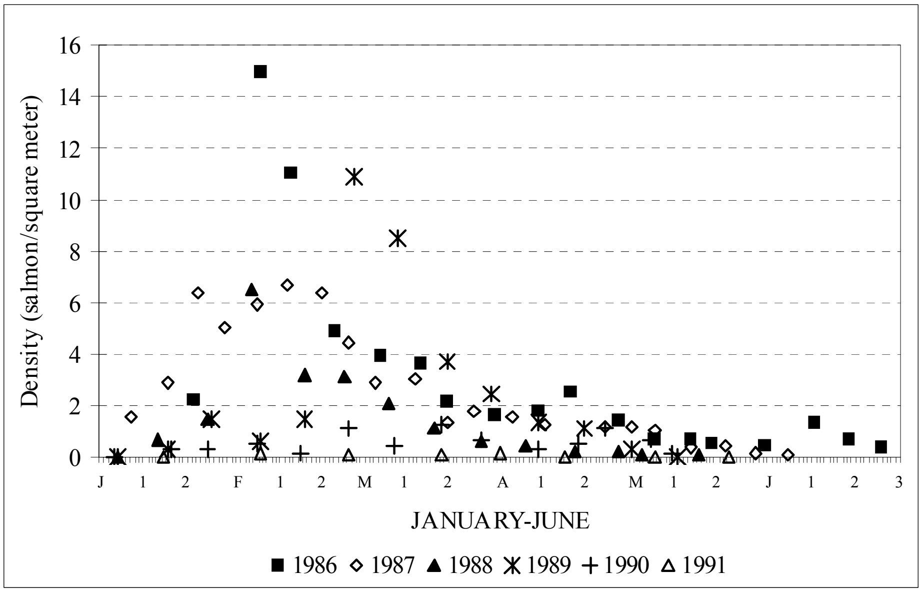
The catch rate of the rotary screw traps was lower in 1995 than in 1996 (Figure 13). Peaks in juvenile salmon abundance were less obvious in 1995 compared to 1996.

No juvenile salmon were captured during the summer flow study in 1991, 1992, and 1994 (Table 8). Most juvenile salmon were captured in the early period with the largest catches upstream of rkm 74. Few juvenile salmon were captured in the late sampling as compared to the early periods. All but one of the juvenile salmon observed during the late period were found upstream of rkm 74.

Resident Fishes

A total of 33 taxa of fish, including chinook salmon, was captured during the various sampling programs (Table 9). Of the 33 taxa, 12 taxa are native to California and 21 are introduced. All lampreys captured were identified as Pacific lamprey; however, not every individual was examined in detail and it is possible that river lamprey (*Lampetra ayersi*) was also present. Similarly, several black bullheads (*Ameiurus melas*) were identified but the remaining *Ameiurus* species were combined into the general category of bullhead catfish.

The six methods of sampling used in the studies varied in effectiveness with regard to the capture of resident fish species. Winter-spring methods included seining, rotary screw trapping and fyke netting. Winter-spring seining generally caught few species in addition to chinook salmon during any single sampling effort (Figure 14). Mean number of species captured per sampling period varied from 1.0 to 2.4 species with standard deviations ranging from 0.8 to 1.2. However, over the course of the study winter-spring seining captured 28 of the 33 taxa present in the river (Table 10). Rotary screw trapping at rkm 5.6 resulted in a mean of 2.4 species (standard deviation 1.8) captured per sampling effort (usually daily), which was comparable to the seining results for that site (mean = 2.0, standard deviation = 1.2). Rotary screw trapping captured about 23 taxa; however, there may have been additional species included in some of the general categories used (Table 11). Fyke netting also captured few species during any single sampling effort with the mean number of species captured at the five sites ranging from 1.1 to 1.7. Standard deviations ranged from 1.0 to 1.5. Fyke netting captured about 27 taxa (Tables 12 and 13).



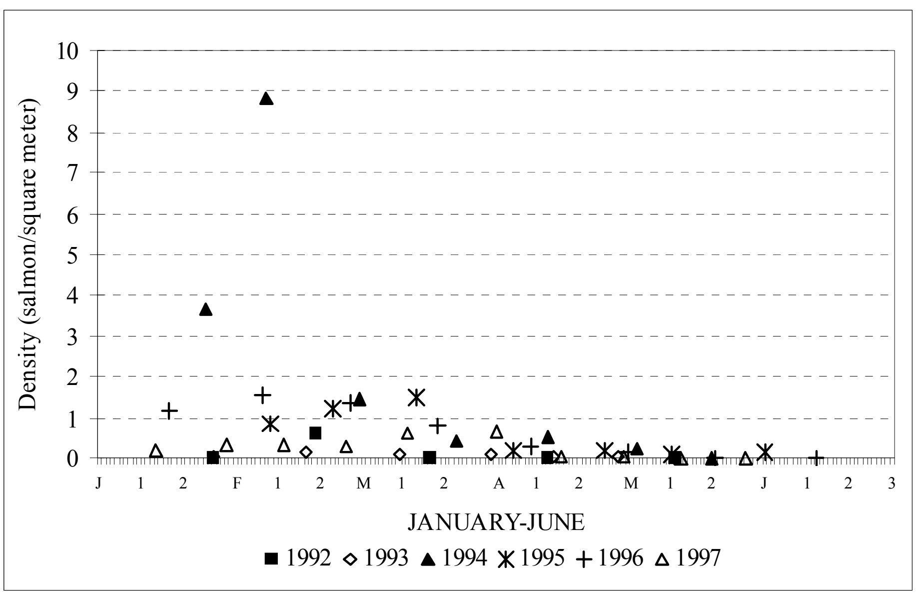


Figure 7 Densities of salmon from seining surveys from 1986 to 1997

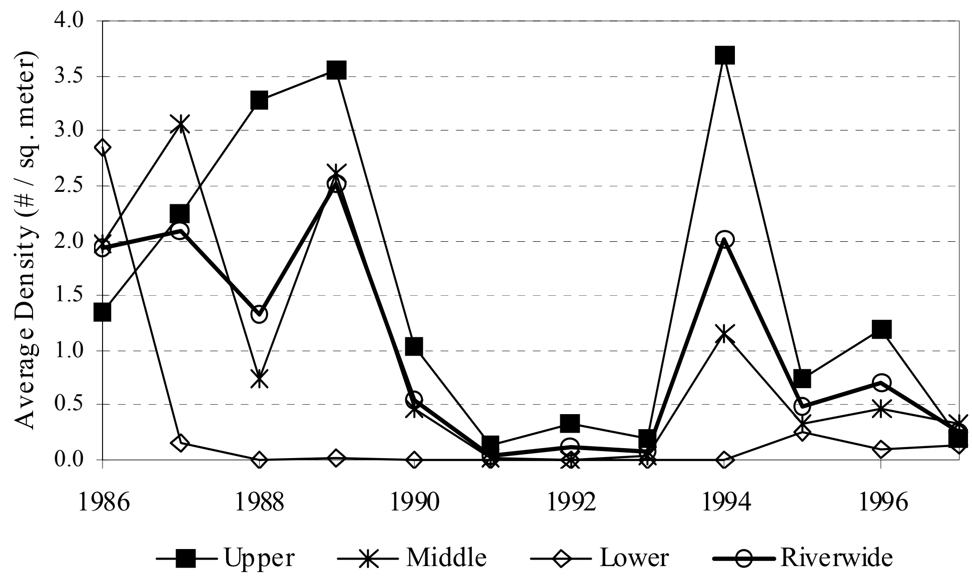


Figure 8 Densities of juvenile salmon captured during seining surveys for upper, middle, and lower sections of the river and for the entire river

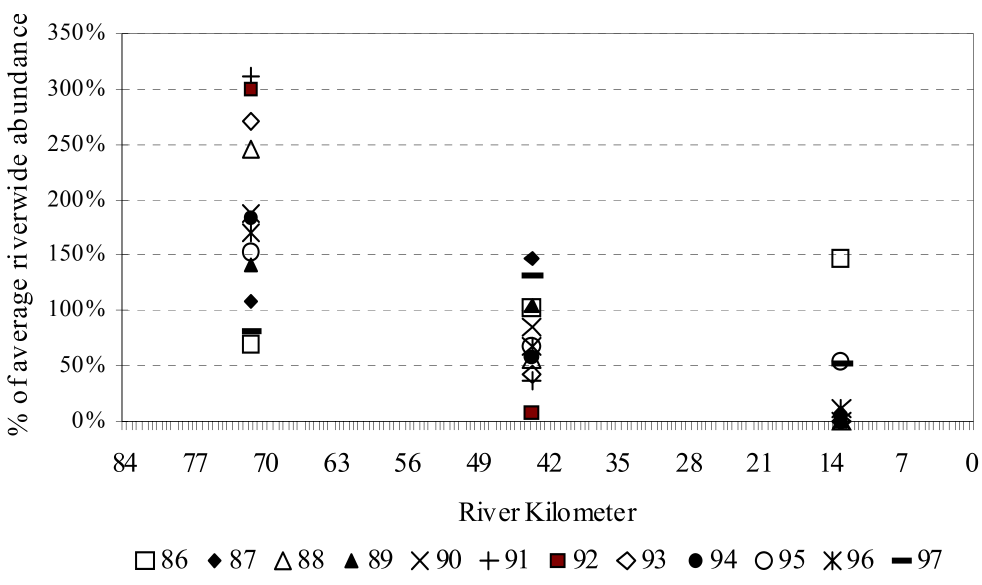


Figure 9 Densities of juvenile salmon in upper, middle, and lower sections standardized as percentage of the annual riverwide density and plotted at section midpoints

