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STRIPED BASS SPAWNING IN THE SACRAMENTO AND SAN JOAQUIN RIVERS IN CENTRAL CALIFORNIA FROM 1963 TO 1972

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Striped bass eggs and larvae were collected in the Sacramento and San Joaquin Rivers during spawning surveys from 1963 to 1972. Spawning was heaviest at water temperatures from 17.2 to 20 C. Most spawning in the San Joaquin Delta occurred from April 23, to May 25. Spawning in the Sacramento River above the Delta was primarily from May 10 to June 12. The middle of the spawning period in the Delta averaged 15 days earlier than in the Sacramento River. The time difference was greatest in years of high flow. Most spawning in the Sacramento River occurred from the City of Sacramento upstream to Colusa. Most spawning in the Sacramento-San Joaquin Delta occurred between Antioch and Venice Island where salinities during spawning have usually been less than 200 mg/1 TDS but occasionally have been up to 1,500 mg/1. Both eggs and larvae were more concentrated near the bottom than at the surface in the Sacramento River above the Delta. The survey in 1972 indicated almost all larvae in the Sacramento River upstream from Isleton are 6 mm or less in length. In 1972 about 55% of the season's spawning occurred in the Sacramento River.

INTRODUCTION

The two major spawning areas of striped bass in the Central Valley of California are the Sacramento River upstream from the Sacramento-San Joaquin Delta and the San Joaquin River and adjacent sloughs in the Delta (Calhoun, Woodhull, and Johnson 1950; Chadwick 1958; Farley 1966). Present and future water diversions may affect the survival of striped bass eggs and larvae in these areas. An understanding of the factors affecting the time and location of spawning is necessary to recommend means of modifying water development plans to protect striped bass. This report describes the understanding developed from several surveys conducted from 1963 to 1972.

METHODS

Striped bass eggs and larvae were collected by several methods. Plankton nets were used each spring from 1963 through 1966 in the Sacramento River and from 1963 to 1965 in the Delta. The nets had a 46 centimeter (18 inch) mouth and a 102 centimeter (40 inch) cone of 9 mesh per centimeter bolting cloth. Ten minute surface tows were made 2 to 3 times a week at selected locations. Farley (1966) described the methods and location of the sampling stations.

A 0.5 hp Moyno utility pump with a synthetic rubber helical rotor was used to collect continuous samples of eggs and larvae in the Sacramento River from 1967 to 1969 and in the San Joaquin River above the Delta in 1968. Eggs and larvae were pumped into a container where they were strained from the water by a fine mesh screen. At some locations, samples were taken from several depths. The catch was collected every 24 hours. Many samples could not be used because they overflowed when detritus clogged the screens.

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Large cone-shaped tow nets were used in the Delta from 1966–1972 and in the Sacramento River in 1972. The nets were 3.2 m (10.5 ft) long with a mouth of 0.76 (2.5 ft) in diameter. In 1966 the front half of the net was constructed of 0.64 cm (1.4 inch) mesh nylon webbing. The back half was 7.9 mesh per cm nylon marquisette. From 1967 to 1972 the entire net was 7.9 mesh marquisette. Essentially all eggs are retained by this mesh, but many larvae shorter than 7 mm pass through it. All tows were 10 minutes and the volume of water strained was metered. Tows were diagonal from bottom to surface to obtain a sample integrated over depth.

Each station was occupied every second day during the sampling period, except when mechanical problems prevented sampling. The number of stations and sampling period varied from year to year (Table 1). Locations of sampling stations are shown for the Sacramento-San Joaquin Delta from 1966–1972 and for the Sacramento River above the Delta in 1972 (Figure 1).

All samples were preserved in formalin. The ages of the eggs collected from the Sacramento River from 1963 to 1969 were estimated through examination with a dissecting microscope and comparison with stages of development described by Mansueti (1958). The geographical origin of each egg was then estimated by multiplying its estimated age by the river

TABLE 1. **Sampling Methods Used in Striped Bass Egg and Larvae Studies.**

Year	Number of stations	Method	Depth	Sampling period
Sacramento River Above Delta				
1965	3	Plankton net	Surface	April 27–June 23
1966	7	Plankton net	Surface	May 7–June 27
1967	1	Pump	Surface	May 8–July 1
1968	2	Pump	Surface, Bottom	May 21–June 14
1969	2	Pump	Surface, mid-depth, bottom	April 30–July 14
1972	17	Plankton tow net	Diagonal tow from bottom to surface	April 25–June 26
Sacramento-San Joaquin Delta				
1965	6	Plankton net	Surface	April 27–June 23
1966	62	Plankton tow net	Diagonal tow from bottom to surface	April 8–June 30
1967	62	Plankton tow net	Diagonal tow from bottom to surface	April 25–June 28
1968	32	Plankton tow net	Diagonal tow from bottom to surface	April 3–June 28
1969	32	Plankton tow net	Diagonal tow from bottom to surface	April 17–July 10
1970	32	Plankton tow net	Diagonal tow from bottom to surface	April 21–June 28
1971	32	Plankton tow net	Diagonal tow from bottom to surface	May 24–July 15
1972	32	Plankton tow net	Diagonal tow from bottom to surface	April 28–July 15
San Joaquin River Above Delta				
1968	8	Pump	Surface	March 28–May 14