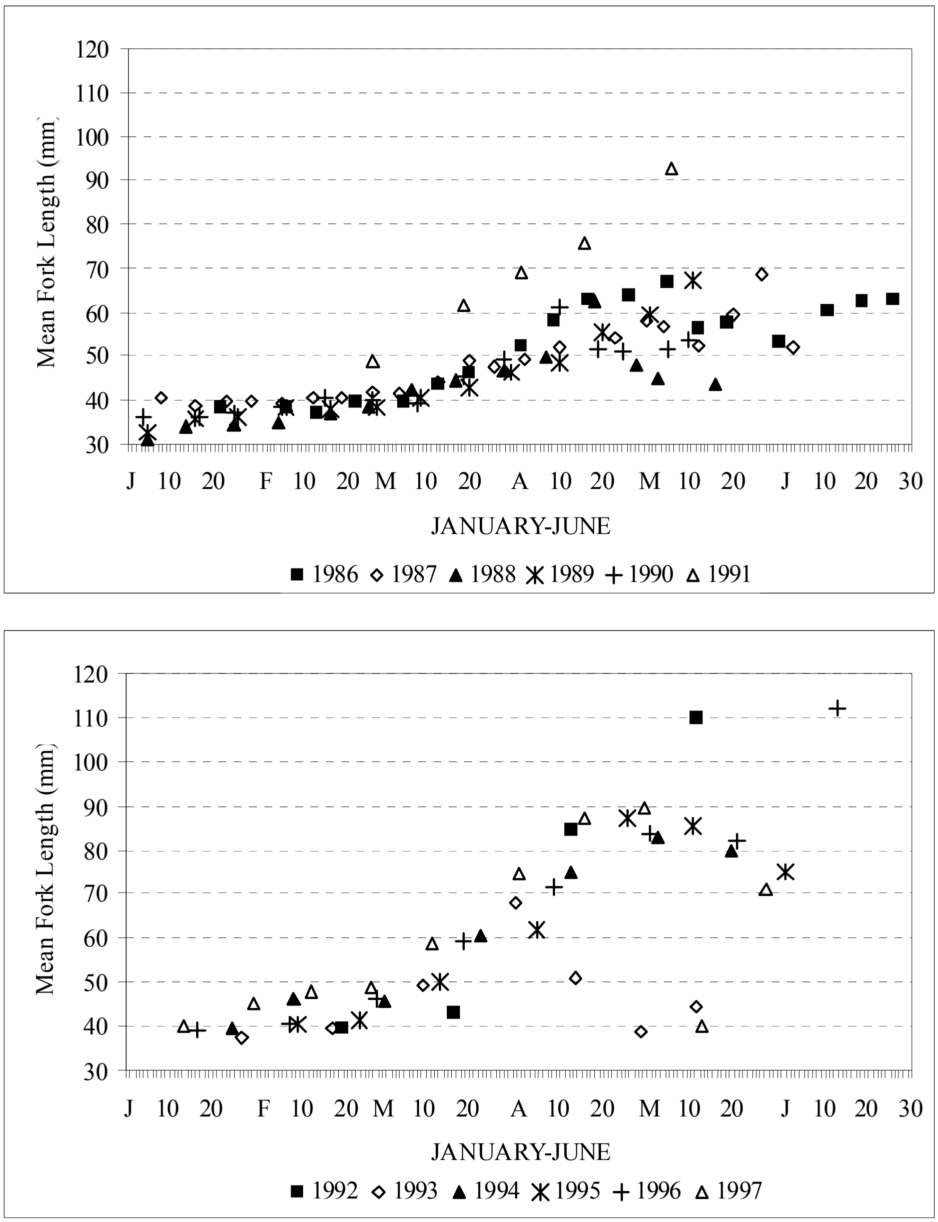


Figure 10 Mean fork length of salmon captured during seining surveys from 1986 to 1997

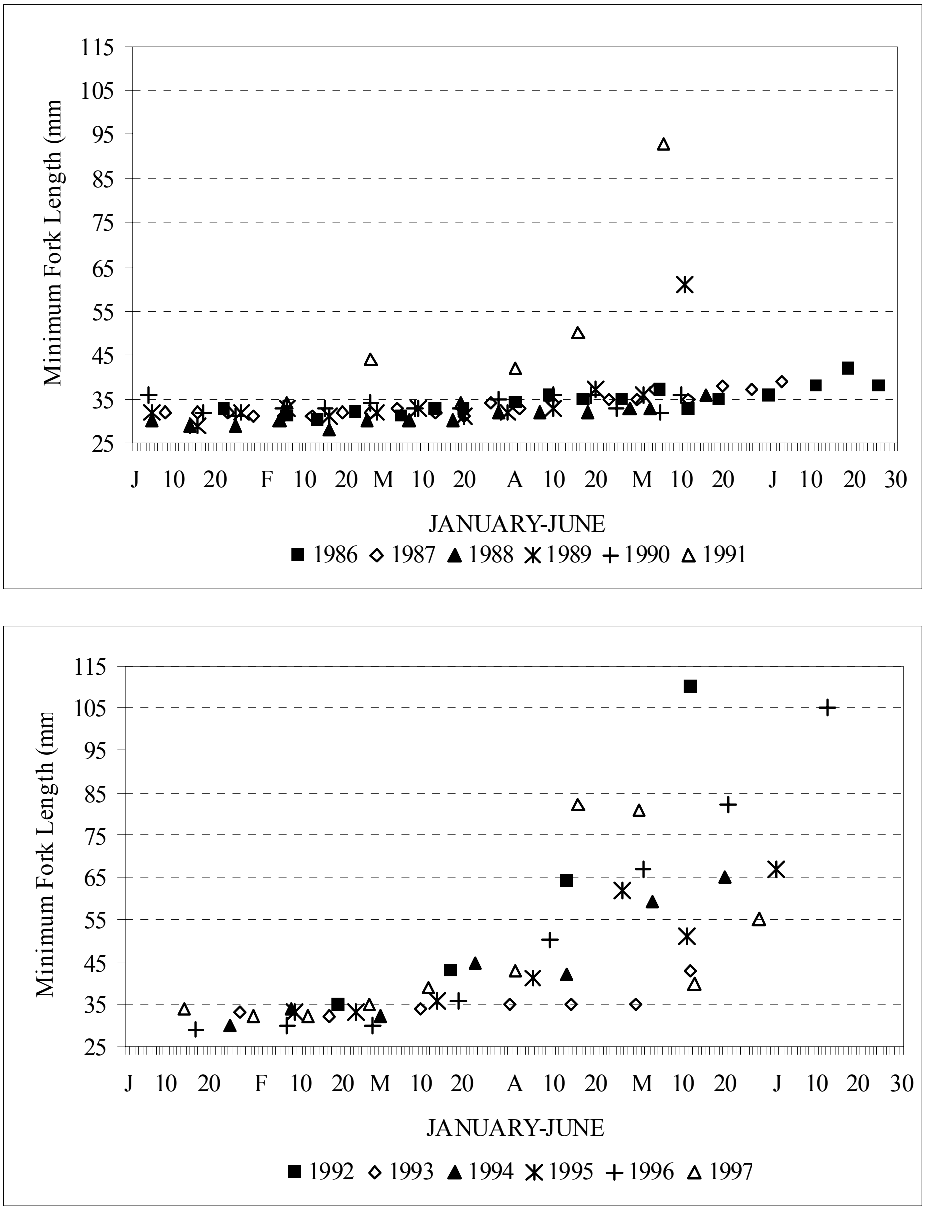


Figure 11 Minimum fork length of salmon captured during seining surveys from 1986 to 1997

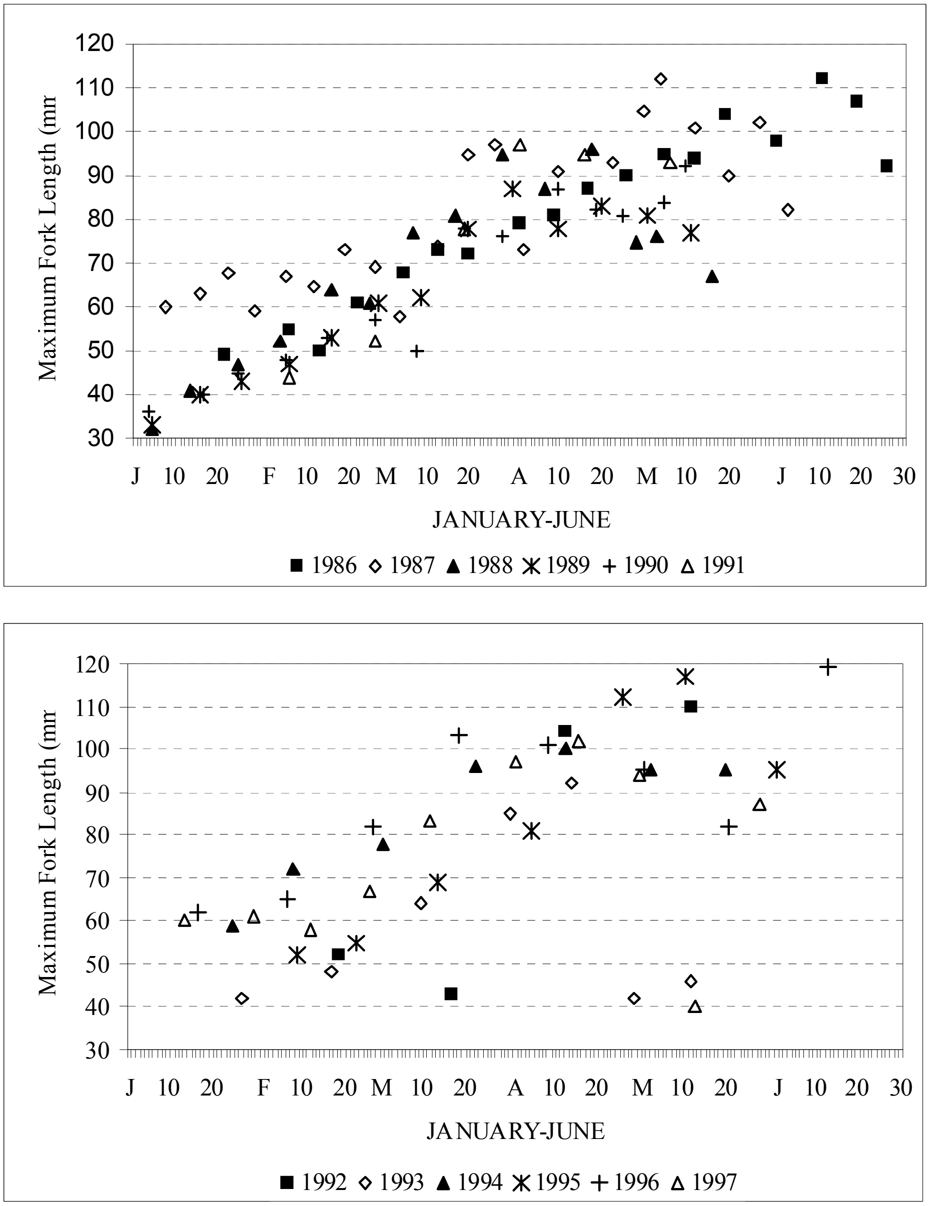


Figure 12 Maximum fork length of salmon captured during seining surveys from 1986 to 1997

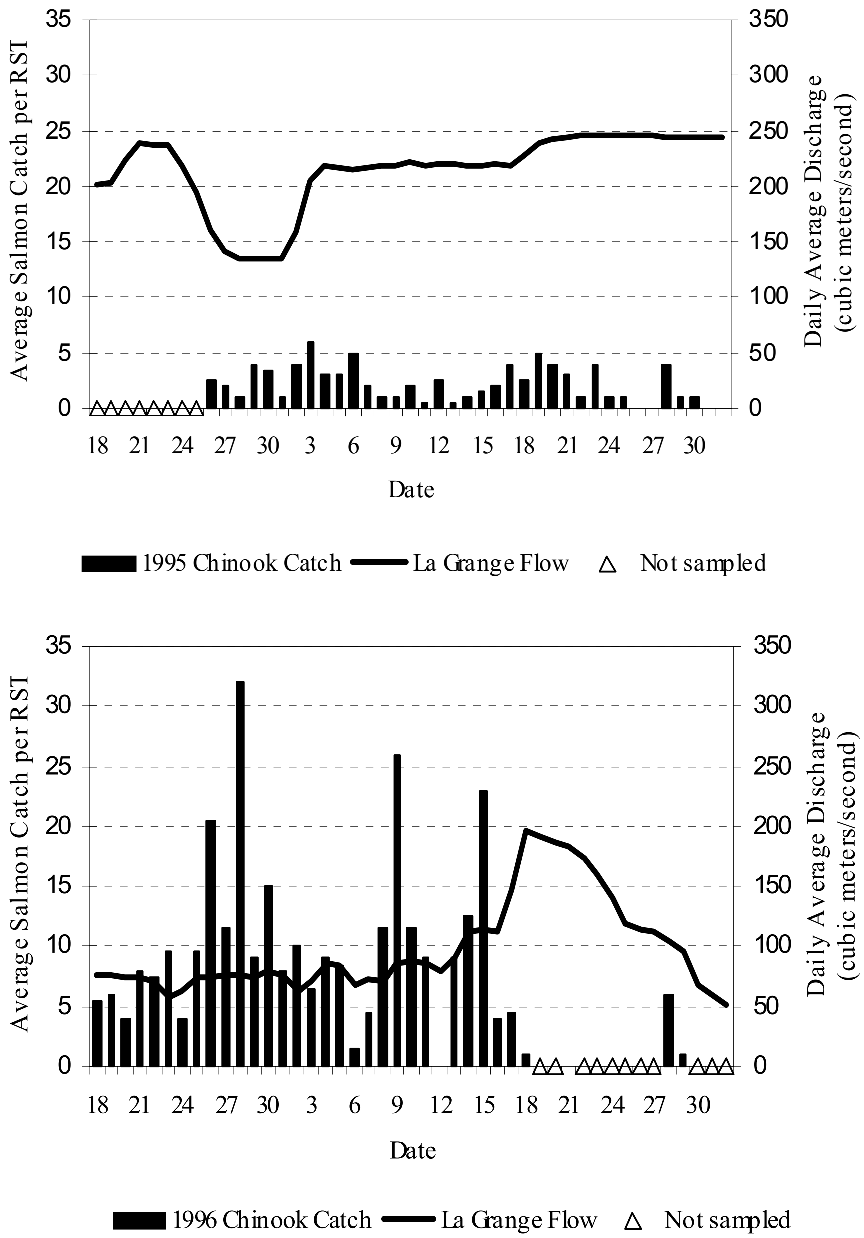


Figure 13 Rotary screw trap salmon catch data from 1995 and 1996 at Shiloh Road (rkm 5.8) during 18 April to 1 June. Days when sampling did not occur are indicated by a triangle.

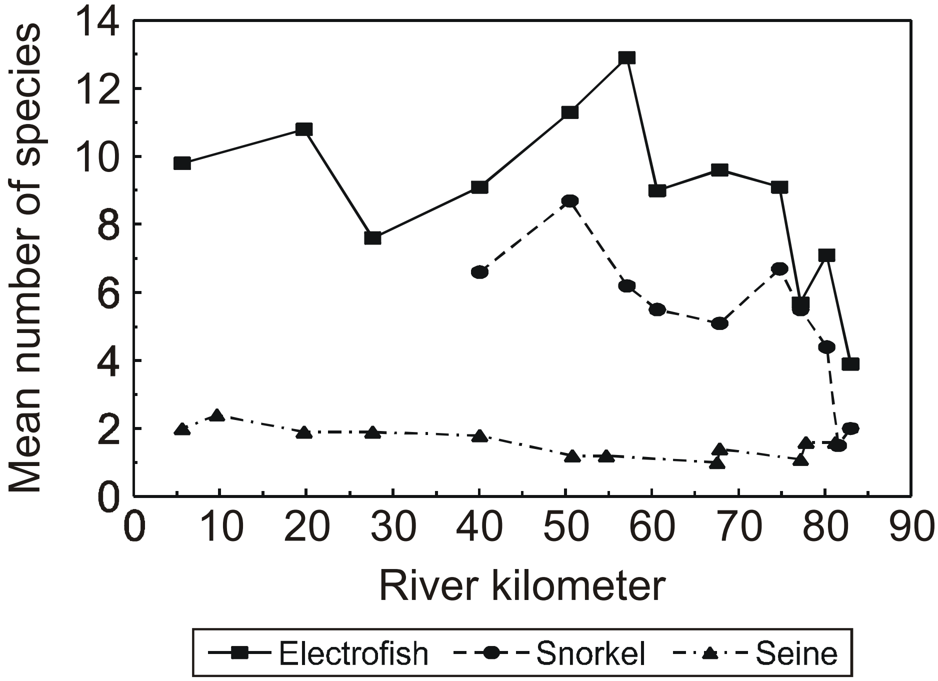


Figure 14 Mean number of species, excluding chinook salmon, captured during annual winter-spring seining and summer snorkeling and electrofishing

Table 8 Number of juvenile salmon captured during primary summer survey periods, listed by date, method, location, and river kilometer

Date	*Sampling method*	*Location*	*River kilometer*	*Number captured*
05 May 88	Seine	RA3	83.0	3
05 May 88	Snorkel	RA3	83.0	3
13 May 88	Snorkel	OLGB	81.3	22
06 May 88	Seine	R2	80.3	1
06 May 88	Snorkel	R2	80.3	1
13 May 88	Snorkel	R3B	79.0	1
13 May 88	Snorkel	R4A	78.5	1
13 May 88	Snorkel	R4B	77.9	1
24 May 88	Electroshocking	R5	77.2	1
13 May 88	Snorkel	R5	77.2	25
06 May 88	Electroshocking	R5	77.2	8
06 May 88	Snorkel	R5	77.2	104
11 May 88	Electroshocking	R9	74.8	3
11 May 88	Snorkel	R9	74.8	3

Table 8 Number of juvenile salmon captured during primary summer survey periods, listed by date, method, location, and river kilometer (Continued)

Date	*Sampling method*	*Location*	*River kilometer*	*Number captured*
11 May 88	Seine	TRR	67.9	1
12 May 88	Snorkel	R33	60.7	1
23 May 89	Electroshocking	RA3	83.0	2
23 May 89	Snorkel	RA3	83.0	127
23 May 89	Electroshocking	RA7	81.6	6
24 May 89	Electroshocking	R2	80.3	1
24 May 89	Electroshocking	R5	77.2	5
01 Jun 89	Electroshocking	R9	74.8	5
25 May 89	Electroshocking	TRR	67.9	2
25 May 89	Electroshocking	R33	60.7	10
01 Jun 89	Electroshocking	R39	57.1	2
02 Jun 89	Electroshocking	R58	50.5	2
26 May 89	Electroshocking	CROAD	40.1	1
09 Jul 89	Electroshocking	RA3	83.0	1
29 May 90	Electroshocking	RA3	83.0	20
05 Jun 90	Snorkel	RA3	83.0	12
29 May 90	Electroshocking	RA7	81.6	50
30 May 90	Electroshocking	R2	80.3	16
30 May 90	Electroshocking	R5	77.2	8
31 May 90	Electroshocking	R9	74.8	37
31 May 90	Electroshocking	TRR	67.9	4
01 Jun 90	Electroshocking	R33	60.7	4
01 Jun 90	Electroshocking	R39	57.1	3
02 Jun 90	Electroshocking	R58	50.5	13
18 Sep 90	Electroshocking	RA3	83.0	1
18 Sep 90	Electroshocking	RA7	81.6	2
08 Jun 93	Electroshocking	RA3	83.0	1
07 Jun 93	Snorkel	RA3	83.0	35
07 Jun 93	Snorkel	R2	80.3	2
09 Jun 93	Electroshocking	R58	50.5	1
08 Jun 93	Snorkel	CROAD	40.1	1
27 Oct 93	Snorkel	RA3	83.0	10
25 Oct 93	Snorkel	RA7	81.6	7
25 Oct 93	Snorkel	R1A	81.3	7
27 Oct 93	Snorkel	R2	80.3	11
25 Oct 93	Snorkel	R5	77.2	3
27 Oct 93	Snorkel	R9	74.8	7
25 Oct 93	Electroshocking	R58	50.5	1

Table 9 Common name, scientific name, origin, and code for species captured during Tuolumne River fish monitoring

Common name	Scientific name	Origin[a]	Code[b]
Petromyzontidae (lampreys)			
Pacific lamprey	*Lampetra tridentata*	N	LMP
Clupeidae (shad and herring)			
Threadfin shad	*Dorosoma petenense*	I	--
Salmonidae (salmon and trout)			
Chinook salmon	*Oncorhynchus tshawytscha*	N	--
Rainbow trout	*Oncorhynchus mykiss*	N	--
Cyprinidae (minnows)			
Common carp[c]	*Cyprinus carpio*	I	CP
Fathead minnow	*Pimephales promelas*	I	--
Golden shiner	*Notemigonus crysoleucas*	I	GSH
Goldfish	*Carassius auratus*	I	GF
Hardhead	*Mylopharodon conocephalus*	N	HH
Hitch	*Lavinia exilicauda*	N	--
Red shiner	*Cyprinella lutrensis*	I	RSH
Sacramento blackfish	*Orthodon microlepidotus*	N	--
Sacramento splittail	*Pogonichthys macrolepidotus*	N	--
Sacramento pikeminnow	*Ptychocheilus grandis*	N	SQ
Catostomidae (suckers)			
Sacramento sucker	*Catostomus occidentalis*	N	SKR
Ictaluridae (catfish)			
Black bullhead	*Ameiurus melas*	I	--
Bullhead catfish[d]	*Ameiurus spp.*	I	BCF
Channel catfish	*Ictalurus punctatus*	I	CCF
White catfish	*Ameiurus catus*	I	WCF
Poeciliidae (livebearers)			
Western mosquitofish	*Gambusia affinis*	I	GAM
Atherinidae (silversides)			
Inland silverside	*Menidia beryllina*	I	ISS
Percichthyidae (temperate basses)			
Striped bass	*Morone saxatilis*	I	--
Centrarchidae (basses and sunfish)			
Black crappie	*Pomoxis nigromaculatus*	I	--
Bluegill	*Lepomis macrochirus*	I	BG
Green sunfish	*Lepomis cyanellus*	I	GSF
Largemouth bass	*Micropterus salmoides*	I	LMB
Redear sunfish	*Lepomis microlophus*	I	RSF
Smallmouth bass	*Micropterus dolomieu*	I	SMB
Warmouth	*Lepomis gulosus*	I	--
White crappie	*Pomoxis annularis*	I	--
Percidae (perch)			
Bigscale logperch	*Percina macrolepida*	I	--
Embiotocidae (surf perch)			
Tule perch	*Hysterocarpus traski*	N	--
Cottidae (sculpins)			
Prickly sculpin	*Cottus asper*	N	--
Riffle sculpin	*Cottus gulosus*	N	RSCP

[a] N = native, I = introduced.
[b] Dashes (--) indicate no code was assigned.
[c] A single mirror carp, a variety of common carp, was captured.
[d] Because of difficulty in field identification of bullhead catfish, they were combined into a single category.