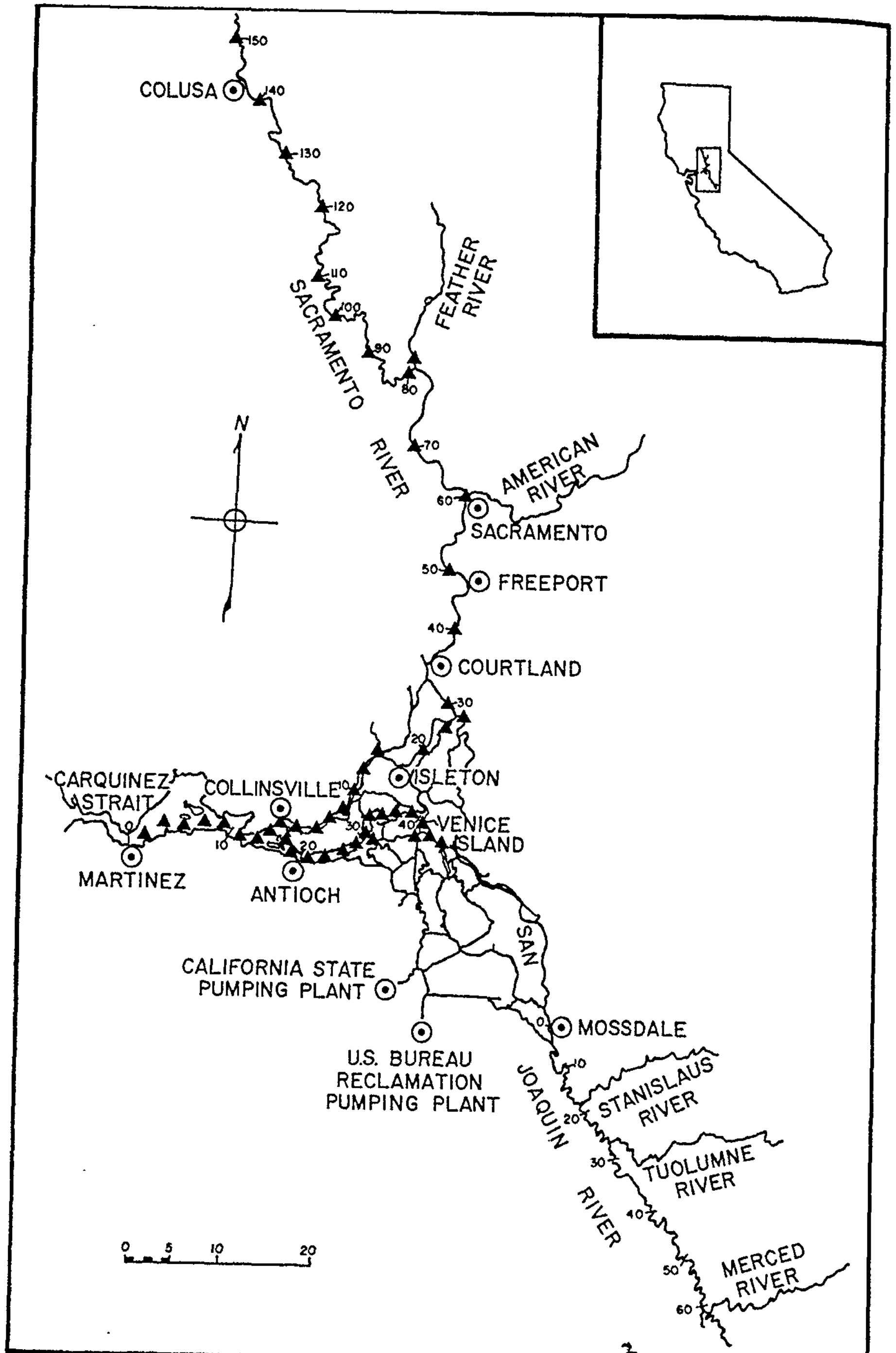

FIGURE 1. Map of study area showing location of sampling stations in 1972.

velocity upstream from the collection site which was provided by the California Department of Water Resources.