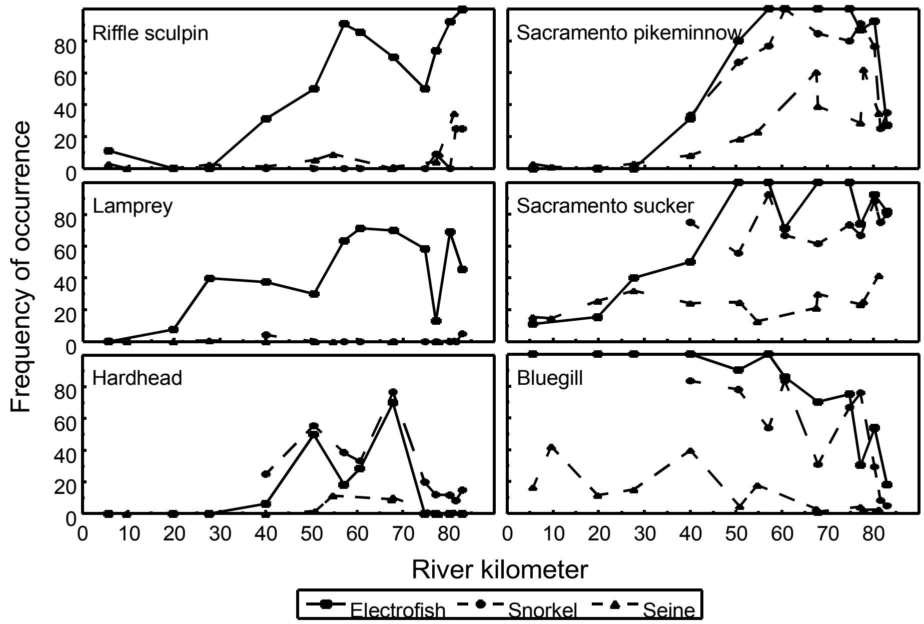


Figure 15A Frequency of occurrence plots for common native species (and bluegill) included in detrended correspondence analysis of annual winter-spring seining and summer electroshocking and snorkeling

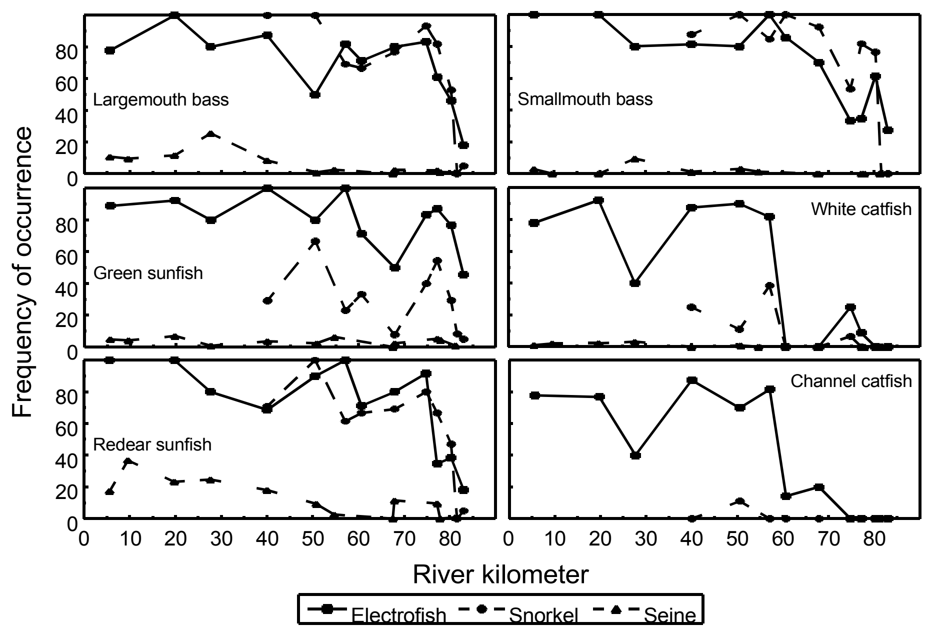


Figure 15B Frequency of occurrence plots for common centrarchid and ictalurid species included in detrended correspondence analysis of annual winter-spring seining and summer electroshocking and snorkeling

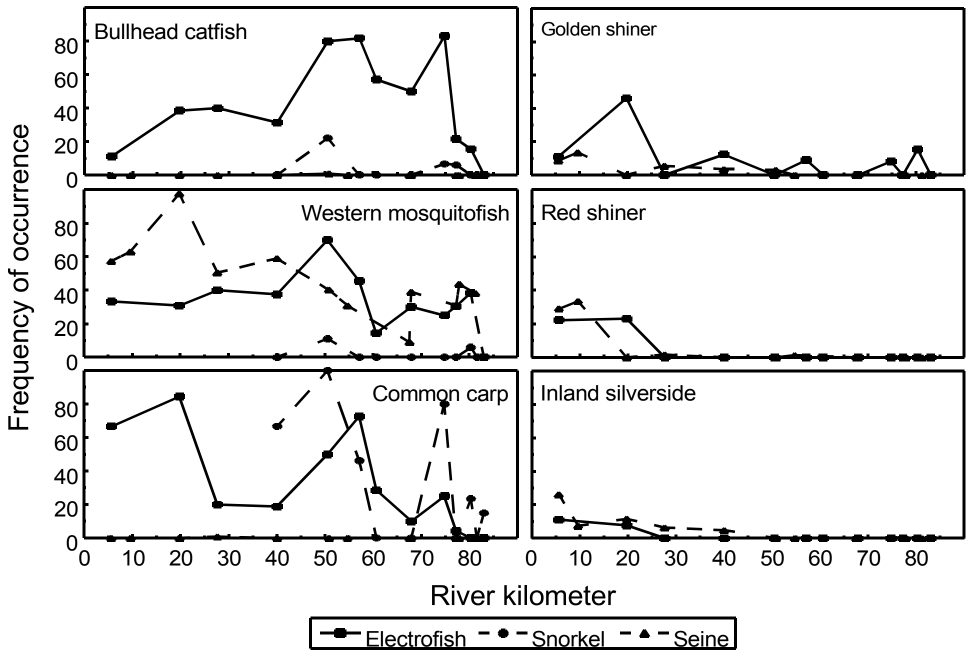


Figure 15C Frequency of occurrence plots for other common introduced species included in detrended correspondence analysis of annual winter-spring seining and summer electroshocking and snorkeling

Table 10 Percentages of fishes (excluding chinook salmon) captured during winter-spring salmon seining surveys (Jan–Jun, 1986–1997) and summer survey electroshocking (May–Oct, 1988–1993), snorkeling (May–Oct, 1988–1993), and seining (May–Sep 1988)

	Winter-spring survey	*Summer survey*		
Taxon	*Seining*	*Seining*	*Electroshocking*	*Snorkeling*
Bigscale logperch	<0.1	0	<0.1	0
Black bullhead	<0.1	0	<0.1	0
Black crappie	<0.1	0	0	0
Bluegill	2.4	9.5	10.6	7.3
Bullhead catfish	<0.1	0	1.6	0.7
Centrarchids (unknown)	0.6	0.1	1.9	2.0
Channel catfish	0	<0.1	1.9	<0.1
Common carp	<0.1	0	0.6	1.0
Cyprinids (unknown)	0.1	0	0	3.1
Golden shiner	2.1	0.1	0.2	0
Goldfish	<0.1	<0.1	0.7	0.8
Green sunfish	0.2	0.2	9.7	2.0
Hardhead	1.0	0	0.7	2.2
Hitch	0	0	0.1	<0.1
Inland silverside	1.3	0.6	<0.1	0
Largemouth bass	1.1	2.5	5.7	8.6
Pacific lamprey	<0.1	0	1.1	<0.1
Prickly sculpin	<0.1	0	0	0
Rainbow trout	0.1	0	<0.1	<0.1
Redear sunfish	5.0	2.0	8.0	17.1
Red shiner	6.2	0	0.1	0
Riffle sculpin	1.9	0.1	19.0	0.1
Sacramento blackfish	<0.1	0	0.1	<0.1
Sacramento pikeminnow	7.3	1.6	10.2	12.2
Sacramento splittail	0.1	0	<0.1	0
Sacramento sucker	35.4	0.9	13.3	36.9
Smallmouth bass	0.2	1.6	4.5	5.6
Striped bass	0	0	<0.1	0
Threadfin shad	0.3	0	<0.1	0
Tule perch	0	0	<0.1	0
Warmouth	<0.1	0	0.1	<0.1
Western mosquitofish	34.4	80.5	1.0	<0.1
White crappie	<0.1	0	0	0
White catfish	0.1	0.2	8.6	0.2
Number of samples	1,077	37	148	194
Total fish captured	21,736	3,611	23,774	26,371

Table 11 Percentage abundance of fish species, excluding chinook salmon, captured in rotary screw traps at river kilometer 5.6 in 1995 (25 April to 30 May) and 1996 (18 April to 29 May)[a]

Taxon	*1995*	*1996*
Native taxa		
Cottidae	0	1.0
Hardhead	0	0.3
Hitch	0	0.3
Sacramento blackfish	0	0.3
Sacramento pikeminnow	1.5	0.7
Sacramento sucker	5.5	3.9
Introduced taxa		
Black bullhead	0.1	0
Bluegill	0.1	8.5
Bullhead catfish	0	0.7
Centrarchidae	0.4	0.7
Channel catfish	0.1	0.3
Common carp	0.1	0
Golden shiner	0.3	3.6
Goldfish	4.5	3.9
Green sunfish	0.3	0.7
Ictaluridae	0	13.1
Inland silverside	0.4	33.4
Largemouth bass	0.3	18.4
Red shiner	1.7	0.7
Threadfin shad	0	0.3
Warmouth	0	0.3
Western mosquitofish	2.9	7.2
White catfish	2.0	0.7
White crappie	0	1.0
Unknown		
Cyprinidae	79.7	0
Total number of fish	715	305

[a] Some fish were not identified to species but were identified to the lowest possible taxon.

Table 12 Percentages of fish taxa (excluding chinook salmon) captured by fyke nets at various river kilometer locations, 1973–1980

Year	*1973*			*1974*			*1977*			*1980*			
Rkm	9.7	49.2	67.6	9.7	49.2	67.6	9.7	49.2	67.6	9.7	42.0	54.7	67.6
Native taxa													
Cottus sp.	0	0	0	0	0	0	0	0	0	0	0.4	0	0
Hardhead	0	0	0	0	0	0	0	0	0	0	0	1.9	0
Hitch	0	0	0	0	0	0	5.4	0	1.8	0	0	1.9	0
Pacific lamprey	0	0	0	2.5	2.9	12.6	6.8	9.9	0.9	5.2	1.6	28.8	10.8
Sacramento blackfish	0	0	0	0	0	0	1.4	0	0	0	0	0	0
Sacramento splittail	0	0	0	11.5	0	0	0	0	0	0	0	0	0
Sacramento pikeminnow	0	0	0	0	0	0	0	0	1.8	0	0	0	1.4
Sacramento sucker	0	0	0	0.6	86.0	16.5	0	60.6	2.7	0	0.4	0	17.6
Introduced taxa													
Bigscale logperch	0	0	0	0	0	0	0	0	0	0	0	0	0
Black bullhead	0	0	0	0	0	0	0	1.4	0	0	0	0	0
Black crappie	0	0	0	0	0	0	0	0	0	0	0	0	0
Bluegill	0	0	0	4.2	2.1	16.5	8.1	2.8	17.9	16.8	5.6	23.1	28.4
Bullhead catfish	0	50	20	0	0	1.6	0	1.4	0	0	0	3.8	0
Centrarchidae	0	0	0	0.3	2.4	3.1	0	0	20.5	0	0	7.7	0
Channel catfish	0	0	40	0	0	0	2.7	0	0	1.1	0	0	0
Common carp	12.5	0	0	0.6	0.1	0	0	0	0	0	0	0	2.7
Golden shiner	0	0	0	1.4	0.2	0	1.4	0	0	0.2	0	0	1.4
Goldfish	0	0	0	2.0	0.1	0	13.5	2.8	0.9	0	0	0	0
Green sunfish	0	0	0	0.6	0	3.1	1.4	0	0	0	0	0	0
Ictaluridae	87.5	0	20	40.3	1.6	6.3	1.4	0	1.8	69.7	0.8	17.3	14.9
Largemouth bass	0	0	0	6.2	0.7	28.3	1.4	0	2.7	0.2	0.4	0	9.5
Pomoxis sp.	0	0	0	0.6	0.2	0	1.4	0	0	0	0	0	0
Redear sunfish	0	0	0	0	0	0	0	0	2.7	0	0	0	0
Smallmouth bass	0	0	0	1.7	3.7	3.9	0	12.7	6.3	0	0	0	0
Striped bass	0	0	0	0.3	0	0	0	0	0	0	0	0	0
Threadfin shad	0	0	0	25.6	0	0	37.8	1.4	34.8	3.5	90.4	11.5	0
Warmouth	0	50	0	1.4	0	6.3	1.4	0	4.5	0	0.4	1.9	13.5
Western mosquitofish	0	0	0	0.3	0.1	1.6	0	0	0	0	0	0	0
White catfish	0	0	20	0	0	0	16.2	7.0	0.9	3.3	0	0	0
Days sampled	23	24	22	28	29	29	24	26	28	57	31	35	54
Total fish	8	2	5	355	1452	127	74	71	112	459	250	52	74

Table 13 Percentages of fish taxa (excluding chinook salmon) captured by fyke nets at various river kilometer locations, 1981–1986

Year	*1981*	*1982*			*1983*	*1986*
River kilometer	*67.6*	*9.7*	*51.5*	*67.6*	*67.6*	*67.6*
Native taxa						
Cottus sp.	0	0	0	0	0	0
Hardhead	0	0	0.3	10.4	0	2.9
Hitch	0	0.9	1.9	0.9	2.2	0
Pacific lamprey	100.0	50.4	52.9	39.6	28.3	82.2
Sacramento blackfish	0	0	0	0	0	0
Sacramento splittail	0	0	0	0	0	0
Sacramento pikeminnow	0	0.9	8.0	9.4	0	0
Sacramento sucker	0	0	0	0	0	0
Introduced taxa						
Bigscale logperch	0	2.6	0	0	0	0
Black bullhead	0	0	0	0	0	0
Black crappie	0	0	0.6	0	0	0.6
Bluegill	0	20.9	23.0	14.2	39.1	12.6
Bullhead catfish	0	0	0	0	0	0
Centrarchidae	0	0	0	0	2.2	0
Channel catfish	0	0	0	0	0	0
Common carp	0	0	1.1	0	0	0
Golden shiner	0	0	0	0	0	0
Goldfish	0	0	0	0	0	0
Green sunfish	0	0	0	0	0	0
Ictaluridae	0	14.1	3.3	16.0	26.1	0.6
Largemouth bass	0	0.4	0.3	3.8	0	0.6
Pomoxis sp.	0	0	0	0	0	0.6
Redear sunfish	0	0	0	0	0	0
Smallmouth bass	0	0	0	0	0	0
Striped bass	0	0	0	0	0	0
Threadfin shad	0	9.8	8.3	0	2.2	0
Warmouth	0	0	0.3	5.7	0	0
Western mosquitofish	0	0	0	0	0	0
White catfish	0	0	0	0	0	0
Days sampled	8	16	23	24	11	15
Total number of fish	4	234	361	106	46	174

Although the three winter-spring methods captured similar numbers of species, catches were dominated by different species. Seining catches were dominated by western mosquitofish (34.4%) and Sacramento sucker (35.4%) (Table 10). No other species exceeded 10% of the catch. The rotary screw trap catch was dominated by unidentified cyprinids (79.7%) in 1995 (Table 11). Of the fish identified to species, Sacramento sucker (5.5%) and goldfish (4.5%) were most common. The catch in 1996 was dominated by unidentified catfish (13.1%), inland silverside (33.4%), and largemouth bass (18.4%) (Table 11). Fyke netting results were variable among sites and years (Tables 12 and 13). Unidentified catfish commonly exceeded 10% of the catch in the lower river (rkm 6.0 and 26.1). Threadfin shad was common (>10%) in 1974 and 1977, as were bluegill in 1980 and 1982. Other species common in at least one year included common carp, splittail, goldfish, white catfish, and Pacific lamprey. Catfish of all kinds were common at more upstream sites. Pacific lamprey, Sacramento sucker, bluegill, warmouth, threadfin shad, and hardhead were common in some years.

Seining was initially included in the summer flow study but was suspended after the first year (1988) because the catch consisted primarily of western mosquitofish with few other species captured (Table 10). Summer seining only captured 15 taxa with only western mosquitofish exceeding 10% of the catch. Summer snorkeling and electroshocking captured many more species than winter-spring seining (Figure 14) and the other methods. Mean number of species (mean ± standard deviation) ranged from 1.5 ± 1.3 to 8.7 ± 2.2 for snorkeling and from 3.9 ± 1.6 to 12.9 ± 2.2 for electroshocking. Snorkeling and electroshocking captured 22 and 30 taxa, respectively. Snorkeling was limited to the more upstream reaches of the river where visibility was sufficient to identify and count the fish present.

Fish Species Distributions

Only the annual winter-spring seining and summer electroshocking and snorkeling surveys sampled enough sites to give good information on resident fish species distributions. Percentage abundance of species in the winter-spring seining and summer surveys indicates that a number of species were relatively rare in the system (Table 10). The native species hitch, prickly sculpin, rainbow trout, Sacramento blackfish, Sacramento splittail, and tule perch never exceeded 1% of the total catch with any of the methods used. The introduced species black crappie, bigscale logperch, goldfish, striped bass, threadfin shad, white crappie and warmouth were similarly rare.

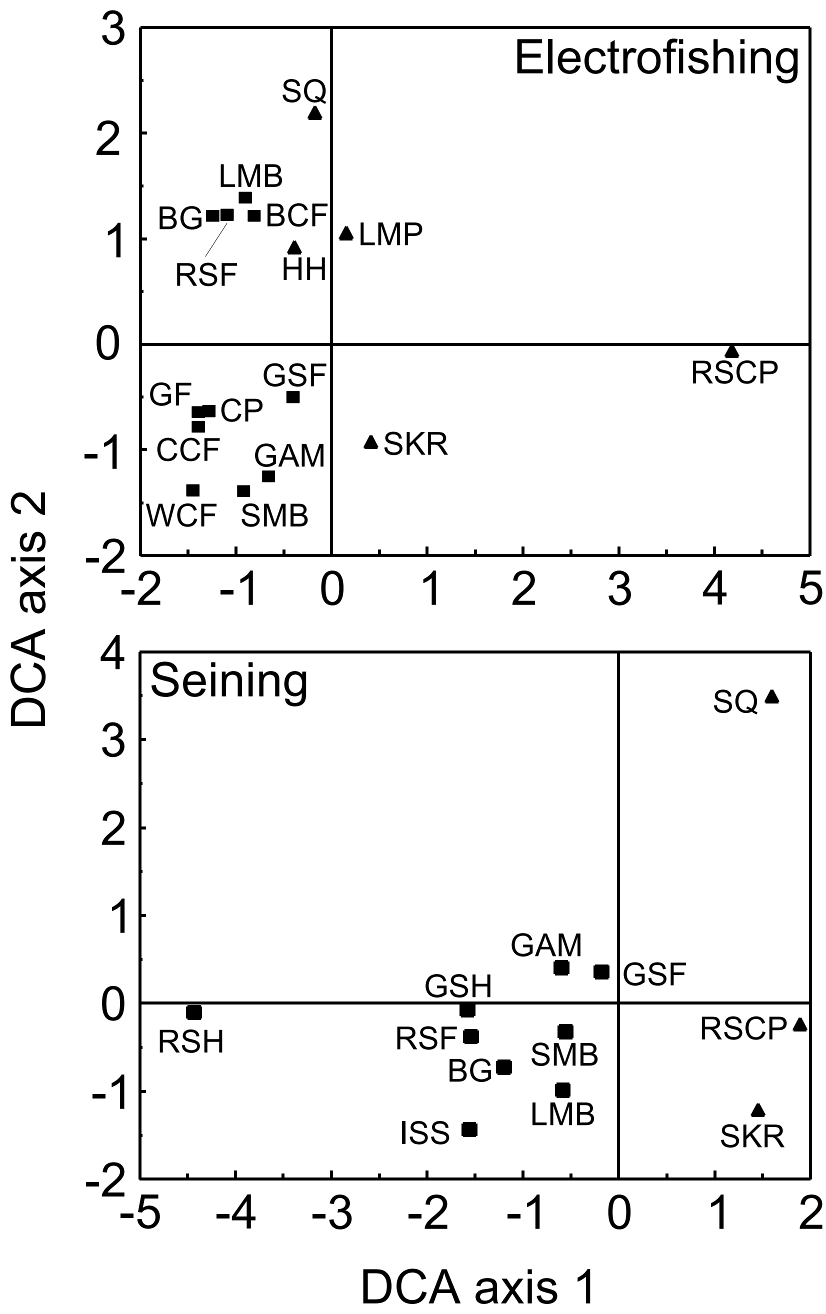


Figure 16 Species scores on DCA axes 1 and 2 resulting from analysis of the summer electrofishing data and winter-spring seining data. Species codes as in Table 9. Triangles indicate native species and squares indicate introduced species.

Frequency of occurrence plots for the common species included in DCA analyses indicated that the species were not evenly distributed in the river, particularly during the summer (Figure 15A). The common native species exhibited two basic patterns of distribution. In the summer electrofishing surveys, Sacramento sucker, lamprey, and riffle sculpin occurred most frequently at upstream sites above about rkm 50. Lamprey and riffle sculpin were rarely captured in the winter-spring seining or summer snorkeling. Sacramento suckers were fairly evenly distributed in the river in the winter-spring seining survey but in the summer surveys were most frequent upstream of rkm 50. The other two common native species, hardhead and Sacramento pikeminnow were most frequently captured upstream of about rkm 50, but there was a subsequent decline in frequency of occurrence around rkm 80.

The common introduced centrarchids exhibited very similar patterns in frequency of occurrence (Figures 15A and 15B). All of the species were well distributed throughout the river during the summer as indicated by both electroshocking and snorkeling. The occurrence of all species declined sharply around rkm 80 with somewhat lower frequencies of occurrence observed upstream of rkm 50. Only bluegill and redear sunfish were regularly captured during winter-spring seining. The winter-spring pattern was similar to the summer pattern with the species occurring most frequently downstream of rkm 50.