Eggs collected in the Sacramento River in 1972 and in the Sacramento-San Joaquin Delta in all years were merely classified as either less or greater than 8 hours old. Spawning was assumed to occur where eggs less than 8 hours old were collected.

Sampling in the Delta from 1966–1972 and in the Sacramento River in 1972 was more intensive and analyses were more refined than for the other surveys. Catches of eggs during these "intensive" surveys were weighted according to the water volumes in the river section represented by the sampling stations (weighted catch = egg catch/m^3 of water strained × water volume of sampling station). The California Department of Water Resources estimated water volumes for the Delta stations. I estimated volumes for the Sacramento River stations by multiplying mean cross sectional areas (estimated by the Department of Water Resources) by distances represented by the stations.

A water sample was taken with each sample of eggs and larvae. The electrical conductivity of each water sample was measured in the laboratory. Total dissolved solids (TDS) concentrations (mg/l) were estimated by multiplying electrical conductivity in micromhos by 0.64. This is an approximation as this constant varies with location and salinity. Most measurements of the constant in the study area fall between 0.5 and 0.7.

RESULTS

Time of Spawning

Most spawning in the Delta occurred between April 23 and May 25, with the possible exception of 1965 (Figure 2). In 1965, only 2,142 eggs were taken during the entire season, and 967 or 45.1% were caught the first sampling day (April 27). Spawning in the San Joaquin River above the Delta in 1968 occurred primarily from April 10 to May 9. In the Sacramento River, most spawning occurred between May 10 and June 12 in all years. The greatest deviations from this period were in 1966 and 1972 when 20 to 25% of the bass spawned before May 10, and in 1969 when about 25% spawned after June 12.

TABLE 2. **Mean Number Striped Bass Eggs per Tow Collected at Various Water Temperatures in the Sacramento River in 1963, 1964, and 1965.** Only Eggs Eight Hours in Age or Less were Considered.

Water temperature F	Number of tows	Eggs per tow	Percent of total eggs per tow
56	10	0	--
57	14	.2	.4
58	36	0	--
59	39	.3	.6
60	70	1.6	3.5
61	52	1.2	2.6
62	55	1.1	2.4
63	64	8.8	19.2
64	71	2.6	5.7
65	52	8.2	17.9
66	66	14.5	31.6
67	32	2.7	5.9
68	35	4.4	9.6
69	25	.3	.6
70	3	0	--
71	1	0	--
72	1	0	--

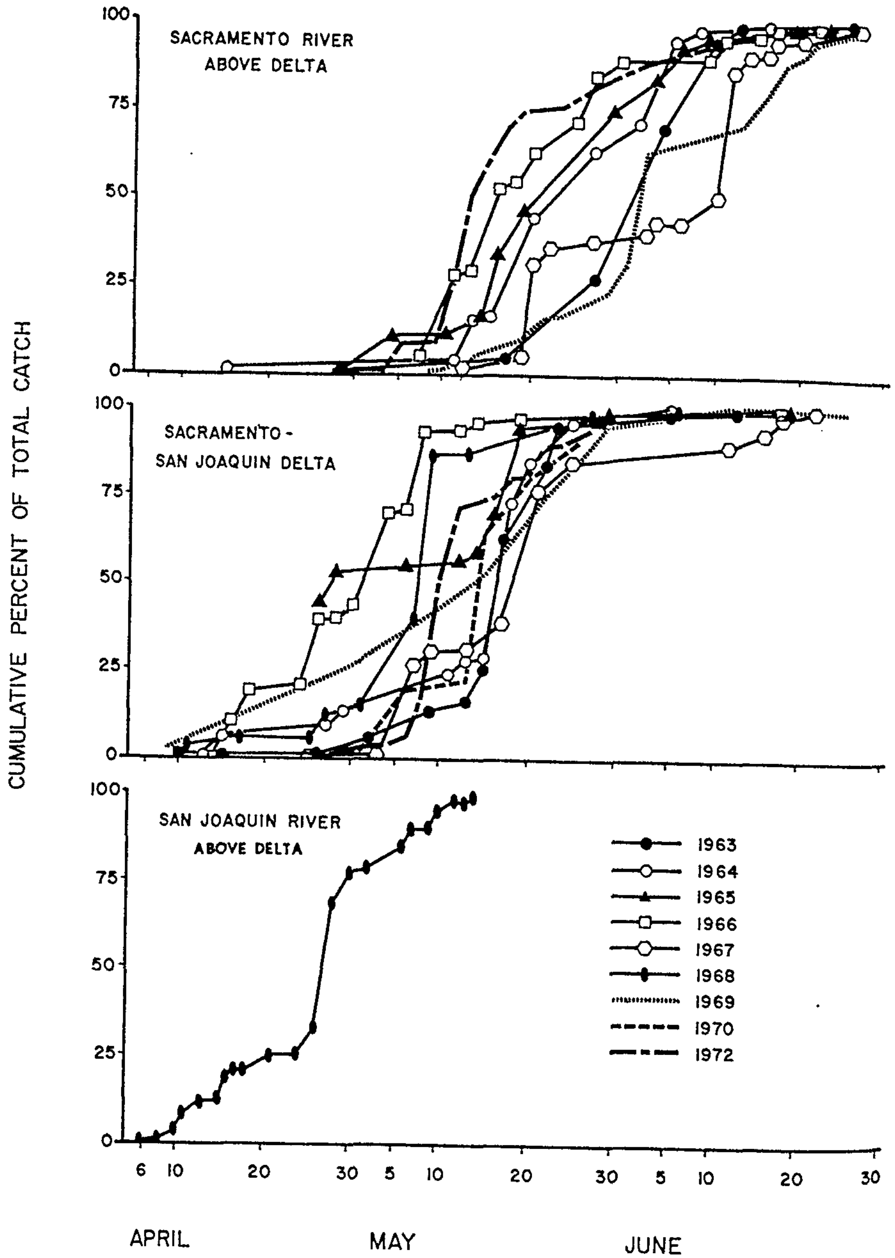

FIGURE 2. Cumulative percentage of striped bass spawning over time in various areas. Daily percentages for the Delta from 1966–1972 and for the Sacramento River in 1972 were estimated by dividing total weighted catches each day by the seasonal total weighted catch. Percentages for the other surveys were estimated by dividing the daily catch per unit effort by the sum of those statistics for the season. The cumulative percentage is a running sum of the daily percentages.

Water temperature was measured at the time of sampling in the Sacramento River from 1963 to 1965. Almost 90% of the spawning occurred from 17.2 to 20 C (63 to 68 F) (Table 2).

The time of the middle of the spawning period is correlated significantly with the mean monthly water temperature for both April and May in the Sacramento River (Table 3). The relationship is not significant for the Delta when all years are considered. However, discounting 1965, when 45.1% of the eggs were caught the first day, the relationship is highly significant there also.

TABLE 3. **Relation Between Middle of Striped Bass Spawning Period and River Temperature.**

Sacramento River Above Delta

Year	Middle[1] of spawning season	Water temperature[2] April	Water temperature[2] May
1963	June 1	54.1	59.3
1964	May 23	58.2	63.7
1965	May 20	53.8	59.6
1966	May 16	57.6	65.9
1967	June 9	49.8	58.1
1969	June 2	55.7	60.7
1972	May 13	58.1	65.6
Correlation coefficient		−.78	−.83

Sacramento-San Joaquin Delta

Year	Middle of spawning season	Water temperature[3] April	Water temperature[3] May
1963	May 16	57.9	64.5
1964	May 16	61.6	65.3
1965	April 28[4]	60.2	66.2
1966	April 30	65.4	69.3
1967	May 18	56.2	66.1
1968	May 8	64.3	66.8
1969	May 13	61.1	66.4
1970	May 14	60.8	66.8
1972	May 10	62.8	68.0
Correlation coefficient (with 65 data)		−.57	−.58
Correlation coefficient (without 65 data)		−.87	−.86

[1] Date when cumulative percentage of spawning reaches 50% for method of calculating, see caption to Figure 2.
[2] Mean of daily maximum and minimum water temperatures at Freeport; from U. S. Geological Survey.
[3] Mean daily water temperature at Contra Costa PG&E steam plant, Antioch.
[4] Only 2142 eggs caught during season of which 967 were taken on the first day (April 27).

The middle of the spawning period in the Sacramento River was 16, 7, 22, 16, 22, 20, and 3 days later than in the San Joaquin Delta for 1963 to 67, 69, and 72 respectively. The average difference was 15 days. The difference between the spawning periods was greatest when river flows were high (r = 0.85 when the difference is compared with May outflow at Chipps Island). This reflects the fact that as flows increase, the normal spring increase in temperatures is retarded more in the Sacramento River than in the San Joaquin Delta spawning area.

Location of Spawning

All eggs caught were assigned to 20 mile sections of the Sacramento River where they were calculated to have been spawned (Table 4). Farley (1966) estimated the spawning location in 1963 and 1964 based on the catch of both eggs and larvae; however, his aging of larval fish appears to have been biased. Hence, I recalculated the location of spawning in 1963 and 1964 based only on egg catches.