The remaining common introduced species exhibited a mixture of distributions. White catfish and channel catfish commonly occurred in summer electrofishing samples at downstream sites but became rare at about rkm 60 (Figure 15B). Both species were rarely captured during snorkeling or winter-spring seining surveys. Similarly, summer snorkeling or winter-spring seining rarely captured bullhead catfish (Figure 15C). Unlike the other catfish, bullheads were less frequently captured at the upstream and downstream ends of the study area compared to the middle section between about rkm 40 and 80. Warmouth, a centrarchid (not shown in Figure 15C), showed a very similar pattern of distribution. Red shiner and inland silverside were relatively rare, but were clearly most frequently captured in the downstream reaches of the river (Figure 15C). Red shiner was not captured upstream of rkm 30 and inland silverside was never captured above rkm 50. Western mosquitofish was fairly evenly distributed along the river in the summer electrofishing survey, but was captured most frequently at downstream sites in the winter-spring seining survey. The remaining common introduced species, common carp, goldfish (not shown but similar to carp), and golden shiner occurred sporadically at certain sites along the river. All occurred rarely at sites near rkm 80 and upstream sites.

Although the data are insufficient to determine distribution in the Tuolumne River, two additional native species deserve mention. A single tule perch was captured during a summer electrofishing survey at rkm 19.8 in June 1991. Splittail was occasionally captured below rkm 30 during winter-spring seining and summer electrofishing. Single individuals were captured during seining at rkm 9.7 in March of 1988 and 1989. In May 1987, seven splittail were captured at rkm 27.7, and five were captured at rkm 5.6. A single individual was captured in a May electrofishing survey at rkm 5.6. Forty-one splittail were captured during fyke netting at rkm 9.7 in 1974.

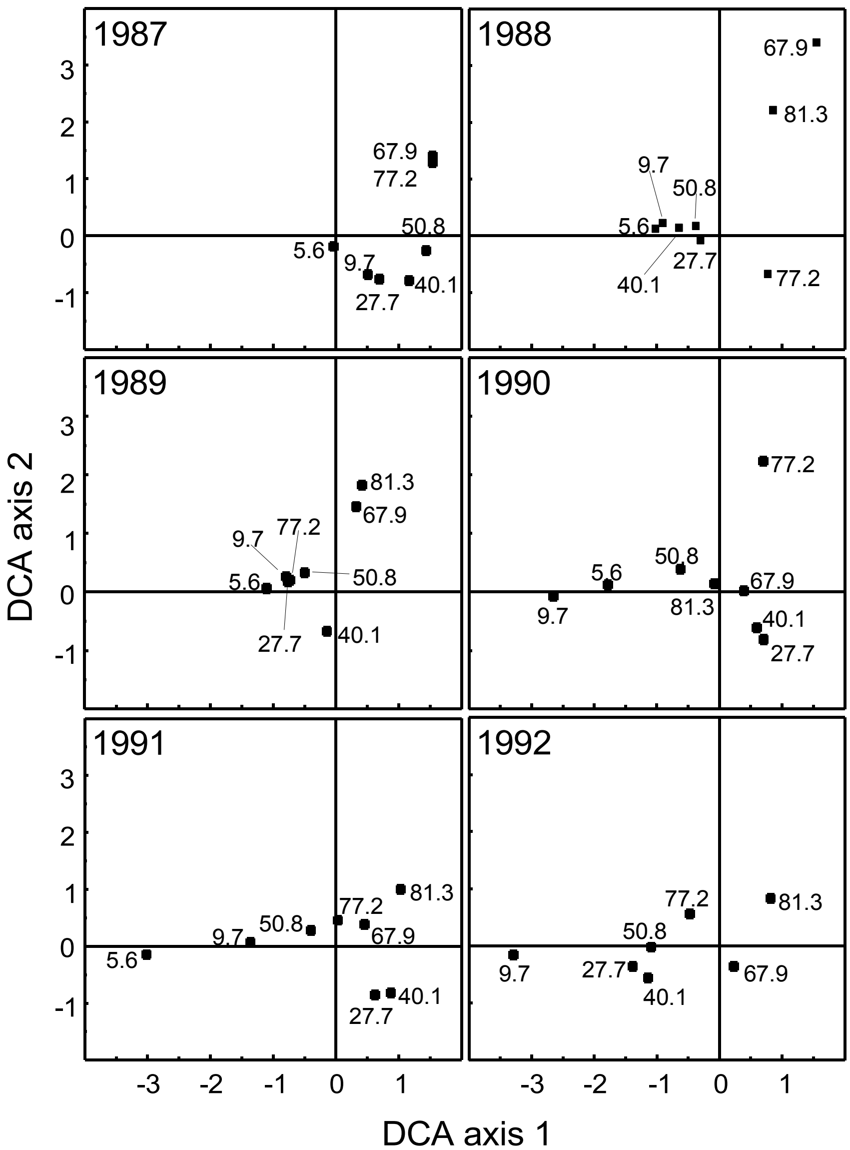


Figure 17A Site scores on DCA axes 1 and 2. Scores were derived from analysis of annual winter-spring seining data. Numbers indicate site location as kilometers from the San Joaquin River.

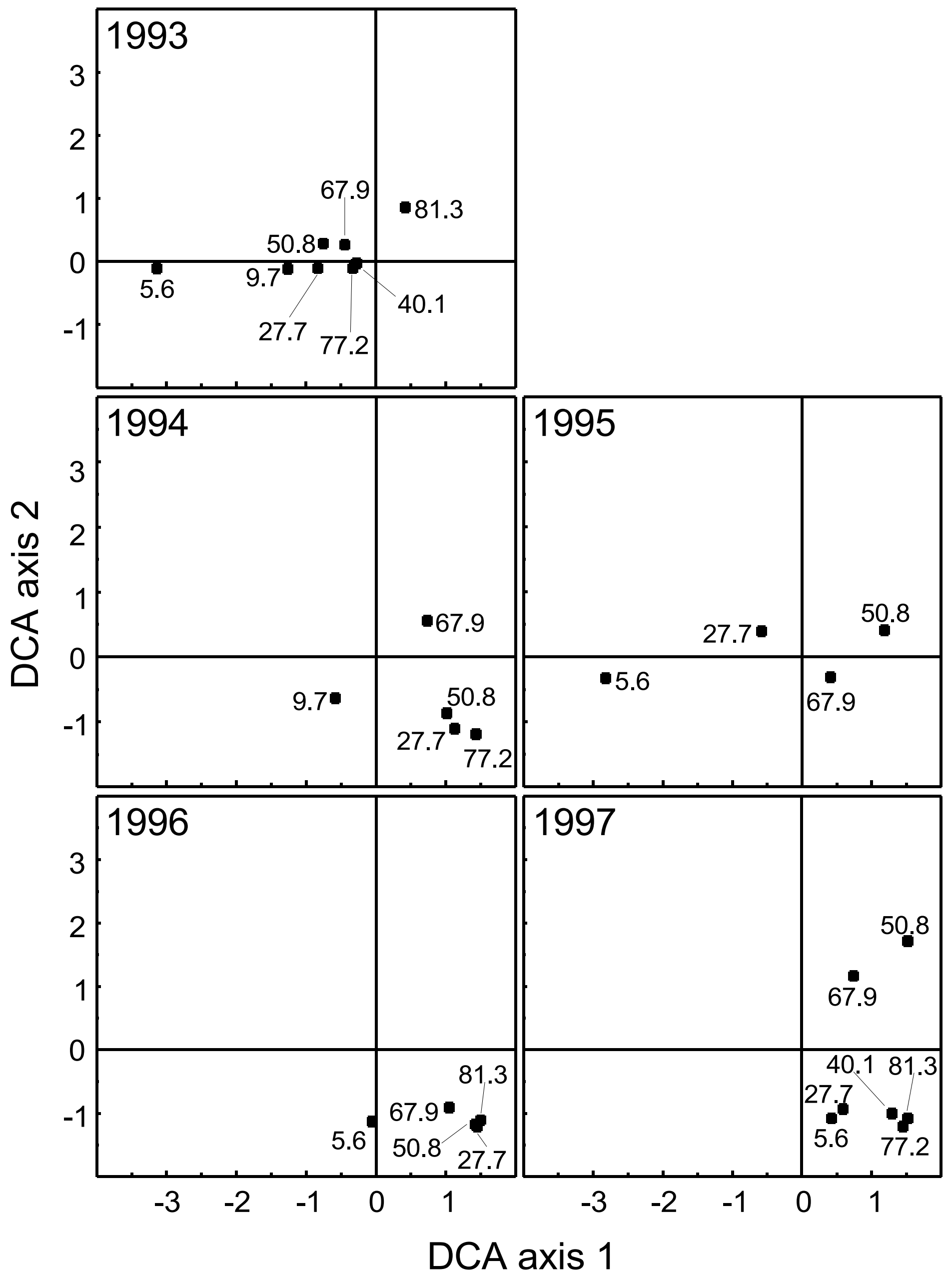


Figure 17B Site scores on DCA axes 1 and 2. Scores were derived from analysis of annual winter-spring seining data. Numbers indicate site location as kilometers from the San Joaquin River.

Fish Species Assemblages

The initial analysis of the winter-spring seining data was heavily influenced by a single sample collected at rkm 50.5 in 1987. Riffle sculpin dominated (94%) this sample. Because the high percentage of riffle sculpin was unusual compared to all other samples collected, it was omitted and the analysis conducted again.

The first four axes of the DCA of the winter-spring seining data explained a total of 51.6% of the variance in the species percentage abundances (Table 14). The distribution of species scores along DCA axis 1 suggests that the species form three groups based on similar percentage abundances (Figure 16). The native species are grouped to the right with positive scores, a large group of introduced species that occur together occurs near the center with scores between 0 and –2, and red shiner occurs alone to the left with the highest negative score. DCA axis 2 primarily separates Sacramento pikeminnow (positive score) from the two other native species (negative scores).

Table 14 Percentage of variance in species percentage abundances explained by detrended correspondence analysis of winter-spring seining data and summer survey electrofishing data

	Detrended correspondence axis			
Data set	*1*	*2*	*3*	*4*
Winter-spring seining	21.7	16.1	8.6	5.2
Summer electroshocking	26.2	9.9	5.6	4.6

The plots of site scores on DCA axes 1 and 2 indicate annual variability in winter-spring resident species assemblages (Figure 17). In 1987, all sites except rkm 5.6 were located to the right of the plot with positive scores on DCA axis 1. Native species were found at all sites, with high percentages of Sacramento pikeminnow at rkm 67.9 and 77.2. In 1988 and 1989, only sites above rkm 60 were found to the right of the plot with positive scores on DCA axis 1. The remaining sites clustered in the area of the plot characterized by the large group of introduced species with scores between 0 and –2. Western mosquitofish dominated the catch at these sites, but bluegill was commonly caught in both years and redear sunfish in 1989. Sacramento pikeminnow and suckers remained common at the upstream sites. From 1990 through 1993 the sites at rkm 5.6 and 9.7 were located to the left of the plot with the most negative scores on DCA axis 1 reflecting high percentages of red shiner. The sites above rkm 60 continued to have relatively high percentages of pikeminnow and sucker but redear sunfish became widespread resulting in a mixture of native and introduced species. Although not all sites were sampled after 1993, the assemblage appeared to shift back to the pattern seen in 1987. However, red shiner and occasionally inland silverside continued to be found in high percentages at the most downstream sites, particularly rkm 5.6. Redear sunfish became much less abundant and less frequent at the most upstream sites. The shifts in percentage abundances of the species indicated by the shifts in site scores are reflected in the annual mean percentage abundances of the three groups identified from the species plot (Table 15).