TABLE 4. **Percentage of Striped Bass Eggs Estimated to Have Been Spawned in 20-mile Segments of the Sacramento River[1].** Measured in River Miles Above the Confluence of the Sacramento-San Joaquin Rivers. Only Years in Which Samples Were Taken Throughout the Length of the River Were Considered[2].

River mile	1963	1964	1966	1972	Average
0– 20	0	.1	*	.2	.1
20– 40	10.1	15.2	.1	.3	6.4
40– 60	6.7	10.0	.3	5.5	5.6
60– 80	3.8	18.1	8.8	20.3	12.8
80–100	13.4	4.2	68.6	30.4	29.1
100–120	3.8	22.9	18.3	34.2	19.8
120–140	54.8	12.9	3.1	9.0	20.0
above 140	7.3	16.5	.8	.1	6.2
Approximate sample size of eggs	2,400	4,700	5,500	186,000	
Midpoint of spawning (river mile)	124	102	92	96	

* No stations below river mile 26.
[1] In 1972 spawning was assumed to occur where eggs ≤8 hours old were collected. Percentages in that year were calculated by dividing the season's total weighted catch in each section by the grand total for all sections. In 1963, 1964, and 1966, the geographical origin of each egg was estimated by multiplying its estimated age by the river velocity upstream. Percentages were calculated by dividing the total eggs assigned to each station by the total examined.
[2] The proposed intake site for the Peripheral Canal is approximately at mile 40.

The middle of the spawning area was assumed to be the river mile above and below which 50% of the spawning was calculated to occur. This point varied from river mile 92 in 1966 to 124 in 1963.

All striped bass eggs caught in the Delta were assigned to 5 mile sections upstream from Martinez (Table 5). The bulk of spawning occurred in the San Joaquin River between Antioch (river mile 21) and Venice Island (river mile 38). A moderate amount of spawning apparently occurred below Antioch in 1967 and 1969, although high flows in those years might have transported young eggs farther seaward.

In 7 of the 9 years in which eggs were sampled in the Delta, more than 80% of all young eggs were collected where total dissolved solids (TDS) were less than 200 mg/l. However, in 1968 and 1972 salinity intruded into the spawning area and sizable numbers of eggs were laid at higher TDS levels (Table 6).

TABLE 5. **Percentages of Striped Bass Eggs Estimated to Have Been Spawned in 5-mile Segments of the San Joaquin River and Suisun Bay.** Measured in River Miles Upstream from the City of Martinez[1].

River mile	1966	1967	1968	1969	1970	1971	1972	Average
0– 5	0	.9	0	2.7	0	0	0	.5
5–10	.3	3.9	0	1.7	0	0	0	.8
10–15	.3	11.8	.1	6.1	.2	2.3	.1	3.0
15–20	.1	29.9	1.6	20.6	2.3	1.3	.5	8.0
20–25	11.7	25.4	28.5	58.2	17.7	53.8	53.0	35.5
25–30	61.0	9.6	36.2	7.9	14.8	42.6	38.0	30.0
30–35	16.4	1.7	26.1	1.9	2.1	0	4.5	7.5
35–40	9.7	13.6	7.1	0	59.8	0	3.3	13.4
40 plus	.5	3.1	.5	.9	3.2	0	.7	1.3
Mean Delta outflow during May (000's cfs)	10	74	6	64	10	24	6	

[1] Spawning was assumed to occur where eggs ≤8 hours old were collected. Percentages were calculated by dividing the season's total weighted catch in each section by the grand total for all sections.

TABLE 6. **Percentages of Total Striped Bass Eggs Estimated to Have Been Spawned in Various Ranges of Total Dissolved Solids in the Sacramento-San Joaquin Delta[1].**

Range of total[2] dissolved solids	1964	1965	1966	1967	1968	1969	1970	1971	1972
<200	84.2	100.0	96.7	99.6	38.8	94.2	89.9	100.0	5.1
200– 500	15.5	0.0	3.3	.4	37.7	5.8	7.7	0.0	20.7
500– 600	.3	0.0	0.0	0.0	20.7	0.0	2.0	0.0	29.6
600– 700	0.0	0.0	0.0	0.0	.1	0.0	.5	0.0	7.0
700–800	0.0	0.0	0.0	0.0	.5	0.0	0.0	0.0	1.9
800–900	0.0	0.0	0.0	0.0	1.7	0.0	0.0	0.0	9.2
900–1,000	0.0	0.0	0.0	0.0	.1	0.0	0.0	0.0	0.4
1,000–1,200	0.0	0.0	0.0	0.0	.4	0.0	0.0	0.0	25.3
1,200–1,400	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.9
>1,400	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.8

[1] Spawning was assumed to occur where eggs ≤8 hours old were collected. Percentages for 1966–72 were estimated by dividing the season's total weighted catch of eggs ≤8 hours old in each salinity range by the season's grand total weighted catch. Percentages for 1964 and 1965 were estimated by dividing the season's catch/m³ of water strained in each salinity range by the sum of the catch/m³ for all salinity ranges.
[2] Salinity concentrations were estimated by measuring electrical conductivity in micromhos and multiplying by 0.64 to estimate salinity in mg/l TDS.

Most spawning in the San Joaquin River above the Delta in 1968 apparently occurred between the mouths of the Stanislaus and Merced Rivers (Table 7). Pumps located inside the mouths of the Stanislaus, Tuolumne, and Merced Rivers caught only one egg. It was taken in the Stanislaus River. Most of these eggs from the San Joaquin River above the Delta were collected at TDS ranging from 600–800 mg/l (Table 8); however, 94% of these eggs were dead (no cell division or broken embryos). In the Sacramento River where TDS levels were always less than 200 mg/l, only 46% of the eggs collected by the pumps were dead.

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TABLE 7. **Percentages of Striped Bass Egg Catch[1] at Sampling Stations in 1968 in the San Joaquin River Upstream from Mossdale.**

Station	Percent
Mossdale—River mile 59	1.4
Stanislaus River	0.1
Highway 132 Crossing—River mile 82	58.0
Tuolumne River	0.0
Patterson—River mile 104	39.6
Crows Landing—River mile 113	0.8
Merced River	0.0
Gustine—River mile 130	0.0

[1] Sample size = 348 eggs

TABLE 8. **Percentages of Total Striped Bass Eggs Collected in Various Ranges of Total Dissolved Solids in the San Joaquin River Above the Delta.**

Range of total dissolved solids (mg/l)	1968
200– 500	.7
500– 600	4.8
600– 700	30.6
700– 800	52.2
800– 900	6.9
900–1,000	3.3
1,000–1,200	1.5
>1,200	0

Vertical and Lateral Distribution of Eggs and Larvae in the Sacramento River

In 1968 the vertical and lateral distribution of striped bass eggs and larvae was measured in the Sacramento River at Courtland (river mile 35) and just above the City of Sacramento (river mile 61). Tidal effects in this section of the river are negligible. At Courtland, pumps obtained samples 0.9 m (3 ft) under the surface and 0.9 m (3 ft) off the bottom near the center of the channel where the river was 7 m (23 ft) deep, and 0.9 m (3 ft) below the surface near shore where the river was 1.5 m (5 ft) deep. At Sacramento samples were taken 0.9 m (3 ft) below the surface and off the bottom near the center, where the river was 5.5 m (18 ft) deep.

At Sacramento 91% of the catch was eggs, while at Courtland the larvae constituted 97% of the catch. Obviously most eggs hatched into larvae between these two stations.

At Sacramento the mean concentration of eggs at the surface was less than half that at the bottom (0.31 vs. 0.76 eggs/m^3). Larvae had a similar distribution pattern at Sacramento, with the mean concentrations being 0.028 and 0.074/m^3 at the surface and bottom, respectively.

Virtually all larvae caught at Courtland were at the bottom station in mid-channel. Mean concentrations were 0.001 and 0.961/m^3 at the surface and bottom, respectively, in mid-channel and 0.022/m^3 near shore.

Length of Larvae in Sacramento River

In 1972, the larval fish were measured. Almost all larvae caught upstream from Isleton were 6 mm or less SL (Table 9). Obviously most larvae coming from the Sacramento River are swept into downstream tidal areas when they are small.

TABLE 9. **Weighted Length Frequency of Young Striped Bass Caught in 1972 in the Sacramento River Upstream From Iselton[1].**

Length (mm)	Weighted catch	Percent total
3	108,489	10.4
4	285,497	27.5
5	605,362	58.2
6	38,763	3.7
7	248	
8	375	
9	0	
10	135	
11	219	
12	267	0.2
13	266	
14	194	
15	136	
16	51	
17	99	
18	46	
Total	1,040,147	

[1] Recent net efficiency tests indicate that many larvae shorter than 7 mm passed through the mesh.

Relative Amount of Spawning in the Two River Systems

In 1964, Farley (1966) estimated that 66% of the striped bass spawning occurred in the Sacramento River and 33% occurred in the Delta.

Estimates were made in 1972 for both river systems by weighting catches according to the volume of water represented by the sampling stations. Only eggs (all ages) were considered in these estimates. The estimates indicate that 55% of the spawning occurred in the Sacramento River and 45% in the Sacramento-San Joaquin Delta.