The one-way ANOVA supported the observed variability in assemblage structure. Significant differences among years were found ($P = 0.001$). Tukey HSD pairwise tests indicated that DCA axis 1 scores in 1987 were significantly higher than in 1992 and 1993 ($P < 0.05$). Similarly DCA axis 1 scores in 1997 were higher than 1993 ($P < 0.05$). The other years appear to represent transitional states between the high and low years. There were no significant differences for DCA axis 2.

Table 15 Mean percentage (± standard deviation) of species groups for all sites sampled in each year[a]

Year	*N*	*Red shiner*	*Introduced species[b]*	*Native species[c]*
1987	8	0	19.6 ± 25.4	74.7 ± 24.4
1988	8	0	66.5 ± 38.2	31.2 ± 35.5
1989	8	0.6 ± 0.7	82.0 ± 20.2	17.5 ± 20.6
1990	8	29.8 ± 29.0	54.9 ± 23.8	33.9 ± 27.7
1991	8	22.3 ± 29.2	52.1 ± 25.6	39.4 ± 32.2
1992	7	32.6 ± 46.1	72.8 ± 30.7	17.5 ± 27.0
1993	8	27.0 ± 33.4	74.1 ± 21.7	15.3 ± 15.4
1994	5	2.3 ± 3.2	26.2 ± 24.0	70.0 ± 27.4
1995	4	25.8 ± 36.5	54.7 ± 32.8	29.9 ± 35.1
1996	5	2.7 ± 3.7	12.0 ± 17.3	86.1 ± 21.1
1997	7	5.1 ± 6.4	12.4 ± 14.4	83.7 ± 18.9

[a] Means were calculated on the basis of all sites sampled (N), except for red shiner. Means for red shiner were calculated based on data from the three most downstream stations, the only sites where red shiner were captured during the study. Species groups were identified by DCA analysis of the annual winter-spring seining data.

[b] Introduced species include bluegill, largemouth bass, green sunfish, redear sunfish, smallmouth bass, white catfish, channel catfish, bullhead catfish, western mosquitofish, and common carp.

[c] Native species include Sacramento pikeminnow, hardhead, Sacramento sucker, lamprey, and riffle sculpin.

The first four axes of the DCA of the summer electrofishing data explained 46.3% of the variance in the species percentage abundance data (Table 14). Based on species scores on the first two DCA axes, the fish species appeared to form three groups (Figure 16). The native species tended to have scores near 0 with riffle sculpin clearly different with a high positive score. The other native species tended to occur in high percentage abundance with species of introduced fishes. Hardhead, Sacramento pikeminnow and lamprey were found in association with largemouth bass, bluegill, redear sunfish, and bullhead catfish. These species had positive scores on DCA axis 2. Sacramento sucker was associated with green sunfish, western mosquitofish, smallmouth bass, goldfish, carp, channel catfish, and white catfish. These species had negative scores on DCA axis 2.

Plots of site scores on the first two DCA axes indicated that summer fish assemblages were relatively stable on an annual basis but there appeared to be some seasonal variability in species assemblages at some sites in some years (Figure 18). The overall range of scores did not change dramatically from year to year, suggesting the diversity of fish assemblages was relatively constant on an annual basis. These observations were supported by results of the two-way ANOVA. For both DCA axis 1 and 2, there was no significant effect of year, season, or year-by-season interaction (all $P > 0.05$).

The sites at rkm 80.3 and 83.0 were consistently located to the right of the plot with positive scores on DCA axis 1, consistent with high percentages of native species, particularly riffle sculpin. Sites between rkm 60 and rkm 80 were generally located in the upper left quadrant of the plot with positive scores on DCA axis 2, consistent with high percentages of Sacramento pikeminnow and associated species. The remaining sites were generally located in the lower left of the plot with negative scores on DCA axis 2. Despite these general trends there were exceptions, particularly in 1992.

Comparisons of scores for the early and late samples from the same site, indicated significant seasonal changes at some sites in some years. For example, there was little change in the species assemblage at site rkm 80.3 in 1989 and 1991 but in 1990 and 1992, the site scores indicate that higher percentages of introduced species were present by late summer. The site at rkm 77.2 had similar seasonal scores in three out of four years. There was a large shift in the species assemblage only in 1989. The most seasonally stable fish assemblages were at rkm 19.8, 40.1, and 67.9.

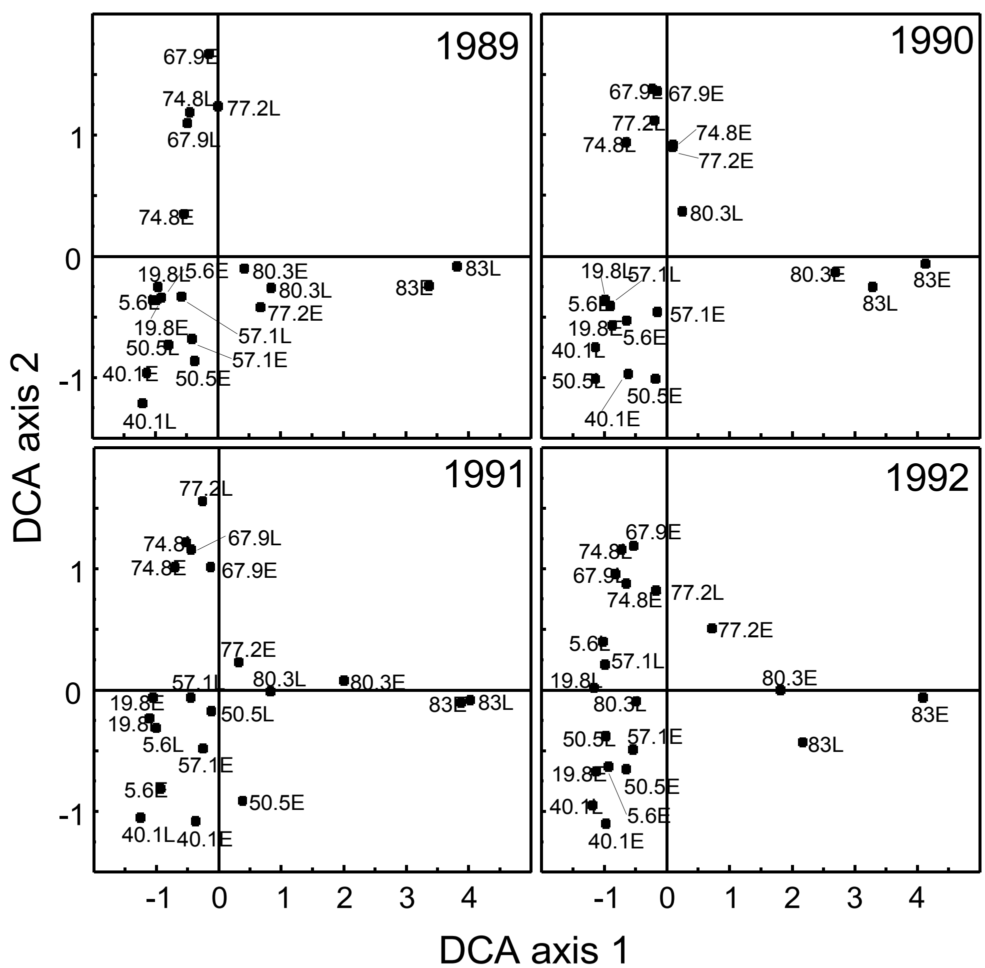


Figure 18 Site scores on DCA axes 1 and 2. Scores were derived from analysis of summer electrofishing data. Numbers indicate site location as kilometers from the San Joaquin River. The letters designate the early (E) or late (L) summer sample from each site.

Discussion

Adult Fall-run Chinook Salmon

The three years with run estimates greater than 50,000 occurred in the 1940s before completion of Friant Dam (1946) and the Tracy Pumping Plant (1951) in the Delta, both features of the Central Valley Project. The New Don Pedro Dam (1971) on the Tuolumne River and the State Water Project's Banks Pumping Plant (1968) in the Delta are other major water development factors affecting Tuolumne River salmon survival since the 1950s. Since that time, the runs have generally corresponded to overall hydrologic trends and streamflow conditions, with major declines following droughts in 1959–1961, 1976–1977, and 1987–1992. The high estimate of 40,300 in 1985 was associated with high juvenile survival in 1983, a very wet year. The effects of the ocean harvest on survival from juvenile to adult influence the trends.

The basis for the spawning run estimates has varied substantially over time, which means caution should be applied in considering their accuracy and comparability. The only direct counts were made at Modesto from 1940–1946 when fish passed over a weir. Since then all estimates are derived from carcass surveys in the upstream spawning reach. The estimates from 1947–1966 are questionable because no mark-recapture data were gathered. Carcass tagging began in 1967, but DFG estimates through 1978 are not entirely based on calculations from the tag recovery data. Methods have improved since 1979 due to the use of mark-recapture data, but various techniques and formulas have been used to calculate the population estimates and the variability of the estimates has not been fully analyzed. Expansions based on redd counts have been applied since 1981 to account for reaches not surveyed weekly for carcasses, but this was not done in prior years. The population estimates for recent years are still subject to revision as different statistical methods are applied.

The Tuolumne River is one of the few remaining major Central Valley salmon streams without a hatchery. However, hatchery salmon, as documented by the recovery of fish with CWTs, have become much more prevalent in the runs since 1986. Most of these CWT salmon originate from the Merced River Hatchery, with many returning from smolt survival releases made by DFG into the Tuolumne River. Others are mainly from releases into the Sacramento-San Joaquin Delta originating from other hatcheries in the Central Valley. The CWT recoveries represent a minimum for the hatchery salmon component of the runs because many unmarked Merced hatchery salmon are released as well. The determination of the status and dynamics of the wild population are not only complicated by the presence of hatchery fish, but the hatchery fish may also pose a threat to the long-term survival of the wild population (NMFS 1998; NRC 1996).

Juvenile Fall-run Chinook Salmon

Based on the maximum size of fry seined in January, fry began to emerge from the gravel in December in some years and continued in some years into April and May. The later fry emergence could be, in part, the result of spawning after December but there were no spawning survey data from later than 5 January since 1986. Maximum fork length data indicated that salmon >70 mm FL (potentially smolts) were present as early as March of most years.

The limited presence of salmon in the summer flow study suggests that few juvenile salmon reared for extended periods in the Tuolumne River; however, these studies were conducted during a series of low flow years and may not be representative of all conditions. The minimum summer flow requirements were increased since the sampling took place (FERC 1996) so the river reach with suitable temperatures for summertime rearing is now more extensive.