DISCUSSION

Results presented in this paper will help develop criteria for operating water projects in a manner that will benefit the Sacramento-San Joaquin Estuary's striped bass population. Presently, large amounts of water from the Sacramento River are transported in existing channels across the central portion of the Delta to export pumps at State and Federal facilities near Tracy (Figure 1). Eggs, larvae, and young fish are diverted along with the water. Fish screens at the intake are efficient only in removing those fish large enough to swim well. They salvage from 25 to 90% of young striped bass in various length groups between 1.3 and 5.1 cm (0.5 and 2 inches) (Hallock, Iselin, and Fry 1968; California Departments of Water Resources and Fish and Game, 1973). Few larvae approaching the screen are salvaged (California Departments of Water Resources and Fish and Game, 1973), and presumably few eggs are salvaged. The diversion of striped bass eggs by the export pumps has been estimated to be 15 to 30% [illegible]

One approach to minimizing the diversion of striped bass is to transfer water around the Delta rather than through it. The Peripheral Canal, which would divert the water from the Sacramento River above the Delta was recommended in part to do that.

While the Canal would eliminate the diversion of eggs and larvae from the San Joaquin River, a major problem would still remain in that eggs produced in the Sacramento River above the proposed intake to the Canal would reach the Canal as eggs or larvae less than 6 mm long. No screen presently available could remove these eggs and larvae from the water being diverted.

This problem could be solved if water diversions were curtailed during the period when eggs and larvae pass the Canal. My study shows that curtailment between May 10 and June 12 each year would cover most spawning. Briefer periods of curtailment could be effective, if they were timed to coincide with the actual passage of eggs and larvae. Such shorter curtailments would have to be based on monitoring of egg and larval abundance each spring, as the exact time of spawning is not predictable.

The effect of diverting eggs and larvae is difficult to define. Eggs, larvae, and young of prolific fish such as striped bass, experience high natural mortality, so 100% curtailment is obviously not essential to maintain the population. However, the number of young bass surviving until mid-summer is closely correlated with environmental conditions, and losses of eggs and young in diversions may contribute to this correlation (Turner and Chadwick 1972). Hence, the diversion of eggs and larvae may have a significant effect, but additional information on survival is necessary to evaluate any such effect.

The area where striped bass spawn in the Sacramento River is probably affected less by runoff than indicated by prior analyses. Calhoun, Woodhull, and Johnson (1950) theorized that the spawning location of striped bass in the Sacramento River was related to how fast the river warms in the spring. The river warms slowly when runoff is high; hence, under their theory, bass would spawn farther upstream in those years than in years of low runoff. Farley's (1966) analysis of egg and larval catches supported this theory. He found that spawning was much farther upstream in 1963, a wet spring, than in 1964, a dry spring.

My recalculation of spawning location in 1963, based only on egg catches, substantiated that the spawning location was farther upstream in 1963 than in 1964. The difference though was substantially less than indicated by Farley's calculations. Also, results from 1963, 1964, 1966, and 1972 do not demonstrate a consistent relationship between spawning location and river discharge (Table 10).

TABLE 10. **Striped Bass Spawning Location vs. Sacramento River Discharge.**

Year	Mean April–May flow at Sacramento (cfs)	Estimated midpoint of spawning (distance in miles above Collinsville)
1963	52,205	124
1964	13,230	102
1966	17,960	92
1972	12,985	96

In 1972, the estimated midpoint of spawning was river mile 96, but two changes in methodology bias the 1972 estimate downstream relative to the other years. (1) Eggs were assumed to be spawned where they were caught in 1972 rather than back tracked to some point upstream based on their age and current velocity. (2) Catches were weighted according to the water volume in the section of the river represented by the sampling station only in 1972, and the downstream stations tend to represent larger volumes than those represented by the upstream stations.

In the Delta, striped bass generally spawn where the water is very fresh (<200 mg/l TDS). At least in the short run though, water that fresh is not essential, as spawning occurred in approximately the same location in 1968 and 1972, despite ocean derived salinities reaching 1,500 mg/l TDS. Laboratory studies have indicated salinities up to 1,000 mg/l TDS do not affect egg survival adversely (Turner and Farley 1971), and field collections provided evidence that salinity intrusion did not influence egg survival in the Delta in 1972 (Table 11). The cause of the observed 94% mortality of eggs collected in the upper San Joaquin River in 1968, where TDS levels were 600–800 mg/l, is unknown. Eggs incubated in water from that reach of the river did not experience an unusual mortality (Turner and Farley 1971).