Resident Fishes

Although the results suggest the different sampling methods varied substantially in their ability to sample the resident fish communities, it is difficult to separate differences due to method from differences due to year, season, and location. Also, because the major purpose of the winter-spring sampling effort was to document the distribution and abundance of juvenile chinook salmon, sampling of the resident fish assemblage only had secondary importance. In contrast, the purpose of the summer flow study was specifically to document the resident fish assemblage.

The three winter-spring sampling methods were very successful at capturing juvenile chinook salmon but less successful at capturing other species. A number of factors likely contribute to the low catches. Low water temperatures during the winter-spring period are likely associated with reduced activity levels for most of the resident species, the majority of which are considered warm-water species. Resident fish populations are probably at their lowest abundance at this time of year due to cumulative mortality of small, young fish over the previous summer and fall. Flows are often high during the winter-spring period, increasing the size of the river, making it more difficult to sample a significant portion of the habitat. High flows are also often associated with reduced sampling efficiency because of high water velocities, greater depths, and increased debris in the river.

There were some obvious differences among the three winter-spring methods used. Fyke netting was clearly most effective for sampling bottom-oriented species, particularly catfish and lamprey (Tables 12 and 13). Rotary screw trapping emphasized pelagic species (Table 11). Seining emphasized stream-edge species, particularly western mosquitofish (Table 10). Although all the methods are somewhat biased as to the species sampled, seining has the advantage of simplicity. It is possible to sample many more locations by seining, making it possible to document species distributions as well as abundance. Electrofishing is another alternative but it was not used in winter-spring surveys and has the disadvantages of requiring expensive equipment and more likely causing mortality to captured salmon.

There were also some obvious differences among the three methods used during the summer flow study (Table 10). Seining was largely ineffective, except in capturing western mosquitofish, in the one year it was used. Presumably larger fish were able to detect and avoid the seine in the lower, clearer water present during the summer period. Electrofishing and snorkeling provided very similar data for larger more pelagic species. Snorkeling provided a more accurate assessment of large individuals, especially of the larger native species including Sacramento pikeminnow, hardhead, and Sacramento sucker. However, snorkeling tended to overlook bottom-oriented species such as catfish and sculpins and also small fishes such as red shiner and golden shiner. Snorkeling was also limited by water clarity to the upstream reaches of the river. Overall, of the three methods used, electrofishing appeared to provide the best data on the resident fish assemblage.

There are two species that were not captured, but their presence is expected based on angler reports or known occurrence in the San Joaquin River. These species are the native white sturgeon and the introduced American shad. Their absence in this data set could be due to low susceptibility to the sampling methods employed and intermittent occurrence in the river.

Fish Species Distributions

Fish species distributions, based on frequency of occurrence, were much more distinctive during the summer than during the winter-spring seining surveys (Figures 15A, 15B, and 15C). Winter-spring distributions were usually similar to the summer distributions. However, differences with river kilometer were generally of smaller magnitude because high values rarely exceeded 50% for winter-spring seining, yet were often 100% for summer electrofishing and snorkeling.

The summer sampling indicated several distribution patterns for fishes (Figure 15A, 15B, and 15C). There was a very sharp transition for many species around rkm 80. Most species (except Sacramento sucker, riffle sculpin, and lamprey), occurred much less frequently at locations upstream of about rkm 80. These most upstream locations represent a very distinct habitat. Significant broad gravel riffles dominate the reach, as do cooler water temperatures.

All three of these native species are commonly associated with such habitats in other areas of California (Moyle 1976; Moyle and others 1982).

Another transition occurs at about rkm 50 (Figure 15A, 15B, and 15C). Downstream of this point the native species occur less frequently in samples and most of the introduced species reach their maximum frequency of occurrence. This location approximately corresponds to a reach of river that has been significantly affected by gravel mining. The gravel pits serve as a velocity refuge during high flows for many of the introduced species found in the river. When flows decrease the introduced species can re-invade both upstream and downstream areas. The area between rkm 50 and rkm 80 represents an area of overlap between the areas dominated by native and introduced species.

Red shiner, inland silverside, and golden shiner exhibited another pattern of distribution. These species were most commonly found at the most downstream stations. These results are consistent with Brown (2000) who described the former two species as San Joaquin River mainstem species because they were most abundant in that river and only entered tributaries such as the Tuolumne River for short distances. These results were interpreted to indicate that these species consistently invade the tributaries and perhaps maintain populations there but conditions in more upstream areas are unfavorable in some way. Brown (2000) did not capture golden shiners in his study (sampling 1993–1995), suggesting a different process may be occurring for this species.

The data on splittail and tule perch indicate that other native species do occasionally make their way into the Tuolumne River. The data on splittail were particularly interesting because previously published studies of fishes in the San Joaquin River drainage indicated splittail only occurred rarely in the system (Saiki 1984; Brown and Moyle 1993). Sommer and others (1997) noted those studies were based on summer sampling. It appears that splittail move into the upper San Joaquin River to spawn in some years (Sommer and others 1997) and that either additional spawning or young-of-year rearing occurs in the lower reaches of the tributary rivers including the Tuolumne River. Brown (2000) captured young-of-year splittail in the lower reaches of both the Tuolumne and Merced rivers in 1995. Brown (2000) found tule perch to be abundant in the Stanislaus River but not in the mainstem San Joaquin River or the other tributaries. Saiki (1984) observed tule perch in the San Joaquin River but did not sample the tributaries extensively. Brown (2000) suggested that the high summer flows in the Stanislaus River combined with extensive beds of aquatic vegetation provided a type of habitat not widely available in other streams in the lower San Joaquin River drainage.

Fish Species Assemblages

No other long-term data sets are available for winter-spring resident fish assemblages in the San Joaquin River system (Brown 1997), making this data set unusual. The results of the DCA indicate that there is significant annual variability in the winter-spring resident fish assemblage that appears to be related to flow conditions. Examination of daily flow records suggests high percentages of native species are associated with high stream discharge in the winter of the previous year. Native species dominated in 1987 after the wet winter of 1985–1986. Introduced species became more dominant during the drought (1988–1992) with native species returning to high percentages at many sites in 1994 after the wet winter of 1993–1994. Native species continually occurred in high percentages starting in 1996 after the wet winter of 1994–1995.

The mechanism causing this switching is unclear. The native species are all riffle spawners and many of the introduced species are nesting species (Moyle 1976). It is likely that high outflows provide more appropriate spawning conditions for the native riffle spawners and poorer conditions for the introduced nesters. A number of recent analyses has suggested that natural flow regimes, including high winter-spring discharges, benefit native California stream species over introduced species (Baltz and Moyle 1993; Moyle and Light 1996a, 1996b; Brown and Moyle 1997). The spawning success hypothesis also explains why winter-spring assemblage structure lags behind the wet winter by a year. The bulk of the seining occurs before or during the spawning seasons of the majority of the resident species. The effect is seen in the seining data the following year, after the young have become large enough to be susceptible to the seine.

Another complication is the importance of red shiner in the analysis (Figure 16). Red shiner is a recent introduction and the species was actively invading the San Joaquin River system in 1986 (Jennings and Saiki 1990). It is likely that the invasion process is complete (Brown 2000); however, there are no conclusive data to that effect. It is unknown if the same patterns of annual change would be apparent in the absence of red shiner; however, it seems likely that inland silverside, which exhibits a similar pattern in frequency of occurrence (Figure 15C), might assume similar importance in the absence of red shiner.

The summer resident fish assemblage did not exhibit significant annual change, but the data were not as extensive as the winter-spring seining data, being limited to four years during the 1987–1992 drought. There was also little change in the winter-spring assemblage during the years (1989–1992) of summer sampling (compare Figures 17 and 18). Brown's study (2000) did include years with very different flow conditions and there were obvious differences in the summer fish assemblages. In the wet year (1995), native species were present in downstream areas where they were absent or very rare during drier years (1993 and 1994). Despite the inability to use data from the present study to look at changes with flow conditions, the analysis did indicate some interesting patterns within the period analyzed.

In contrast to the winter-spring data, red shiner was only a minor component of the summer assemblage. As noted, this is consistent with Brown's (2000) observation that red shiner was rarely found in the large tributary rivers (Merced, Tuolumne, and Stanislaus rivers) to the San Joaquin River. Brown (2000) hypothesized that the low, clear water conditions prevalent in the tributaries during the summer are favorable for predators, resulting in heavy predation on red shiners that moved upstream during the winter and spring. Thus, the distribution of red shiners is a balance of invasion and predation mortality processes.

Native and introduced species appear to be more closely associated during the summer than during the winter and spring, with the exception of riffle sculpin (Figure 16). Riffle sculpin were found in high percentages at the most upstream sites probably for two reasons. The gravel riffle habitat they were associated with is most abundant in the most upstream areas and water temperatures are coolest there. Temperature has been found to limit the downstream distribution of riffle sculpin in other Central Valley streams (Baltz and others 1982).

The other native species were closely associated with introduced species (Figure 16). This is unusual compared to the Merced and Stanislaus rivers. Multivariate analyses presented in Brown (2000) indicate a close association of native and introduced species in the Tuolumne River, but in the Merced and the Stanislaus rivers, the most upstream sites were clearly dominated by native species. This difference may be related to the summer flow regimes and water diversion practices in the two rivers. In the Merced River, the native species dominate the river upstream of a series of diversion dams, but introduced species dominate downstream of the diversions. Flows in the Stanislaus River are relatively high all summer because of upstream releases to control water quality in the San Joaquin River and native species are dominant at several upstream sites. In the Tuolumne River, the major diversions are made at La Grange Dam with summer releases being relatively small (particularly during the period of study), and introduced species were present throughout the system. These results are also consistent with the hypothesis described earlier that natural hydrologic patterns appear to favor the native species (Baltz and Moyle 1993; Moyle and Light 1996a, 1996b; Brown and Moyle 1997). The recent implementation of new minimum summer flow requirements (FERC 1996) may change the pattern to one more similar to that observed in the other tributaries.

The comparisons between early and late samples indicate that significant changes can occur in resident fish assemblages over the course of the summer (Figure 18). It is unclear what process is causing these changes. There may simply be random events due to immigration and emigration. Changes might also result from physical or biological processes such as temperature avoidance as the river warms during the summer or competition or predation among species as low summer flows concentrate fishes into limited depth and cover refugia. More detailed field and laboratory work is necessary to clarify such processes and their interactions.

Monitoring of the resident fish community provides useful data on the effects of flow conditions on the river ecosystem. Continuation of the documentation of resident fishes in the winter-spring seining will provide a long-term database unmatched in any other Central Valley stream. Resumption of annual monitoring of summer fish assemblages could provide useful data on the positive or negative effects of changes in water management activities on native species of interest. Though resident species often appear to be of little management interest in the short term, they can often become critically important when populations reach low levels and threatened or endangered status becomes a possibility. The splittail, recently listed as a federal threatened species, is a good example. Effective monitoring of all species seems a worthwhile investment to reduce future uncertainty in management concerns.

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