TABLE 11. **Percentages of Eggs Dead When Collected at Various Salinity Ranges in the Delta in 1972.**

TDS	Total weighted catch	Percent dead
<200	480,074	22.5
200– 500	1,390,010	14.4
500– 600	2,308,725	19.9
600– 700	390,520	8.3
700– 800	156,625	13.0
800– 900	418,562	10.2
900–1,000	41,642	7.0
1,000–1,200	2,120,384	21.9
1,200–1,400	66,627	19.1
>1,400	129,504	18.1
Average	7,502,673	18.2

While salinity within the ranges discussed above apparently does not increase egg mortality and has at most a limited short term effect on the location of spawning, the longer term effect of such salinities is uncertain. Striped bass have a pronounced tendency to return to the same spawning area each year (Chadwick 1967), and thus might respond little to occasional less than optimum salinity conditions. Yet, regular occurrence of the same salinities could reduce spawning in the area gradually, due to accumulative effects of either small differences in survival or migratory preferences.

The possibility of such a reduction in spawning related to salinity is suggested by several facts. One fact is tag returns suggest spawning in the lower San Joaquin River has already declined during the past 25 years. Striped bass tag returns from the Sacramento River spawning area increased from 3% of the total in 1950 to 7% in the years 1958–64 (Chadwick 1967). During the same period, returns from the San Joaquin Delta decreased from 10% to only 1% of the total. These trends suggest that

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spawning striped bass have shifted from the Delta to the Sacramento River. This shift presumably reflects some deterioration in habitat quality in the Delta.

Secondly, striped bass universally spawn in essentially freshwater, although in a numer of estuaries they do spawn immediately upstream from the limits of ocean salinity intrusion, as they do in the lower San Joaquin River.

Finally, striped bass sometimes do respond to water quality while seeking a place to spawn. This occurs farther up the San Joaquin River where migrating bass are repelled by water from the upper San Joaquin drainage having a salinity greater than about 350 mg/l TDS (Radtke and Turner 1967).

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EFFECTS OF SALTON SEA WATER ON THE EGGS AND LARVAE OF *BAIRDIELLA ICISTIA* (Pisces: Sciaenidae) [1]

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In laboratory experiments, eggs and early larvae of the sciaenid fish *Bairdiella icistia* survived well in sea water but displayed extremely poor survival in water from the Salton Sea. Mortality in Salton Sea water was expressed mainly among hatched larvae prior to complete yolk absorption. Experiments conducted in both natural and artificial sea water and Salton Sea water indicated that this poor survival was related to the unusual ionic composition of the Salton Sea.

INTRODUCTION

This paper investigates the effect of the chemical composition of water from the Salton Sea, a saline lake in Southern California, on the eggs and larvae of *Bairdiella icistia* (Jordan and Gilbert), a fish which has existed in that lake since it was introduced there in 1950 (Walker, Whitney, and Barlow 1961). The salinity of the Salton Sea is gradually rising (Carpelan 1961*a*, U. S. Dept. Int. and Resour. Agency Calif. 1969), and concern has been expressed that the fish fauna of the Sea, which supports an important recreational fishery, will suffer as upper salinity tolerance limits are exceeded (Walker, Whitney, and Carpelan 1961). Lasker, Tenaza, and Chamberlain (1972) studied the ability of bairdiella eggs and larvae to tolerate elevated salinities of Salton Sea water and found that a salinity of 40 ‰ severely inhibited survival. The purpose of the present work was to determine to what extent this tolerance limit was influenced by the peculiar ionic composition of Salton Sea water (Carpelan 1961*a*, Young 1970).

METHODS

Adult bairdiella were captured in the Salton Sea, transported to La Jolla, California, and maintained in sea water at the Southwest Fisheries Center. Gonadal maturation was induced in captive fish by controlling photoperiod and temperature, and spawning was induced by hormone injections, as described elsewhere (Haydock 1971, May 1975). All eggs and larvae used in the present experiments were obtained from fish which had been held in sea water for at least 1 year.

First Experiment

Salton Sea water (SSW) having salinity of about 36 ‰ was collected along the southwest shore of the Sea 2 days before the experiment (in May 1970) and filtered through activated charcoal to remove dissolved organic matter. Ordinary sea water of 33 ‰ was taken from the Southwest Fisheries Center sea-water system and passed through a cartridge filter (CUNO aquapure filter). A portion of each of the two batches of water was also passed through membrane filters (HA Millipore, 0.45 μm pore size) shortly before the experiment, and another portion was not membrane-filtered. Even after charcoal and membrane filtration, SSW usually has a slight yellow-green hue, probably indicating the presence of a persistent dissolved organic fraction.